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Slip Critical Bolted Connections – A Reliability Analysis for Design at the Ultimate Limit State

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Slip Critical Bolted Connections

Executive Summary

A review of four North American design specifications has indicated some discrepancies between the various design specifications. The 2005 edition of the AISC specification is the only one to provide guidance for the design of connections to prevent slip at the service load and the factored load levels. Design issues that need to be reviewed for the design of slip-critical joints are the evaluation of the slip resistance of joints, which depends on the slip coefficient associated with the faying surfaces and the clamping force provided by the bolts. These two quantities show considerable variation. In order to assess the level of safety offered by slip-critical connections at service and factored load levels, the mean values and the variation of the slip coefficient and clamping force must be included in a reliability analysis. The main objective of this preliminary study of the slip resistance of bolted joints was to collect available test data on the slip resistance of bolted joints, assess their applicability for a reliability analysis and make use of the available data to assess the required performance factor for the prediction of the slip resistance at the ultimate limit state level.

Another objective of this investigation was to determine the consequence of slip in typical long span roof trusses with bolted gusset plate connections with regular and oversized bolt holes.

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1. Introduction

Slip-critical (or friction type) joints are joints that have a low probability of slip during the life of the structure. Because of their increased cost compared to connections with snug tight bolts, slip-critical connections should be used only when it is expected that slip in the joints would jeopardize serviceability of the structure, or would result in a reduction of the ultimate strength of the structure. The RCSC guide suggests that slip-critical joints should be designed to prevent slip under service load conditions and prevent rupture at factored loads, thus making the slip-critical joint behave as a bearing-type joint at the factored load level. This requirement was clarified in the latest edition of the RCSC bolt specification (Schlafly, 2004). It is also possible that slippage in the joints may result in significant second order effects in the structure, which could reduce the stability and strength of the structure. In this situation, the AISC specification has included in its 2005 edition provisions to design against slip at the factored load level.

The design of slip-critical joints has traditionally been performed to prevent slip of a joint at the service load level. The consequence of slip at the service load level is usually minimal.

2. Review of the Literature

2.1 Current design provisions

Four North American design provisions are reviewed, namely, AISC (2005), CAN/CSA-S16-01 (2001), AASHTO (2005), and the 2004 Bolt Council Specification (RCSC, 2004). Since the Guide to Design Criteria for Bolted and Riveted Joints (the Bolt Guide) (Kulak *et al.*, 1987) serves as the basis for the development of the various North American design standards, it will be reviewed first. The equations presented in this section have been modified so that: 1) the resistance is given for one bolt and one shear plane; 2) the symbols have been unified and are those adopted in AISC (2005).

The Bolt Guide (Kulak *et al.*, 1987) presents the following equation to calculate the slip resistance of a bolted joint:

$$R_n = \mu \, D \, T_b \tag{1}$$

where the mean slip coefficient, μ, is reported to be 0.33 for faying surfaces consisting of clean mill scale and 0.51 for unpainted blast-cleaned surfaces. The guide also reports a limited number of test results for hot-dip galvanized faying surface where a mean value of 0.18 is obtained based on 27 test results. The pretension, T_b, is taken as 70% of the nominal tensile strength of the bolt. The statistical parameter D accounts for the difference between the actual bolt pretension and the nominal value and the difference between the measured slip coefficient and the value used in the equation. Table 1 provides values of D corresponding to a probability of slip of 5% , two methods of bolt installation, two different grades of high strength bolts, and three different values of slip coefficient, namely, 0.33, 0.40, and 0.50. Equation (1) is intended for no slip at the service load.

Table 1 – Values of Statistical Parameter D (Kulak *et al*., 1987)

	Turn-of-nut		Calibrated wrench
Slip Coefficient	A325	A490	A325 & A490
0.33	0.82	0.78	0.72
0.40	0.90	0.85	0.78
0.50	0.90	0.85	0.79

AISC 2005 specification presents provisions for slip-critical connections designed to prevent slip either at service load or at factored load. The nominal slip resistance is taken as:

$$R_n = \mu D_u h_{sc} T_b \tag{2}$$

where

μ = the slip coefficient, taken as 0.35 for clean mill scale and roughened hot-dip galvanized surfaces and 0.50 for blast clean surfaces.

D_u = 1.13 and reflects the ratio of the mean installed bolt pretension to the specified minimum bolt pretension, the mean value of slip coefficient to the value used for the calculations and the probability of slip. This factor accounts for the fact that the calculations are performed at the factored load level despite the fact that slip is prevented at the service load level when the resistance factor, ϕ, is taken as 1.0 (RCSC, 2004).

h_{sc} = is the hole factor, taken as 1.0 for regular size holes, 0.85 for oversized and short slotted holes, and 0.7 for long-slotted holes.

T_b = minimum bolt pretension, taken as 70% of the bolt tensile strength.

Equation (2) is used with factored loads, but is intended to prevent slip at the service load level. When used with a resistance factor $\phi = 1.0$ it provides a probability of slip at service load level of approximately 5%. In order to prevent slip at the factored load level, AISC recommends a resistance factor $\phi = 0.85$. No other North American specification provides guidelines for design of slip-critical connections to prevent slip at the factored load level.

The design equation provided in CAN/CSA–S16–01 is used at the service load level and is intended to prevent slip at the service load level. The equation is identical to Equation (1) and the values of D presented in Table 1 are used for clean mill scale ($\mu = 0.33$), roughened galvanized surfaces ($\mu = 0.40$) and blast-cleaned surfaces ($\mu = 0.50$).

AASHTO (2004) provides a single equation, intended for use with service load combination II, where the live load effect is factored by 1.3. It is intended to prevent slip under a condition of moderate overload. The design equation takes the following form:

$$R_n = \mu \, h_{sc} \, T_b \tag{3}$$

where μ is taken as 0.33 for clean mill scale and hot-dip galvanized surfaces roughened by wire brushing after galvanizing, and 0.50 for blast-cleaned surfaces. As for the other North American codes, the bolt pretension, T_b, is taken as 70% of the nominal tensile strength. The hole factor, h_{sc}, is taken as 1.00 for standard holes, 0.85 for oversized and short slotted holes, 0.70 for long-slotted holes with the slot perpendicular to the applied force, and 0.60 for long-slotted holes with the slot parallel to the applied force.

RCSC (2004) provides two equations to design slip critical connections. Although both equations are for no slip at service load, one equation is to be used with service loads and the other with factored loads. The factored load equation was calibrated so that the design based on factored loads would yield the same result as the design at service load level. The factored load equation was provided only for the expedience of working at only one load level. The factored load equation takes the same form as Equation (2). The slip coefficients are taken as 0.33 for faying surfaces with clean mill scale, 0.50 for blast-cleaned surfaces, and 0.35 for roughened hot-dip galvanized surfaces. The multiplier D_u is taken as 1.13 and the hole factor h_{sc} is taken as 1.0 for standards holes, 0.85 for oversized or short-slotted holes, 0.70 for long-slotted holes perpendicular to the load direction, and 0.60 for long-slotted holes parallel to the load direction. As for the other specifications, the bolt pretension is taken as 70% of the nominal bolt tensile strength. The service load equation is identical to Equation (1). All the variables in the equation are the same as described above. The statistical constant D is taken as 0.80 for all surface conditions, bolt grades and method of installation.

All North American specifications for slip-critical joints should result in about the same number of bolts, resulting in a similar probability of slip at service load level. AASHTO has a load factor greater than 1.0, which is intended to prevent slip at a load level 30% larger than the design service load. The bolt specification of the RCSC (2004) provides two equations to design slip-critical joints using either service loads or factored loads. Both equations are intended to prevent slip at the service load level. The 2005 edition of the AISC specification is the only North American specification that provides the option of designing slip-critical joints to prevent slip at the service load level or to prevent slip at the factored load level.

2.2 Slip resistance of joints

Numerous test programs have been conducted to investigate the slip resistance of bolted joints. Testing started in the mid 1950's and the most recent tests were reported in 2007. This section reports the results of tests on bolted joints that are readily available in the literature. The important parameters that are required to make the test results useable in a reliability analysis are the accurate description of the faying surface preparation and the measurement of the pretension force in the bolts used to introduce the clamping force in the test joints. A summary of various test programs to determine the slip coefficient of various surfaces is presented below. Detailed test results are presented in chronological order in Appendix A.

In the research conducted at the University of Washington (Chiang and Vasarhelyi, 1964; Vasishth *et al*., 1957), a distinction was made between the term *coefficient of friction* and the term *slip coefficient* (also called *coefficient of slip*). The slip coefficient is calculated from the load at which major slip of the joint takes place whereas the coefficient of friction is calculated from the load at which first sign of slip takes place within the joint, which is usually at the ends of the joint. Although for many joints the two coefficients are identical, in some joints the coefficient of friction can be significantly lower than the slip coefficient, which is the value that has been reported by most researchers and is used in the RCSC specification. The researchers from the University of Washington have reported the coefficient of friction. Therefore, their test results will tend to lower the mean slip coefficient when used in a reliability analysis, thus resulting in a lower required resistance factor for a given safety index. For this reason, the tests from the University of Washington will be reported, but will not be used for the reliability analysis.

Laub and Phillips (1954) conducted tests on 14 joints with four bolts, some of A307 grade and some of A325 grade. All the test specimens were prepared with A7 steel plates and the faying surface consisted of clean mill-scale. The bolt pretension was assessed from measured bolt elongation. The mean slip coefficient was obtained as 0.275, with a standard deviation of 0.06.

Steinhardt and Möhler (1954) conducted slip tests on 271 double lap joints of St 37 steel with two and six bolts. 145 tests were conducted on surfaces with mill scale cleaned with a wire brush, nine tests were on specimens with sand-blasted surfaces, 67 tests were conducted on surfaces that were flame blasted and 50 tests were conducted on plates with peened and derusted surfaces. Various procedures were used for removing the rust on the surface and various portions of the faying surfaces were treated, varying from the entire surfaces to only a small surface around the bolt holes. The bolt pretension was not measured directly: it was measured using a calibrated wrench. The average slip coefficient for the 145 tests on mill scale cleaned by wire brushing was 0.357, with a standard deviation of 0.098. The mean and standard deviation for the nine test specimens with a sand blasted surface were 0.626 and 0.072, respectively. The 67 tests on flame blasted surfaces showed a mean slip coefficient of 0.642 and a standard deviation of

0.331. The peened and derusted surfaces showed a mean slip coefficient of 0.42 with a standard deviation of 0.074. Although the flame blasted surfaces show an exceptionally high variation, all the surfaces showed a relatively large slip coefficient. Part of the variability is attributed to the uncertainty in bolt pretension due to the fact that pretension was assessed from the applied torque during installation. Because the bolt pretension was not measured directly in the test program, the test results are not used for the reliability analysis.

In 1955 Hechtman *et al*. presented the results of 67 slip tests on double lap joints of A7 steel with four, six and eight bolts. A total of 64 tests were conducted on joints with clean mill scale whereas three tests were conducted on joints with sand blasted faying surfaces. The mean and standard deviation for the specimens with mill scale faying surface were 0.355 and 0.055, respectively. For the three sand blasted specimens, the mean slip coefficient was 0.485 and the standard deviation 0.110. The bolts were tightened to an elongation corresponding to the desired bolt pretension as determined in prior bolt calibration tests.

Vasishth *et al*. (1957) presented the results of slip tests from various sources, including their own test results. Although several test results are reported, the number of tests from other than their own source is not clear and the testing details are not provided. Out of the reported test results, only the ones conducted by Vasishth *et al*. are usable in a statistical analysis since the results for test groups from other sources are reported only in terms of mean values and minimum values. The reader is reminded that the University of Washington test results are presented in terms of coefficient of friction, i.e. first sign of slip, rather than slip coefficient. The bolt pretension in the tests conducted by the authors was evaluated indirectly from calibration of the turn-of-nut used for the installation. All the bolts were installed by giving a half turn pass the snug tight position. A total of 36 individual test results were reported for clean mill scale faying surfaces. The mean coefficient of friction and the standard deviation for these tests are 0.322 and 0.089, respectively.

Another test program from the University of Washington (Beano and Vasarhelyi, 1958) looked at the effect of red lead paint coating on the slip resistance of double lap joints of A7 steel plates with four bolts. A total of 21 tests were conducted and seven different coating conditions were investigated. Because the scope of the present report does not include the effect of coatings of the faying surfaces, these tests were not included in the reliability analysis. Nevertheless, the test results are reported in Appendix A.

Hojarczyk *et al*. (1959) presented the results of 24 tests on double lap joints with two bolts in the test joints made of St 37 steel plates. Six joints were tested with mill scale wire brush cleaned, six test specimens consisted of sand blasted faying surfaces and the remaining tests included red lead paint and sprayed zinc, aluminium, or chromium. The bolt pretension was measured through the calibration of gauged bolts. Of the six specimens with clean mill-scale, only three were conducted with pretension bolts. The test specimens with sand blasted faying surfaces did not show a clear slip load. Therefore, only three of the 24 tests conducted are retained for this reliability analysis. The mean and standard deviation for the slip coefficient for the three tests on clean mill scale are 0.269 and 0.088, respectively.

Additional test results by Steinhardt and Möhler were presented in 1959. A total of 138 tests were conducted on test specimens with ST52 and ST37 steel plates with clean mill scale (cleaned by wiring brushing), flame cleaned surfaces, sand blasted surfaces, and hot dip galvanized surfaces. Most tests were conducted on specimens with flame cleaned surfaces. The pretension was evaluated from the applied installation torque. Joints with two, three and ten bolts were tested. Six specimens were tested with wire brush cleaned mill scale. The mean and standard deviation were 0.420 and 0.038, respectively. Eight test specimens had sand blasted faying surfaces. The mean and standard deviation for these test specimens were 0.535 and 0.066, respectively. The mean and standard deviation for the eight test specimens that were hot dip galvanized were 0.151 and 0.022, respectively. Because bolt pretension was not measured directly, the test results presented by Steinhardt and Möhler cannot be used in the reliability analysis.

van Douwen *et al*. (1959) conducted 24 tests on untreated surfaces, 24 test on flame cleaned surfaces, and 64 tests on shot blasted surfaces. For all tests the bolt pretension was measured using bolt elongation measurement. The mean and standard deviation for the slip coefficient on blast cleaned surfaces were 0.486 and 0.085, respectively.

Foreman and Rumpf (1961) presented the results of eight tests on double lap joints with 12 to 30 bolts of 7/8 in. to 1-1/8 in. diameter and A7 steel plates. The faying surfaces consisted of clean mill scale (degreased) and bolt pretension was determined from measurement of bolt elongation. The average slip coefficient is 0.42, with a standard deviation of 0.053.

Bendigo *et al*. (1963) conducted slip tests on bolted joints made of A7 steel plates with 4 to 32 bolts in the joints. Two different surface preparations were investigated, namely, mill scale removed by power brushing and clean mill scale (wire brushed and degreased). In all cases the bolt pretension was determined using bolt elongation measurements. The mean slip coefficient and standard deviation of the 12 test specimens with mill scale removed were 0.294 and 0.046, respectively. For the eight test specimens with clean mill scale, the mean slip coefficient and standard deviation were 0.458 and 0.078, respectively. However, because the mill scale was wire brushed, the test results are not used for the reliability analysis.

Fisher *et al*. (1963) reported the results of 14 tests on double lap joints with eight to 32 bolts. The faying surfaces consisted of clean mill scale (wire brushed and degreased) with plates of grade A440 steel. The pretension in the bolts was obtained from bolt elongation measurements. The mean slip coefficient and the standard deviation were 0.317 and 0.033, respectively.

Chesson and Munse (1964) presented the results of fatigue tests on double lap splice connections with four bolts and A7 steel plates. The slip resistance was measured in the first load cycle and bolt pretension was measured using bolt elongation measurements. The faying surfaces consisted of clean mill scale, wire brushed and degreased before assembly of the joints. The mean slip coefficient and standard deviation of 14 tests were 0.240 and 0.061, respectively.

Chen and Vasarhelyi (1965) presented the results of 27 tests on double lap joints with 9, 12, or 15 bolts made with A7 steel plates. Although the pretension forces were obtained from bolt elongation measurements, the slip load was defined differently for different tests. The mean slip coefficient and the standard deviation of the tested specimens were 0.292 and 0.038, respectively. Because of the different slip definition used in this test program, the test data could not be used for the reliability analysis.

The results of 54 slip tests were presented by Klöppel, and Seeger (1965). The double lap joints were made with St37 steel and included one, two, or six bolts in double shear. Three test specimens consisted of as-received mill scale and all the other test specimens had sand blasted faying surfaces. The pretension was evaluated indirectly by the applied torque. The mean slip coefficient and standard deviation of the sand blasted specimens were 0.554 and 0.083, respectively. For the three specimens with as-received mill scale, the mean slip coefficient was 0.435 and the standard deviation was 0.044. Because the bolt pretension was not measured directly in the test program, the test results are not used for the reliability analysis.

Prynne (1965) presented the results of 39 slip tests; four on plates in the as-received condition and 35 on plates with surface machined to a surface roughness "not far removed from that of the as-received plates". The plates were of mild steel and the pretension in the bolts was determined by strain gauging. The mean slip coefficient for the plates in the as-received condition was 0.483, with a standard deviation of 0.031. The mean slip coefficient for the specimens with a machined surface was 0.421, with a standard deviation of 0.106. It is not clear what the condition of the as-received surface was.

Brookhart *et al*. (1966) investigated the effect of galvanizing and other surface treatments on the slip resistance of bolted joints. A total of 31 test results were presented for double lap joints containing four A325 bolts. The bolt pretension was assessed through bolt elongation measurement. The mean and standard deviation for the slip coefficient of six tests with clean mill scale were 0.292 and 0.036, respectively. A total of 10 specimens with hot dip galvanized faying surfaces were tested and showed a mean slip coefficient and standard deviation of 0.228 and 0.023, respectively. Small samples of zinc painted and metallised surfaces were also tested in the test program. They both showed slightly higher mean slip coefficient than the specimens with clean mill scale, although the difference was not statistically significant. In addition, three other types of coating were investigated, namely, two types of vinyl coating and rust ban coating. As for all the tests from the University of Washington, the load at first sign of slip at the end of the connections was the load from which the slip coefficient was calculated.

Kuperus (1966) conducted a series of tests on double lap joints to study the effect of exposure of the faying surfaces before assembly of the joints. Two grades of steel were used for the test specimens, namely, Fe37 and Fe52. One series of tests consisted of 16 tests on untreated surfaces for each one of the steel grades. The faying surfaces were exposed to open air from 0 to 60 days before testing. All rust formed during exposure was removed by wire brushing before assembly of the joints. Another series of 48 tests were conducted to investigate the effect of open air exposure after the faying surfaces had been cleaned by shot blasting. Exposure to air varied from 0 to 21 days. Due to the test specimen configuration, each test specimen provided two test results. All test specimens used 20 mm diameter pretensioned bolts. Bolt pretensioning was controlled by measuring the elongation of bolts that had been calibrated prior to installation. The results of the test program demonstrated a significant difference in slip coefficient between the two steels both for the shot-blasted and the untreated surfaces. The difference in slip coefficient for samples exposed to air for 7 and 21 days after shot blasting showed no significant change in slip coefficient compared to the specimens that were not exposed. For this reason, all test results from shot blasted test specimens presented in that test program are used for the database of test results. The tests on untreated surfaces (clean mill scale) showed a marked increase in slip coefficient for test specimens exposed to open air for 14 days and 60 days. Because this increase in slip coefficient is not expected for clean mill scale, the test results for clean mill scale exposed to air for 14 and 60 days were not in the reliability analysis. The mean slip coefficient and standard deviation for all the untreated specimens were 0.39 and 0.11, respectively. The mean slip coefficient and standard deviation for the shot blasted specimens were 0.57 and 0.07, respectively.

In the 1960's joints with varying geometry were tested at Lehigh University to study the influence of various factors such as joint length, bolt pitch and relative proportions of the net tensile area of the plate to the bolt shear area on the strength of bearing type connections. Data on the slip resistance was also reported for these tests. Sterling and Fisher (1966) reported the results of eight such tests on joints made of A440 plates and pretensioned A490 bolts. The faying surfaces were clean and degreased mill scale. The average and standard deviation for the tests were 0.35 and 0.027, respectively. Similar tests, conducted with A325 bolts, were also reported by Nester (1966). From 18 tests conducted double lap joints, the mean slip coefficient was reported as 0.31 and the standard deviation as 0.036. Nester (1966) investigated the effect of contact surface area on slip resistance. Fifteen tests were conducted on double lap joints with four A325 bolts. The steel plates were of A36 grade and the surface consisted of mill scale cleaned with wire brushing and a solvent. The faying surfaces were separated with washers of different sizes made of the same steel as the main and lap plates. Three of the test specimens did not have any washers between the main and lap plates and were used as control specimens. In all the tests, bolt pretension was assessed from measured bolt elongation and strain gauges mounted on the shank. The tests indicated no correlation between contact surface area and slip coefficient. The mean and standard deviation for the slip coefficient were 0.27 and 0.055, respectively.

Vasarhelyi and Chiang (1967) investigated the effect of steel grade on the slip resistance of their mill scale. A7, A36, A440 and T1 steels were tested in a series of 29 tests. Some of the tests were conducted with main plate and lap plates of different grades. The bolt pretension was measured directly using instrumented bolts. The test results indicated no significant difference in slip resistance between the different steel grades. Although the tests were conducted with great care, as discussed above, the load at first sign of slip was reported rather than the load a general slip. The mean coefficient of friction and the standard deviation obtained from their test program were 0.27 and 0.046, respectively.

Allan and Fisher (1968) presented the results of tests on specimens with clean mill scale (loose mill scale and burrs were removed) where bolt pretension was determined from bolt elongation measurements. The behavior of joints with standard holes, oversized holes and slotted holes (some oriented perpendicular to the applied load and some parallel to the applied load) was investigated. All test specimens were prepared with A36 steel plates. The tests indicated no significant difference is slip coefficient between the different hole configurations. The mean and standard deviation for the slip coefficient measured in 21 tests were 0.25 and 0.039, respectively. Because of the uncertainties with slip behavior of plates with slotted holes, the test specimens with slotted holes (a total of nine test specimens) are not used in the reliability analysis.

Fisher and Kulak (1968) presented the results of an investigation of the behavior of hybrid joints with a combination of A514, A36 and A440 steel plates. Nine bolted joint specimens including 11, 13, or 19 bolts were tested with sand blasted faying surfaces. The mean slip coefficient and standard deviation were 0.34 and 0.052, respectively. Kulak and Fisher (1968) reported an additional 17 test results on joints made of A514 steel plates with blast clean faying surfaces and high strength bolts of grade A325 and A490. The slip coefficient for all tests was similar, with an average of 0.33 and a standard deviation of 0.040.

Additional tests from Lehigh University were presented by Lee and Fisher (1968). A total of 21 slip tests on double lap joints with four bolts and grade A36 steel plates were conducted to determine the slip coefficient for sand blasted surfaces. The mean slip coefficient and standard deviation were 0.49 and 0.15, respectively.

Kennedy and Sanderson (1968) conducted a series of fatigue tests on hot dip galvanized high strength bolted joints. The steel plates used were of CSA-G40.8 (yield strength of 280 MPa (40 ksi)). Eighteen test specimens were fabricated with hot dip galvanized steel plates and 23 specimens were fabricated with steel plate with clean mill scale. The slip load was defined as the load at which all the bolts were in bearing for the specimen with clean mill scale faying surfaces and the load at a slip of 0.01 in. for the galvanized specimens. The mean slip coefficient and standard deviation for the plates with clean mill scale were reported as 0.25 and 0.017, respectively. The mean and standard deviation for the galvanized plates were 0.15 and 0.028, respectively.

Munse (1968) presented the results of fatigue tests on four-bolt double lap splice specimens coated with inorganic zinc coatings Dimecote 5 and 6. The two coatings yielded about the same slip coefficient. The mean slip coefficient and standard deviation for all 5 tests was 0.49 and 0.027, respectively. In a later paper, Munse (1969) presented the results of five other tests on specimens with galvanized faying surfaces. The mean slip coefficient and the standard deviation were 0.18 and 0.021, respectively.

The effect of surface coatings and exposure on the slip resistance of bolted joints was investigated by Lee *et al*. (1969). A combination of blast cleaned, linseed oil coating vinyl wash and exposure to the environment for up to 12 months before assembly of the test specimens made part of the experimental design. The plates were of A36 steel and bolt holes were either regular size, oversized, or slotted in the direction of the applied load. As for other test programs from Lehigh University, the bolt pretension was assessed from measured bolt elongation. The three blast cleaned specimens that were assembled immediately after cleaning showed a mean slip coefficient of 0.49, with a standard deviation of 0.012. Exposure to the environment for 2, 6 and 12 months before assembly of the joints changed the slip coefficient to 0.43, 0.47 and 0.39, respectively. Although exposure for up to six months had little effect on the slip coefficient, exposure for 12 months resulted in a significant reduction in slip coefficient.

Dusel *et al*. (1977) conducted a series of 28 slip tests to investigate various types of surface preparation for A36 steel plates and channel sections. Surface preparation consisted either of sand blasting, clean mill scale, hot dip galvanized, vinyl wash primer or organic zinc-rich primer. In all cases 7/8 in. dia. A325 bolts were used and the pretension was assessed through bolt elongation measurements. Of seven joints with sand blasted faying surfaces the mean slip coefficient and standard deviation were 0.53 and 0.082, respectively. Only one specimen was tested with mill scale in the "as-received" condition. The slip coefficient was 0.28. The mean slip coefficient and standard deviation from four hot dip galvanized test specimens were 0.43 and 0.041, respectively. No indication of any special treatment of the hot dip galvanized specimen is found in the report to explain the exceptionally high slip coefficient obtained from these tests compared to the slip coefficient obtained for similar surface treatment in other test programs.

A large number of slip tests were conducted at the University of Texas (Fouad, 1978) to investigate slip resistance of bolted joints, with varying steel grades, different faying surfaces and bolt grade as the main parameters. The test specimens were single bolt compression slip specimen as illustrated in Figure A-1 of the RCSC Specification (2004). The bolt pretension was measured directly using a load cell. A total of 103 tests were conducted on sand blasted specimens. Both A325 and A490 bolts were used and the steel plates were either of grade A572, A514 or A36. The plate material grade and the bolt grade did not have a significant effect on joint slip behavior. A series of 103 tests on specimen with blast clean faying surfaces of different steel grade and bolt grades showed a mean slip coefficient and a standard deviation of 0.52 and 0.087, respectively. A series of 104 tests on specimens with an organic zinc primer coating on the faying surfaces showed a mean slip coefficient of 0.46 and a standard deviation of 0.071. A series of 90 tests with organic zinc coating and epoxy top coat showed a significant reduction in slip coefficient, showing a mean value of 0.27 and a standard deviation of 0.032. Ninety test specimens with inorganic zinc primer and vinyl top coat showed a mean slip coefficient of 0.51 and a coefficient of variation of 0.061. A series of 15 tests conducted on specimens with a vinyl primer on the faying surfaces showed a mean slip coefficient of 0.19 and a standard deviation of 0.016. An additional six test specimens with vinyl primer and top coat showed a slip coefficient of 0.20 and a standard deviation of 0.0138. Ten specimens with powder epoxy coating showed a mean slip coefficient of 0.078 and standard deviation of 0.011. A series of 20 slip tests were conducted to determine the effect of the zinc content in inorganic zinc-rich primer. It was found that the slip coefficient increases with the amount of zinc in the primer. A mean slip coefficient of 0.61 was obtained with surface primer containing 80% zinc whereas the same primer with no zinc showed a slip coefficient of 0.28, obtained from five tests. Five tests on specimens with 75% zinc showed a mean slip coefficient of 0.51, with a standard deviation of 0.010.

Moss (1979) investigated the effect of weathering on the slip resistance of double lap splice connections. Various surface treatments and exposure conditions were investigated. For some of the test specimens the individual plates were exposed to outdoor environment after grit blasting, but before assembly. In other specimens the joints were assembled before exposure. Four different surface treatments were implemented, namely, grit blasted with no corrosion resistant treatment, grit blasted followed by zinc or aluminum metal spray, and grit blasted followed by a zinc rich silicate primer. Both A514 and A36 steels were investigated, with no significant difference between the two steels being detected. The mean slip coefficient and standard deviation for six specimens with grit blasted faying surfaces assembled immediately after grit blasting were 0.45 and 0.038, respectively. The 10 joints that were grit blasted and exposed to an industrial environment for 10 weeks and lightly wire brushed before assembly showed a mean slip coefficient of 0.51 and a standard deviation of 0.050. The increased slip coefficient was attributed to the increased surface roughness resulting from the corrosion process.

Hansen (1980) investigated the effect of filler plate thickness on the slip coefficient. Test specimens with A514 steel for the main and splice plates were prepared with A36 steel filler plates, all with clean mill scale. Two tests were conducted without filler plates (mean slip coefficient and standard deviation of 0.32 and 0.034, respectively), two tests were conducted with a single 1/4 in. filler plate (mean slip coefficient and standard deviation of 0.27 and 0.025, respectively), and two tests were conducted with three 1/4 in. filler plates (mean slip coefficient and standard deviation of 0.17 and 0.026, respectively). Although the test results showed that the presence of fillers decreased the slip coefficient, the cause for this reduction was not investigated.

Frank and Yura (1981), in an investigation of the surface coating effect on the slip coefficient of A572 and A514 steel plates used in compression slip test specimens as illustrated in Figure A-1 of the RCSC Specification. The bolt force was measured directly using a load cell. Two sets of specimens were prepared without coating. One set of 10 specimens had clean mill scale. These specimens showed a mean slip coefficient of 0.26 and a standard deviation of 0.066. One set of 10 test specimens consisted of plates with sand blasted surfaces. The mean slip coefficient for these specimens was 0.69 and the standard deviation was 0.067. No significant difference between A36 and A514 steel plates was observed for both surface preparations. Additional tests were conducted on joints fabricated with A588 steel (Yura *et al*., 1981). A total of 31 tests on plates with clean mill scale showed a mean slip coefficient of 0.23 and a standard deviation of 0.032. Twenty test specimens with sand blasted faying surface, made of A588 steel, showed a mean slip coefficient of 0.52 and a standard deviation of 0.107.

Hou and He (1995) presented the results of 15 slip tests on single bolt double lap joints tested in tension. The grade of steel used for the plates was not reported and the method used to assess the bolt pretension was not specified. However, since they are reporting a different bolt pretension for each test, it is probable that the bolt pretension was measured directly for each test specimen. Two faying surface preparations were investigated, namely, sand blasted and smoothed surfaces. The paper does not specify how the faying surfaces were prepared for the smoothed specimens. A total of 10 sand blasted test specimens were conducted and a mean slip coefficient of 0.44 was obtained. The standard deviation was 0.040. For the smoothed specimen, the mean of five test specimens was 0.19 and the standard deviation was 0.037.

Slip tests were recently conducted at the University of Alberta (Stankevicius *et al*., 2007) to investigate the slip coefficient for A588 steel with clean mill scale, which showed a particularly low value of slip coefficient in a series of tests conducted at the University of Texas (Yura *et al*., 1981). The test program conducted at the University of Alberta used double lapped joints loaded in tension. The test specimens were designed to investigate slip in a one bolt joint and in a two-bolt joint. A total of 99 test specimens were tested to investigate the effect of surface preparation (degreased versus as-received with cutting oil left on the surface to evaporate), bolt preload, hole size (standard versus oversized), and punched versus drilled holes. The test program provided 190 independent measurements of slip coefficient for A588 steel plates with "clean" mill scale. For a small number of joints with two bolt holes, the slip load was not clearly discernible. These test results are not included in the database of test results used for the reliability analysis, although, because of the large number of test results, it is weighted. The tests showed a mean slip coefficient of 0.38 (including test specimens that were degreased and some that were tested without degreasing the plates before testing) and a standard deviation of 0.064. The effect of surface cleaning was found to be important. The slip coefficient of the test specimens tested without degreasing the faying surfaces showed an average slip coefficient of 0.34. The degreased plates showed a mean slip coefficient of 0.40. As expected, hole oversize was found to have negligible effect on the slip coefficient. Both levels of bolt pretension used in the test program resulted in the same slip coefficient. Finally, the effect of hole making process was found to be negligible. Figure 1 shows a comparison between the test results from Yura *et al.* (1981) and the test results from the University of Alberta (Stankevicius *et al.*, 2007).

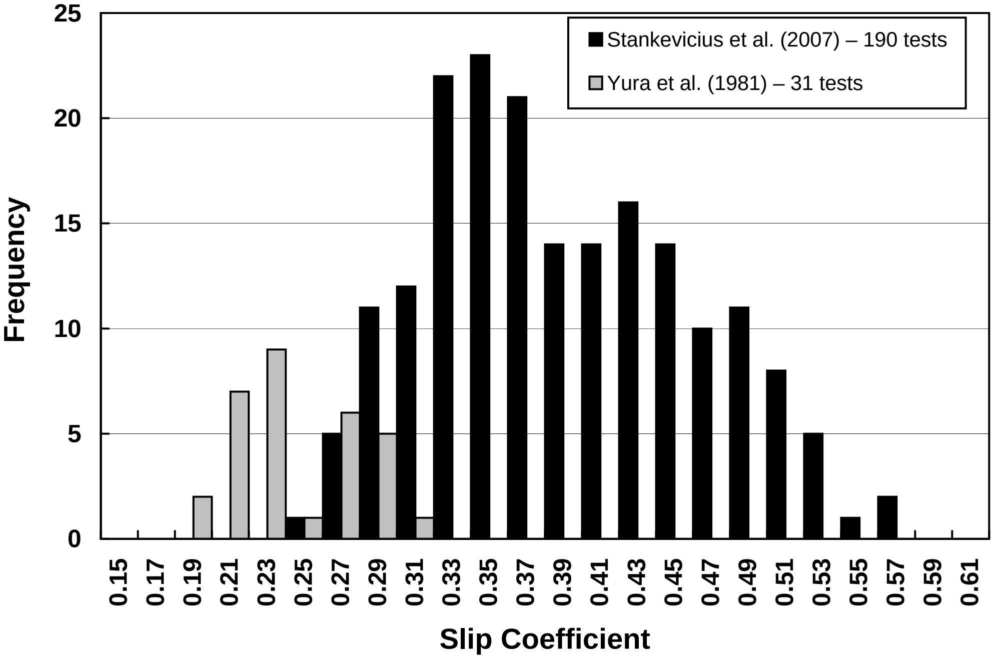
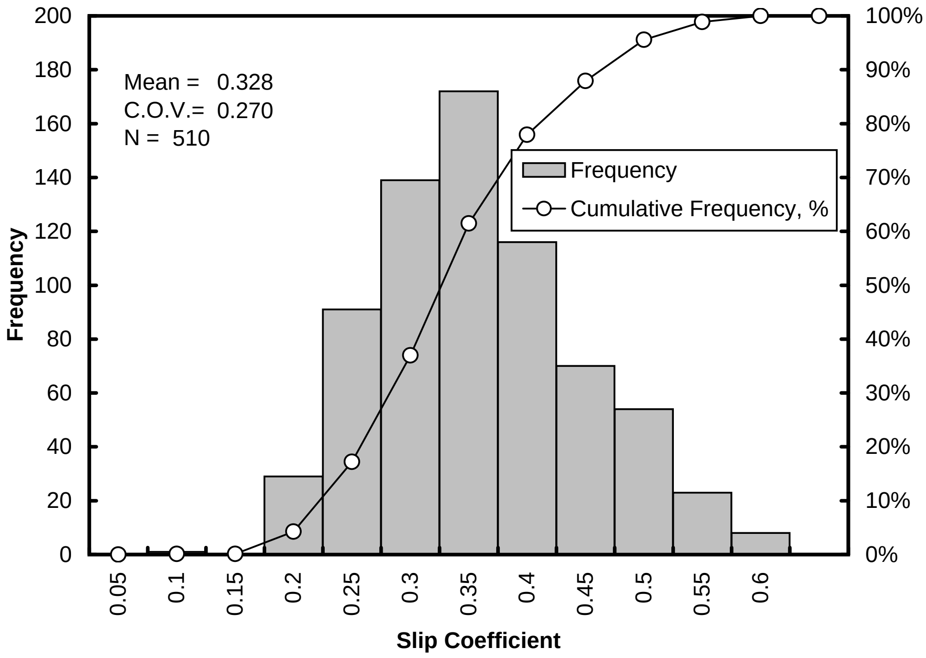
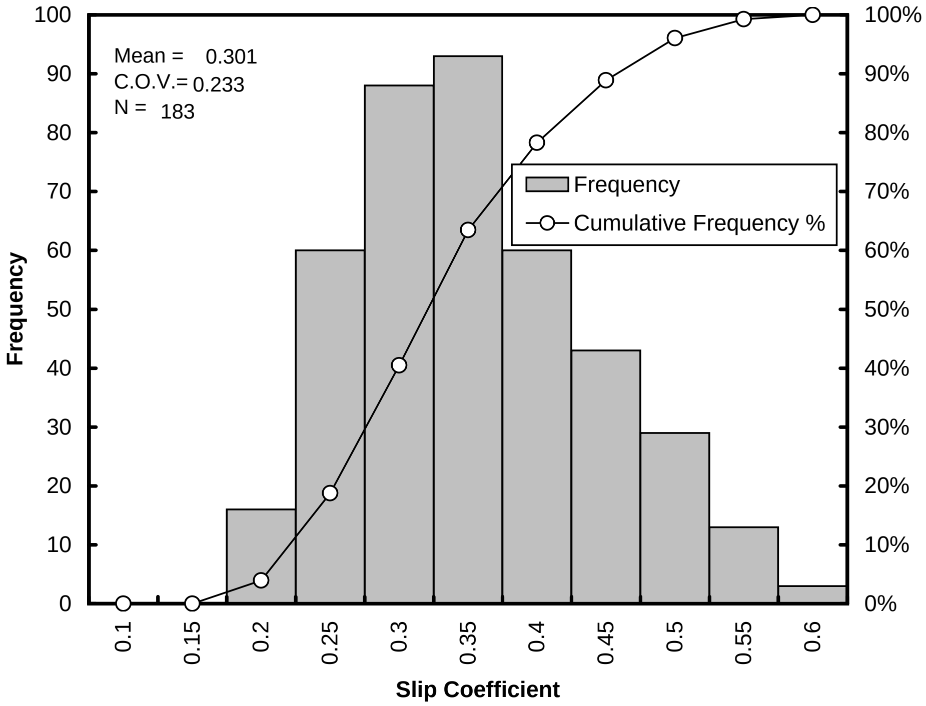


Figure 1 – Measured slip coefficient on A588 steel plates

The frequency distributions for all the test results obtained for clean mill scale, blast clean surfaces and galvanized surfaces are presented in Figures 2, 3, and 4, respectively. Figure 2 presents all the collected test data and screened data, except for the test results obtained on A588 steel plates. Figure 3 presents all the test data collected as well as screened data. The screened data exclude some of the test data for one or more of the following reasons: 1) different definition of slip was used; 2) the bolt pretension was not measured directly, or not reported; 3) the surface preparation was not clearly defined, 4) filler plates were used in the test joints, or 5) only the average of the test results were reported and not the standard deviation. Because of the small sample size for galvanized faying surfaces, all the test data available were used for the reliability analysis. The frequency distribution for this condition indicates that the test results consist of two distinct samples, one with a slip coefficient about 0.2 and one with a slip coefficient of about 0.4.

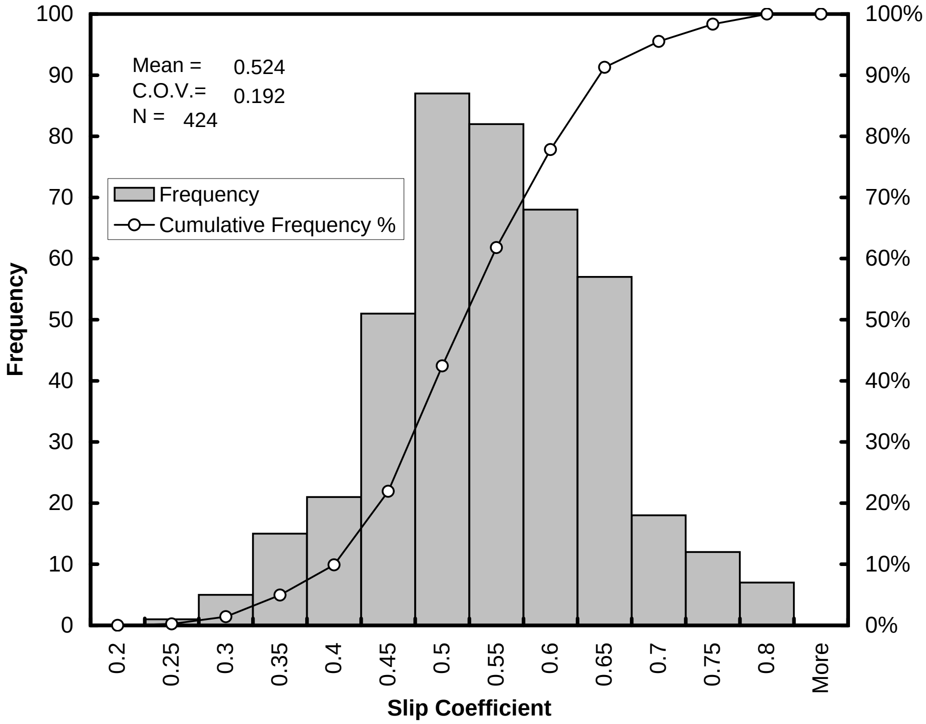


(a) All collected test data (A588 steel plates excluded)

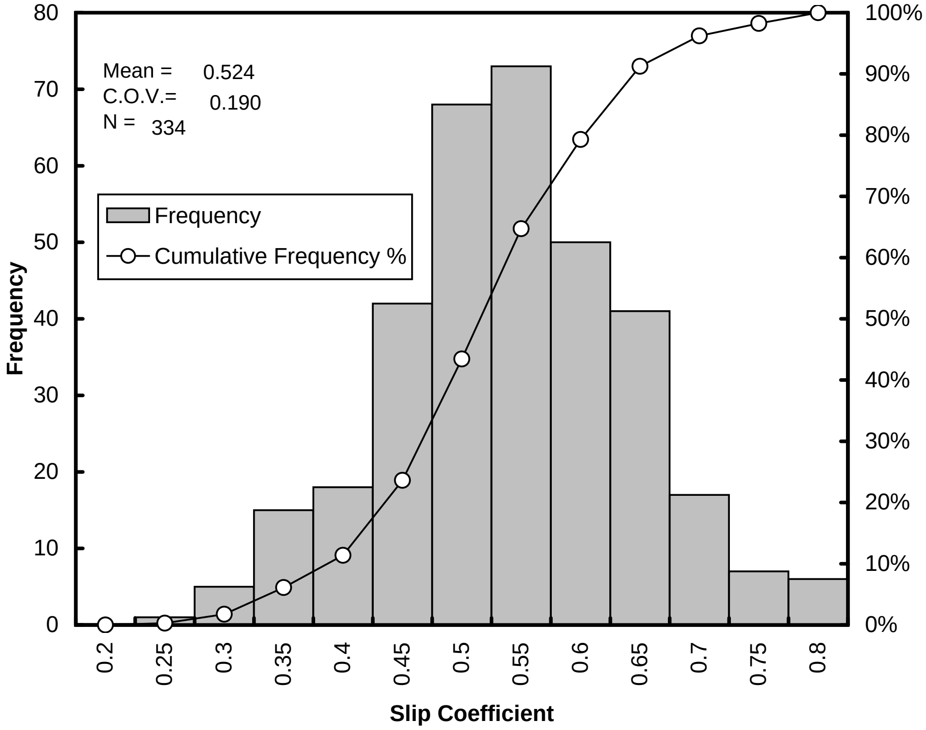


(b) Screened test data (A588 steel plates excluded)

Figure 2 – Distribution of slip coefficient for clean mill scale surfaces



(a) All collected test data



(b) Screened test data

Figure 3 – Distribution of slip coefficient for blast cleaned surfaces

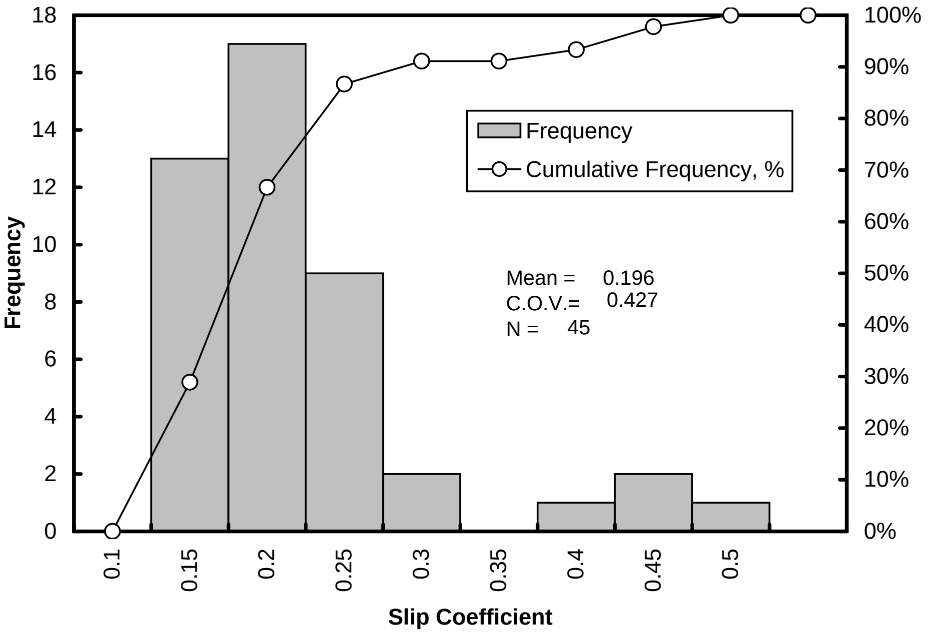


Figure 4 – Distribution of slip coefficient for galvanized surfaces

A summary of the experimental data used for the reliability analysis is presented in Tables 2 to 4 for clean mill scale, blast clean and galvanized faying surfaces, respectively, using only the screened data. Details of the test results are presented in Appendix A.

Table 2 – Measured Slip Coefficients (Clean Mill Scale)

Source	Sample size	Mean	C.O.V.
Allan and Fisher, 1968	12	0.274	0.090
Dusel *et al.*, 1977	1	0.280	0.000
Fisher *et al.*, 1963	14	0.317	0.104
Foreman and Rumpf, 1961	8	0.420	0.125
Frank and Yura, 1981a	10	0.260	0.253
Hansen, 1980	2	0.324	0.105
Hojarczyk *et al.*, 1959	3	0.269	0.328
Kennedy and Sanderson, 1968	23	0.252	0.069
Kuperus, 1966	16	0.310	0.195
Laub and Phillips, 1954	14	0.275	0.219
Nester, 1966	15	0.272	0.201
Prynne, 1965	4	0.483	0.064
Stankevicius *et al.*, 2007	190	0.387	0.183
Sterling and Fisher, 1966	8	0.348	0.078
van Douwen *et al.*, 1959	24	0.352	0.200
Vasarhelyi and Chiang, 1967	29	0.271	0.171
Yura *et al.*, 1981	31	0.232	0.140
All data	404	0.338	0.255

Table 3 – Measured Slip Coefficients (Blast clean surface)

Source	Sample size	Mean	C.O.V.
Douty and McGuire, 1965	7	0.560	0.121
Dusel et al., 1977	7	0.532	0.153
Fisher and Kulak, 1968	9	0.343	0.153
Fouad, 1978	103	0.526	0.177
Frank and Yura, 1981a	10	0.690	0.097
Frank and Yura, 1981b	8	0.515	0.144
Kuperus, 1966	96	0.566	0.124
Lee and Fisher, 1968	21	0.489	0.307
Lee et al., 1969	3	0.493	0.024
Moss, 1979	6	0.394	0.096
van Douwen et al. 1959	64	0.486	0.175
Yura *et al*., 1981	20	0.518	0.207
All data	354	0.525	0.193

Table 4 – Measured Slip Coefficients (Galvanized surface)

Source	Sample size	Mean	C.O.V.
Munse, 1969	5	0.185	0.112
Steinhardt and Möhler, 1959	8	0.151	0.144
Brookhart et al., 1966	10	0.228	0.100
Dusel et al., 1977	4	0.428	0.097
Kennedy and Sanderson, 1968	18	0.150	0.185
All Data	45	0.196	0.427

It is observed that the test data from Stankevicius *et al*. (2007) dominate the data set for clean mill scale. It is therefore desirable to weight the data during the pooling process to avoid having the large data sets overshadow the data pool. Although several approaches can be used to weigh the test data, the method selected was to group the test specimens according to the steel heat used in the various test programs and give each group equal weight. Table 5 presents the test data for the various test programs on plates covered with clean mill scale. A total of 35 different heats of steel are represented in the table. For the test programs where the same steel grade is identified more than once, the different steel heats were identified as different plate thickness. The average of the mean values is 0.310. The coefficient of variation for the mean values from the 35 different heats presented in Table 5 is 0.221. However, this COV represents only the variability between the heats. Also, in order to reflect the variability within heats, the COV for all the data points was calculated for the 397 test results. This COV is 0.253. This value of COV reflects both the variation within and between the samples and will be used for the reliability analysis.

Table 5 – Test results for clean mill-scale sorted by steel heat

Source	Steel grade	Sample size	Mean	C.O.V.
Allan and Fisher, 1968	A36	12	0.274	0.089
Fisher *et al.*, 1963	A440	14	0.317	0.104
Foreman and Rumpf, 1961	A7	8	0.420	0.125
Frank and Yura, 1981a	A36	2	0.350	0.242
	A572	6	0.217	0.069
	A514	2	0.300	0.000
Hansen, 1980	A514	2	0.324	0.105
Hojarczyk *et al.*, 1959	St37	3	0.269	0.328
Kennedy and Sanderson, 1968	G40.8 Grade 8	23	0.252	0.069
Kuperus, 1966	Fe37	8	0.359	0.124
	Fe52	8	0.261	0.080
Laub and Phillips, 1954	A7	14	0.275	0.219
Nester, 1966	A36	15	0.272	0.202
Prynne, 1965	Mild steel	4	0.483	0.064
Stankevicius *et al.*, 2007	A588	92	0.347	0.151
	A588	98	0.426	0.176
Sterling and Fisher, 1966	A440	8	0.348	0.078
van Douwen *et al.*, 1959	St37	4	0.449	0.037
	St37	4	0.437	0.017
	St37	4	0.302	0.066
	St37	4	0.312	0.071
	St37	4	0.324	0.172
	St37	4	0.292	0.056
Vasarhelyi and Chiang, 1967	A7	2	0.286	0.017
	A7	2	0.226	0.037
	A7	2	0.280	0.005
	A7	4	0.334	0.092
	A7	4	0.257	0.100
	A7	4	0.282	0.211
	A7	5	0.243	0.230
Yura *et al.*, 1981	A588	11	0.201	0.080
	A588	5	0.263	0.061
	A588	5	0.284	0.029
	A588	5	0.227	0.082
	A588	5	0.352	0.069
Total		397	0.306	0.260

2.3 Bolt pretension

The Bolt Council recognizes four methods of high strength bolt installation, namely, the turn-of-nut method, the use of direct tension indicator washers (ASTM F959 washers), the use of tension-control bolts of 120/105 ksi tensile strength (ASTM F1852 bolts) or of 150 ksi minimum tensile strength (ASTM F2280 bolts), also known as twist-off bolts, and the calibrated wrench method.

Test data have indicated that the mean value and variability of the installed pretension is different for each of the bolt installation methods. This section presents a brief review of the different installation methods and some of the test data available for each method.

2.3.1 Turn-of-nut method

The turn-of-nut is a simple and reliable method that relates the turns of the nut relative to the bolt from the snug tight position to the amount of pretension developed in the bolt. The fraction of a turn of the nut varies with the bolt length and diameter, but generally varies from one third to one half of a turn. Because the turn-of-nut method is a bolt deformation control method, the pretension developed in the bolts is strongly dependent on the tensile strength of the bolt.

Although the mean and standard deviation of the ratio of applied bolt pretension to minimum specified pretension both vary depending on the bolt length and the bolt grade, values of mean and standard deviation for A325 bolts installed using 1/3 turn are given as 1.22 and 0.061, respectively (Kulak *et al*., 1987). For A490 bolts and bolts installed using 1/2 turn, the mean and standard deviation for the ratio of applied bolt pretension to the minimum specified values are 1.26 and 0.1008, respectively. These values are used as representative values in the reliability analysis.

2.3.2 Direct tension indicator washers

The most common type of direct tension indicator (DTI) is a load-indicating washer. Load-indicating washers have protrusions that deform as the pretension force induced in the bolt is transferred to the washer. The deformation of the protrusions is directly correlated to the pretension force in the bolt. The desired level of pretension is verified by the use of a feeler gauge to check the remaining gap between the bolt head and the washer.

The pretension provided in a bolt assembly that uses DTI washers is reported to be 1.03 (standard deviation not reported) (Struik *et al*., 1973) with respect to the specified minimum pretension when A325 and A490 bolts are installed in a hydraulic calibrator with parallel surfaces. When the bolts were installed in simulated joints, the pretension ratio rose sharply to 1.17 (as reported by Undershute and Kulak (1994)). In the case of simulated joints, bolt tensions were determined by measuring bolt elongations and relating them to bolt loads by means of a load vs. deformation relationship. No explanation for the difference in pretension as attained from the hydraulic calibrator and from the test joints is provided by Struik et al.

A series of experiments have been made to evaluate the accuracy of direct tension indicator washers. Test results showed that the minimum tension required was achieved most of the time. The accuracy ranged from +12% to -10% when DTI's were used between parallel joint surfaces (Bickford, 2008).

Field measurements of 60 7/8 in. diameter A325 bolts installed with a load-indicating washer (Kulak and Birkemoe, 1993) showed that the average pretension was 1.12, with a standard deviation of 0.13.

A subsequent field test program was carried out (Oswald *et al*., 1996) in which pretension was measured in 44 large diameter (1 in. and 1-1/8 in.) A490 bolts installed by construction crews into slip-critical connections in a multistory steel-framed building. The bolts were installed with direct tension indicators into connections that varied from simple bracing connections to large column splices. The field test results showed that the minimum specified pretension was not achieved in a significant number of bolts with long grip lengths (greater than 178 mm), while bolts with shorter grip lengths were adequately tensioned. A combination of factors, including 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, were invoked as the possible reasons for the low pretension stresses measured in the longer bolts. Neither of these two reasons are plausible reasons since the DTI provides a direct reflection of the tension in the bolts.

2.3.3 Tension-control bolts

The literature available on the behavior of tension-control (or twistoff) bolts is very limited. Of the few reports available, most were sponsored by companies involved in tension-control bolt manufacturing. One such study was conducted at Lehigh University (Slutter, 1979) for the T.C. Bolt Corporation. The test program involved measuring the slip load of three joints made from ASTM A36 steel made with 7/8 in. diameter A325 tension-control bolts in short slotted holes without washers under the head of the bolts. Three bolts were mounted in a Skidmore-Wilhelm hydraulic load cell and were installed. The average pretension was 1.051 and the standard deviation 0.013. Slip tests were conducted on steel joints and, based on an assumed coefficient of friction, it was concluded that the pretension might be higher when the bolts are installed in joints rather than in a load cell. This conclusion, however, is not sound and was not supported by any experimental evidence other than slip resistance and assumed slip coefficient.

A series of tests conducted at the Pittsburgh Testing Laboratory (1986) focused on A490 bolts. Standard bolts, T.C. bolts and DTI were investigated. The T.C. bolts were 1 in. diameter and had lengths of 3-1/4 in. and 3-3/4 in. All bolts were tested either after indoor storage of eight weeks or after two weeks of weathering. Of ten bolts tested after indoor storage, only two reached or exceeded the minimum pretension. The average and standard deviation of the tests were 0.93 and 0.087, respectively. Four bolts were weathered outside for two weeks after delivery. Two of these bolts achieved an average pretension of only 0.391. The other two were relubricated with wax and the pretension increased to 0.922.

Studies of LeJeune Tension-control bolts reported by Undershute and Kulak (1994) show a pretension ratio of 1.15 from tests on 24 3/4 in. black bolts and 12 7/8 in. weathering steel bolts. The tests were performed on solid blocks and in a load cell. No significant difference was noticed between the two test series. The ratio of the average hydraulic calibrator pretension to solid block pretension was 0.998. A total of 24 tests were conducted on galvanized bolts of 3/4 in. and 7/8 in. bolts. The test average was 1.46. The high pretension obtained with galvanized bolts was attributed to the special lubricant used on these bolts.

Tension-control bolts from seven manufacturers were tested by Undershute and Kulak. The test bolts were 3/4 in. diameter with lengths varying from 2-1/4 in. to 3-1/4 in. and 7/8 in. bolts with a length of 4 in. The bolts were tested in two series, namely, bolts subjected to various conditions of exposure and bolts with different kinds of friction conditions. The average ratio of pretension to specified minimum pretension for 81 as-delivered bolts was 1.20 with a standard deviation of 0.11. Analysis of the test data showed that the lubricant quality and durability are more important than the age of the bolts. For bolts stored indoor in a sealed metal keg for two and four weeks, the average normalized preloads were 1.16 and 1.20. Other conditions of exposure were investigated.

For the TC bolts tested in the as-delivered condition, after indoor storage in a sealed keg, or after exposure to ambient indoor humidity, the lowest average normalized pretension was 1.16. Thus, in any of these three categories, the TC bolts achieved average non-dimensionalized pretensions between the average pretensions of the turn-of-nut method and the calibrated wrench installation method. For TC bolts exposed to outdoor humidity, the normalized pretension was as low as 1.03 in several cases. The tests show that preloads in TC bolts installed prior to significant exposure were slightly higher than that produced by the calibrated wrench in the lab, but significantly less than that achieved by turn-of-nut, either in the lab or in the field. For TC bolts with full exposure to weather, the average normalized preloads were significantly lower than the preloads achieved by the turn-of-nut method, and lower than that by the calibrated wrench method in the lab. For TC bolts weathered in a simulated steel joint, the average normalized preloads were substantially lower than those obtained by the calibrated wrench method in the lab, and a lot lower than those obtained by the turn-of-nut method.

A recent study at the University of Toronto (Tan *et al*., 2007) has investigated the pretension in tension control bolts installed under different conditions. A sample of 450 bolts was examined. The mean ratio of pretension to minimum specified pretension was obtained as 1.11, with a standard deviation of 0.12. The mean and standard deviation from 79 tests were reported to be 1.16 and 0.17, respectively, after the bolts had been stored indoors in a sealed keg for two weeks. Storage in a sealed keg for four weeks showed a mean value of 1.2 and standard deviation of 0.12 based on 105 tests. For bolts exposed to humidity for two weeks before testing, a mean of 1.16 and a standard deviation of 0.14 were obtained from 79 tests. When exposed to humidity for four weeks, the mean value was 1.17 and standard deviation 0.13 from 105 tests. For bolts subjected to full exposure to the weather for two weeks, the mean was 1.12 and standard deviation 0.11 based on tests on 76 bolts. For exposures to full weather for four weeks, tests on 105 bolts showed a mean value of 1.10 and standard deviation of 0.11. Bolts that were weathered in a simulated joint for two weeks showed a mean of 1.05 and standard deviation of 0.10 based on 93 tests. Tests on 124 bolts weathered in a simulated joint for four weeks showed a mean value of 1/05 and a standard deviation of 0.12.

Tests were conducted on TC bolts of A325 and A490 strength with diameters ranging from 5/8 in. to 1-1/8 in. to investigate the effect of bolt head bearing area on bolt pretension when TC bolts are used with oversized bolt holes and short slots (Schnupp and Murray, 2003). The head bearing surface diameters of the tested bolts included both the minimum required diameter permitted by ASTM F1852 and the larger manufacturer's standard head diameter. Bolt pretension was measured in a Skidmore-Wilhelm load cell. Plates with standard, oversized, excessively oversized and slotted holes were placed under the bolt head. The test program indicated that bolts with the minimum bearing surface diameter on head attained the same pretension as those with the larger manufacturer's standard diameter. Bolt hole size had no significant effect on the bolt pretension. The authors concluded that the pretension in bolts with the minimum head bearing surface diameter is the same as that in bolts with a larger diameter equal to that of a F436 washer for hole sizes within the RCSC Specification limits on hole size.

Recent tests on TC bolts were conducted by Maleev (2007). Several factors were investigated such as the effect of delayed installation (bolts installed after two weeks and four weeks of exposure, both out of a joint and snug tight in a joint consisting of three plates) exposure to high relative humidity before installation (soaked in water for 30 seconds, exposed to 100% relative humidity for one day or one week) and exposure to $-20°C$ for one day or one week before installation. All of these factors were found to have a detrimental effect on the level of pretension achieved during installation. All the tests were conducted on Grade F1852-05 (A325 grade TC bolts) bolts, 7/8 in. diameter.

For the reliability analysis, it was decided to divide all the measurements conducted on TC bolts in two groups: the tests done within two weeks of breaking the seal on the keg (i.e. exposed to outdoor environment) and the tests conducted on bolts with installation delayed by more than two weeks. The test results from TC bolts installed within two weeks of exposure to the outdoor environment are presented in Table 6. These include measurements presented by Undershute and Kulak (1994), Tan *et al*. (2005) and Maleev (2007) and earlier tests presented by Kulak *et al.* (1987). The mean measured to minimum nominal pretension for the 1182 test results in this category are 1.15 and 0.125, respectively.

Table 7 presents the results of measurements on TC bolts installed after exposure to various environments for longer than two weeks. From a sample of 600 measurements, the mean ratio of pretension to minimum specified pretension and the corresponding standard deviation were found to be 1.09 and 0.13, respectively.

Although the test data is divided into two groups depending on the duration of exposure, it is recognized that the designer does not know at the design stage whether the bolts would be pretensioned after a long or short exposure to the environment.

Table 6 – Measured pretension in A325 TC bolts installed within two weeks of exposing the bolts to a moist environment

Source	Number of Bolts	Bolt Description	Mean	Standard Deviation	COV	Comments
Undershute and Kulak (1994)	81	3/4" black bolts	1.20	0.11	0.092	Bolts in as-delivered condition
	79	3/4" black bolts	1.16	0.17	0.147	Bolts stored indoors in a sealed keg for two weeks
	105	3/4" black bolts	1.20	0.12	0.100	Bolts stored indoors in a sealed keg for four weeks
Maleev (2007)	12	7/8" black bolts	1.19	0.07	0.059	Bolts from supplier A tested in a simulated steel joint
	3	7/8" black bolts	1.29	0.01	0.008	Bolts from supplier A tested in Skidmore load cell
	12	7/8" black bolts	1.17	0.01	0.009	Bolts from supplier B tested in simulated steel joint
	3	7/8" black bolts	1.24	0.03	0.024	Bolts from supplier B tested in Skidmore load cell
	12	7/8" black bolts	1.00	0.03	0.030	Bolts from supplier C tested in simulated steel joint
	3	7/8" black bolts	1.06	0.05	0.047	Bolts from supplier C tested in Skidmore load cell
	12	7/8" black bolts	1.00	0.01	0.010	Bolts from supplier D tested in simulated steel joint
	3	7/8" black bolts	1.16	0.02	0.017	Bolts from supplier D tested in Skidmore load cell
	4	7/8" black bolts	1.31	0.01	0.008	Bolts tested in a simulated steel joint (Supplier A) after re-installation
	4	7/8" black bolts	1.29	0.01	0.008	Bolts tested in a simulated steel joint (Supplier B) after re-installation
	4	7/8" black bolts	1.27	0.02	0.016	Bolts tested in a simulated steel joint (Supplier C) after re-installation
	4	7/8" black bolts	1.26	0.01	0.008	Bolts tested in a simulated steel joint (Supplier D) after re-installation
Tan, Maleev, Birkemoe (2005)	3	3/4" black bolts	1.11	0.03	0.027	Bolts tested in the as-received condition measured in Skidmore
	3	3/4" black bolts	1.08	0.01	0.009	Bolts tested in the as-received condition measured in three plate joint
	4	3/4" black bolts	1.08	0.01	0.009	Bolts installed in the as-received condition in typical connection
	12	3/4" black bolts	1.06	0.04	0.038	Bolts from lot 1 and supplier A installed in joint
	3	3/4" black bolts	1.11	0.03	0.027	Bolts from lot 1 and supplier A installed in Skidmore
	3	3/4" black bolts	1.27	0.02	0.016	Bolts from lot 2 and supplier A tested as received in Skidmore
	12	3/4" black bolts	1.18	0.05	0.042	Bolts from supplier B and tested in joint as-received
	3	3/4" black bolts	1.34	0.03	0.022	Bolts from supplier B and tested as received in Skidmore
	12	3/4" black bolts	1.20	0.07	0.058	Bolts from supplier C and tested in joint as-received
	3	3/4" black bolts	1.31	0.02	0.015	Bolts from supplier C and tested as received in Skidmore
	12	3/4" black bolts	1.17	0.10	0.085	Bolts from supplier D and tested in joint as-received
	3	3/4" black bolts	1.26	0.09	0.071	Bolts from supplier D and tested as received in Skidmore

Table 6 – Cont'd

Source	Number of Bolts	Bolt Description	Mean	Standard Deviation	COV	Comments
Undershute and Kulak (1994)	79	3/4" black bolts	1.16	0.14	0.121	Bolts exposed to humidity for two weeks
	76	3/4" black bolts	1.12	0.11	0.098	Bolts given full exposure to the weather for two weeks
	93	3/4" black bolts	1.05	0.10	0.095	Bolts weathered in a simulated steel joint for two weeks
Maleev (2007)	8	7/8" black bolts	0.96	0.07	0.073	Bolts exposed to moist room for one day before installation (supplier A)
	8	7/8" black bolts	0.94	0.11	0.117	Bolts exposed to moist room for one week before installation (supplier A)
	8	7/8" black bolts	1.17	0.01	0.009	Bolts exposed to moist room for one day before installation (supplier B)
	8	7/8" black bolts	1.14	0.05	0.044	Bolts exposed to moist room for one week before installation (supplier B)
	8	7/8" black bolts	0.93	0.03	0.032	Bolts exposed to moist room for one day before installation (supplier C)
	8	7/8" black bolts	0.93	0.02	0.022	Bolts exposed to moist room for one week before installation (supplier C)
	8	7/8" black bolts	0.88	0.03	0.034	Bolts exposed to moist room for one day before installation (supplier D)
	8	7/8" black bolts	0.89	0.02	0.022	Bolts exposed to moist room for one week before installation (supplier D)
	12	7/8" black bolts	1.08	0.06	0.056	Bolts tested after exposure for two weeks
	4	7/8" black bolts	1.27	0.02	0.016	Bolts tested in Skidmore after exposure for two weeks outside joint (supplier A)
	4	7/8" black bolts	1.22	0.02	0.016	Bolts tested in Skidmore after exposure for two weeks in steel joint (supplier A)
	12	7/8" black bolts	1.09	0.05	0.046	Bolts tested in simulated joints after exposure for two weeks
	4	7/8" black bolts	1.22	0.04	0.033	Bolts tested in Skidmore after 2 weeks exposure outside joint (supplier B)
	4	7/8" black bolts	1.13	0.09	0.080	Bolts tested in Skidmore after 2 week exposure in joint (supplier B)
	12	7/8" black bolts	0.96	0.03	0.031	Bolts tested in simulated joints after 2 weeks exposure (supplier C)
	4	7/8" black bolts	1.05	0.02	0.019	Bolts tested in Skidmore after 2 weeks exposure outside joint (supplier C)
	4	7/8" black bolts	1.03	0.07	0.068	Bolts tested in Skidmore after 2 week exposure in joint (supplier C)
	12	7/8" black bolts	0.96	0.02	0.021	Bolts tested in simulated joints after 2 weeks exposure (supplier D)
	4	7/8" black bolts	1.18	0.03	0.025	Bolts tested in Skidmore after 2 weeks exposure outside joint (supplier D)
	4	7/8" black bolts	1.12	0.04	0.036	Bolts tested in Skidmore after 2 weeks exposure in joint (supplier D)
Tan, Maleev, Birkemoe (2005)	4	3/4" black bolts	1.04	0.03	0.029	Bolts installed in typical connection after 2-week exposure
	12	3/4" black bolts	1.03	0.07	0.068	Bolts from lot 1 and supplier A exposed for 2 weeks in snug tight condition
	3	3/4" black bolts	1.10	0.08	0.073	Bolts from lot 1 and supplier A exposed for 2 weeks in snug tight condition
	5	3/4" black bolts	1.24	0.03	0.024	Bolts from lot 2 and supplier A exposed for 2 weeks before testing in Skidmore

Table 6 – Cont'd

Source	Number of Bolts	Bolt Description	Mean	Standard Deviation	COV	Comments
Tan, Maleev, Birkemoe (2005)	12	3/4" black bolts	1.11	0.07	0.063	Bolts from lot 2 and supplier A exposed for 2 weeks in test joint
	12	3/4" black bolts	1.15	0.05	0.043	Bolts from lot 2 and supplier A exposed for 2 weeks
	12	3/4" black bolts	1.10	0.05	0.045	Bolts from supplier B and tested in joint after exposure in joint for 2 weeks
	3	3/4" black bolts	1.24	0.01	0.008	Bolts from supplier B and tested in Skidmore exposure for 2 weeks
	12	3/4" black bolts	1.11	0.05	0.045	Bolts from supplier C and tested in joint after exposure in joint for 2 weeks
	3	3/4" black bolts	1.33	0.08	0.060	Bolts from supplier C and tested in Skidmore after 2 weeks of exposure
	12	3/4" black bolts	1.10	0.15	0.136	Bolts from supplier D and tested in joint after exposure in joint for 2 weeks
	3	3/4" black bolts	1.29	0.07	0.054	Bolts from supplier D and tested in Skidmore after 2 weeks of exposure
Bolt Guide (Kulak *et al.*, 1987)	283		1.22	0.10	0.082	Bolts from supplier D and tested in Skidmore after 2 weeks of exposure
Overall data	**1182**		**1.15**	**0.144**	**0.125**	

Table 7 – Measured Pretension in A325 TC Bolts (installation delayed by more than two weeks)

Source	Number of Bolts	Bolt Description	Mean	Standard Deviation	COV	Comments
Maleev (2007)	12	7/8" black bolts	0.94	0.03	0.032	Bolts tested in simulated joints after 4 weeks exposure (supplier D)
	4	7/8" black bolts	1.18	0.03	0.025	Bolts from supplier D tested in Skidmore after 2 weeks exposure outside joint
	4	7/8" black bolts	1.14	0.05	0.044	Bolts from supplier D tested in Skidmore after 4 weeks exposure outside joint
	4	7/8" black bolts	1.12	0.04	0.036	Bolts tested in Skidmore after 2 week exposure in joint (supplier D)
	4	7/8" black bolts	1.07	0.08	0.075	Bolts tested in Skidmore after 4 week exposrue in joint (supplier D)
	8	7/8" black bolts	0.96	0.07	0.073	Bolts exposed to moist room for one day before installation (supplier A)
	8	7/8" black bolts	0.94	0.11	0.117	Bolts exposed to moist room for one week before installation (supplier A)
	8	7/8" black bolts	1.17	0.01	0.009	Bolts exposed to moist room for one day before installation (supplier B)
	8	7/8" black bolts	1.14	0.05	0.044	Bolts exposed to moist room for one week before installation (supplier B)
	8	7/8" black bolts	0.93	0.03	0.032	Bolts exposed to moist room for one day before installation (supplier C)
	8	7/8" black bolts	0.93	0.02	0.022	Bolts exposed to moist room for one week before installation (supplier C)
	8	7/8" black bolts	0.88	0.03	0.034	Bolts exposed to moist room for one day before installation (supplier D)
	8	7/8" black bolts	0.89	0.02	0.022	Bolts exposed to moist room for one week before installation (supplier D)
Tan, Maleev, Birkemoe (2005)	4	3/4" black bolts	1.04	0.03	0.029	Bolts installed in typical connection after 2-week exposure
	4	3/4" black bolts	0.94	0.06	0.064	Bolts installed in typical connection after 4-week exposure
	4	3/4" black bolts	0.86	0.06	0.070	Bolts installed in typical connection after 8-week exposure
	12	3/4" black bolts	1.03	0.07	0.068	Bolts from lot 1 and supplier A exposed for 2 weeks in snug tight condition
	12	3/4" black bolts	0.93	0.05	0.054	Bolts from lot 1 and supplier A exposed for 4 weeks in snug tight condition
	12	3/4" black bolts	0.86	0.05	0.058	Bolts from lot 1 and sipplier A exposed for 8 weeks in snug tight condition
	3	3/4" black bolts	1.10	0.08	0.073	Bolts from lot 1 and supplier A exposed for 2 weeks in snug tight condition
	3	3/4" black bolts	1.11	0.02	0.018	Bolts from lot 1 and supplier A exposed for 4 weeks in snug tight condition
	3	3/4" black bolts	1.11	0.06	0.054	Bolts from lot 1 and supplier A exposed for 8 weeks in snug tight condition
	5	3/4" black bolts	1.24	0.03	0.024	Bolts from lot 2 and supplier A exposed for 2 weeks before testing in Skidmore
	5	3/4" black bolts	1.21	0.04	0.033	Bolts from lot 2 and supplier A exposed for 4 weeks before testing in Skidmore
	5	3/4" black bolts	1.15	0.04	0.035	Bolts from lot 2 and supplier A exposed for 8 weeks before testing in Skidmore
	12	3/4" black bolts	1.11	0.07	0.063	Bolts from lot 2 and supplier A exposed for 2 weeks while loose in test joint
	12	3/4" black bolts	1.05	0.08	0.076	Bolts from lot 2 and supplier A exposed for 4 weeks while loose in test joint
	12	3/4" black bolts	0.85	0.04	0.047	Bolts from lot 2 and supplier A exposed for 8 weeks while loose in test joint
	12	3/4" black bolts	1.15	0.05	0.043	Bolts from lot 2 and supplier A exposed for 2 weeks while snug
	12	3/4" black bolts	1.13	0.07	0.062	Bolts from lot 2 and supplier A exposed for 4 weeks while snug

Table 7 – Cont'd

Source	Number of Bolts	Bolt Description	Mean	Standard Deviation	COV	Comments
Undershute and Kulak (1994)	105	3/4" black bolts	1.17	0.13	0.111	Bolts exposed to humidity for four weeks
	105	3/4" black bolts	1.10	0.11	0.100	Bolts given full exposure to the weather for four weeks
	124	3/4" black bolts	1.05	0.12	0.114	Bolts weathered in a simulated steel joint for four weeks
Maleev (2007)	12	7/8" black bolts	1.07	0.06	0.056	Bolts tested after exposure for four weeks
	4	7/8" black bolts	1.26	0.02	0.016	Bolts tested in Skidmore load cell after 4 weeks exposure outside joint
	4	7/8" black bolts	1.18	0.08	0.068	Bolts tested in Skidmore load cell after 4 weeks exposure in steel joint
	12	7/8" black bolts	1.10	0.05	0.045	Bolts tested in simulated joints after 4 weeks exposure
	4	7/8" black bolts	1.22	0.03	0.025	Bolts from supplier B tested in Skidmore after 4 weeks exposure outside joint
	4	7/8" black bolts	1.11	0.07	0.063	Bolts tested in Skidmore after 4 week exposure in joint (supplier B)
	12	7/8" black bolts	0.94	0.03	0.032	Bolts tested in simulated joints after 4 weeks exposure (supplier C)
	4	7/8" black bolts	1.06	0.07	0.066	Bolts from supplier C tested in Skidmore after 4 weeks exposure outside joint
	4	7/8" black bolts	1.00	0.04	0.040	Bolts tested in Skidmore after 4 week exposure in joint (supplier C)
	12	7/8" black bolts	0.94	0.03	0.032	Bolts tested in simulated joints after 4 weeks exposure (supplier D)
	4	7/8" black bolts	1.14	0.05	0.044	Bolts from supplier D tested in Skidmore after 4 weeks exposure outside joint
	4	7/8" black bolts	1.07	0.08	0.075	Bolts tested in Skidmore after 4 week exposure in joint (supplier D)
Tan, Maleev, Birkemoe (2005)	4	3/4" black bolts	0.94	0.06	0.064	Bolts installed in typical connection after 4-week exposure
	4	3/4" black bolts	0.86	0.06	0.070	Bolts installed in typical connection after 8-week exposure
	12	3/4" black bolts	0.93	0.05	0.054	Bolts from lot 1 and supplier A exposed for 4 weeks in snug tight condition
	12	3/4" black bolts	0.86	0.05	0.058	Bolts from lot 1 and sipplier A exposed for 8 weeks in snug tight condition
	3	3/4" black bolts	1.11	0.02	0.018	Bolts from lot 1 and supplier A exposed for 4 weeks in snug tight condition
	3	3/4" black bolts	1.11	0.06	0.054	Bolts from lot 1 and supplier A exposed for 8 weeks in snug tight condition
	5	3/4" black bolts	1.21	0.04	0.033	Bolts from lot 2 and supplier A exposed for 4 weeks before testing in Skidmore
	5	3/4" black bolts	1.15	0.04	0.035	Bolts from lot 2 and supplier A exposed for 8 weeks before testing in Skidmore
	12	3/4" black bolts	1.05	0.08	0.076	Bolts from lot 2 and supplier A exposed for 4 weeks in test joint
	12	3/4" black bolts	0.85	0.04	0.047	Bolts from lot 2 and supplier A exposed for 8 weeks in test joint
	12	3/4" black bolts	1.13	0.07	0.062	Bolts from lot 2 and supplier A exposed for 4 weeks while snug
	12	3/4" black bolts	1.04	0.04	0.038	Bolts from lot 2 and supplier A exposed for 8 weeks while snug
	12	3/4" black bolts	1.09	0.05	0.046	Bolts from supplier B and tested in joint after exposure in joint for 4 weeks
	12	3/4" black bolts	1.07	0.07	0.065	Bolts from supplier B and tested in joint after exposure in joint for 8 weeks
	3	3/4" black bolts	1.24	0.04	0.032	Bolts from supplier B and tested in Skidmore after 4 weeks of exposure

Table 7 – Cont'd

	Number of Bolts	Bolt Description	Mean	Standard Deviation	COV	Comments
Tan, Maleev, Birkemoe (2005)	3	3/4" black bolts	1.24	0.03	0.024	Bolts from supplier B and tested in Skidmore after 8 weeks of exposure
	12	3/4" black bolts	1.10	0.05	0.045	Bolts from supplier C and tested in joint after exposure in joint for 4 weeks
	12	3/4" black bolts	1.16	0.06	0.052	Bolts from supplier C and tested in joint after exposure in joint for 8 weeks
	3	3/4" black bolts	1.23	0.06	0.049	Bolts from supplier C and tested in Skidmore after 4 weeks of exposure
	3	3/4" black bolts	1.30	0.02	0.015	Bolts from supplier C and tested in Skidmore after 8 weeks of exposure
	12	3/4" black bolts	1.26	0.09	0.071	Bolts from supplier D and tested in joint after exposure in joint for 4 weeks
	12	3/4" black bolts	1.09	0.10	0.092	Bolts from supplier D and tested in joint after exposure in joint for 8 weeks
	3	3/4" black bolts	1.30	0.14	0.108	Bolts from supplier D and tested in Skidmore after 4 weeks of exposure
	3	3/4" black bolts	1.16	0.11	0.095	Bolts from supplier D and tested in Skidmore after 8 weeks of exposure
Overall data	**600**		**1.09**	**0.13**	**0.121**	

3. Reliability Analysis

The probability of structural failure is related to the safety index defined as follows:

$$\beta = \frac{ln\left(\bar{R} / \bar{Q} \right)}{\sqrt{{V_R}^2 + {V_Q}^2}} \tag{4}$$

where $\bar{R}$ and V_R are the mean value and the coefficient of variation of the resistance, respectively. $\bar{Q}$ and V_Q are the mean value and the coefficient of variation of the total load effect.

Lind (1971) proposed an approximation for $\sqrt{{V_R}^2 + {V_Q}^2}$ using a separation factor, α, as follows:

$$\sqrt{{V_R}^2 + {V_Q}^2} = \alpha \left(V_R + V_Q \right) \tag{5}$$

For a range of V_R / V_Q between 1/3 and 3, with $\alpha = 0.75$ the approximation provided by the right hand side of Eq. (5) is within 6% of the exact value provided by the left hand side of Eq. (5). Galambos and Ravindra (1977) extended this concept further by introducing two separation factors, α_R and α_Q, such that

$$\sqrt{{V_R}^2 + {V_Q}^2} = \alpha_R \, V_R + \alpha_Q \, V_Q \tag{6}$$

Using this approximation, the expression for the safety index, β, can now be rewritten as:

$$\beta = \frac{ln \, \bar{R} / \bar{Q}}{\alpha_R \, V_R + \alpha_Q \, V_Q} \tag{7}$$

from which we can obtain:

$$\bar{R} \, exp(-\beta \, \alpha_R \, V_R) = \bar{Q} \, exp(\beta \, \alpha_Q \, V_Q) \tag{8}$$

This equation relates the mean values of the resistance and the load effect. In order to rewrite the equation in terms of the associated nominal values, we set:

$$\rho_R = \frac{\bar{R}}{\tilde{R}} \qquad and \qquad \rho_Q = \frac{\bar{Q}}{\tilde{Q}} \tag{9}$$

where ρ_R and ρ_Q are the bias coefficient for the resistance and the bias coefficient for the load effect, respectively. The relationship between the nominal values of *R* and *Q* becomes:

$$\rho_R \, exp(-\beta \, \alpha_R \, V_R) \; \tilde{R} \; = \; \rho_Q \, exp(\beta \, \alpha_Q \, V_Q) \; \tilde{Q} \tag{10}$$

The nominal values of *R* and *Q* are related as follows:

$$\phi \, \tilde{R} = \alpha' \, \tilde{Q} \tag{11}$$

where ϕ is the *resistance factor* and α' is the *load factor*. Therefore, from comparison of equations 10 and 11 we can deduce:

$$\phi = \rho_R \, exp(-\beta \, \alpha_R \, V_R) \tag{12}$$

Galambos and Ravindra (1977) proposed a separation factor α_R = 0.55.

Because of the interdependence of the resistance factor and the load factor, when load factors are established for structures as a whole based on a target safety index of 3.0, an adjustment factor less than 1.0 must be applied to Equation 12 when the safety index is greater than 3.0 and an adjustment factor greater than 1.0 must be applied when the safety index is less than 3.0. Eq. (12) must therefore be adjusted as follows:

$$\phi = C \, \rho_R \, exp(-\beta \, \alpha_R \, V_R) \tag{13}$$

where the correction factor *C* can be derived using the procedure described by Fisher *et al*. (1978). The following expression was derived using this procedure:

$$C = \frac{1.086(1.0933 + 1.3936 \, L/D)}{e^{0.0275\beta}[1 + 0.03111\beta + (1 + 0.1313\beta) \, L/D]} \tag{14}$$

where *L/*D is the live to dead load ratio.

Fisher *et al*. (1978) have shown that this factor varies only from 0.86 to 0.90 for a safety index of 4.5 and a wide range of live to dead load ratios. Figure 5 illustrates the variation of the correction factor as a function of the safety index for different values of live load to dead load ratio varying from 0.5 to 3.0. A simple polynomial expression can be fitted through any one of the curves shown in Figure 5 using a least square regression analysis. For a live to dead load ratio, *L/D,* of 3.0 the correction factor can be obtained from:

$$C = 0.008\,\beta^2 - 0.1584\,\beta + 1.4056 \tag{15}$$

The correlation coefficient, r^2, for this approximation to Equation 14 is 1.00, indicating that there is no loss of accuracy when Equation 15 is used in lieu of Equation 14.

The bias coefficient for the resistance, ρ_R, and the corresponding coefficient of variation, V_R, reflect the various sources of variability in the predictions of the resistance. For slip critical joints, the resistance is expressed as:

$$\phi\, R_n = \phi \times \mu \times 0.75\, A_b \times 0.70\, F_u \tag{16}$$

where $\phi\, R_n$ is the factored slip resistance, μ is the nominal slip coefficient, $0.75\, A_b$ is the net tension area, and $0.70\, F_u$ is the minimum specified pretension stress in the bolts. The bias coefficient, ρ_R, reflects the ratio of the measured to predicted resistance to slip and accounts for variation in the slip coefficient, the bolt pretension, the bolt area, and the bolt tensile strength. It is obtained from:

$$\rho_R = \rho_{Ti} \times \rho_{A_b} \times \rho_{F_u} \times \rho_P \tag{17}$$

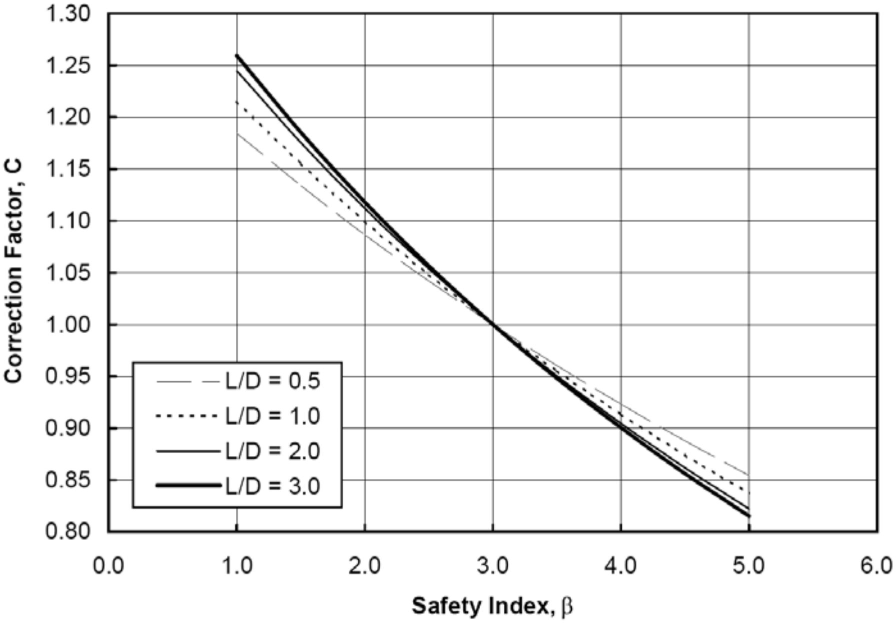


Figure 5 – Variation of the correction factor *C* as a function of live to dead load ratio, *L/D*, and safety index

In Eq. (17) ρ_{Ti} is the ratio of measured to the required minimum pretension in the bolts (ratio of actual to target clamping force), ρ_{A_b} is the ratio of the actual to nominal tension area of the bolts, ρ_{F_u} is the ratio of the actual to the specified bolt tensile strength, and ρ_P is the professional factor, or ratio of the measured slip coefficient to the nominal slip coefficient for the given faying surface condition. The professional factor is the factor that accounts for the uncertainty in the prediction model, namely, equation (16) divided by the resistance factor. The simplified version of this model is the product of the clamping force and the slip coefficient. Since the clamping force is controlled during the tests and the slip load is measured accurately, the calculation of the professional factor reduces to the ratio of the measured slip coefficient to the nominal value. The reliability analysis presented below is performed for a slip coefficient of 0.35 for clean mill scale and galvanized faying surfaces, and 0.50 for blast-clean faying surfaces.

The coefficient of variation, V_R , for the resistance is given as:

$$V_R = \sqrt{V_{Ti}{}^2 \times V_{A_b}{}^2 \times V_{F_u}{}^2 \times V_P{}^2} \tag{18}$$

where V_{Ti} , V_{A_b} , V_{F_u} and V_P are the coefficient of variation for the factors described above.

The bias coefficient and coefficient of variation for the ratio of measured to expected bolt pretension are a function of the method of installation and are summarized in Table 8. The values presented in Table 8 were discussed in section 2 of this report. It should be noted that, although grade A490 TC bolts are commonly used, insufficient statistical data was available to conduct a reliability analysis on this grade of TC bolts. A summary of mill test data provided to the writers by Frank (2007) indicated that the ratio of measured pretension to nominal required pretension using grade A490 TC bolts decreases from 1.21 to 1.15 as the bolt diameter increases from 3/4 in. to 1-1/8 in.

Table 8 – Statistical parameters for bolt pretension

Bolt grade	Method of Installation	ρ_{Ti}	V_{Ti}
A325	Turn-of-nut	1.22	0.050
A490	Turn-of-nut	1.26	0.080
A325	Calibrated wrench	1.13	0.053
A490	Calibrated wrench	1.13	0.053
A325	DTI washers	1.12[1]	0.117[1]
A490	DTI washers	1.12	0.117
A325	Tension control bolts[2]	1.15	0.125
A325	Tension control bolts[3]	1.09	0.121

[1] Based on field measurements on 60 bolts by Kulak and Birkemoe (1993).

[2] Reliability analysis conducted on data from the Bolt Guide (Kulak *et al*. (1987)), Undershute and Kulak (1994), Tan *et al*. (2005) and Maleev (2007) for bolts installed within two (2) weeks of exposing them to the elements.

[3] Reliability analysis conducted on data from the Bolt Guide (Kulak *et al*. (1987)), Undershute and Kulak (1994), Tan *et al*. (2005) and Maleev (2007) for delayed installation greater than two (2) weeks.

The bias coefficient and the coefficient of variation of the ratio of actual bolt strength to minimum specified bolt strength are a function of bolt grade. The values used for the reliability analysis are those reported by Fisher *et al*. (1978) and they are presented in Table 9.

Table 9 – Statistical parameters for bolt strength, F_u

Bolt grade	ρ_{F_u}	V_{F_u}
A325	1.20	0.07
A490	1.07	0.02

The bias coefficient and coefficient of variation for the bolt area are taken as 0.994 and 0.005, respectively, based on measurements on 285 bolts of grades A325 and A490 with nominal diameters of 3/4 in., 7.8 in., and 1 in. (Stankevicius *et al.*, 2007).

Equations (13) to (18) are applicable to all types of faying surfaces and all methods of bolt installation. The variation in bolt tensile strength and bolt area do not affect pretension, and, consequently, slip resistance, of joints with bolts installed using the calibrated wrench method, direct tension indicator washers, and tension control bolts. It is noted that although the torque applied during the installation of TC bolts is governed by the bolt strength, the manufacture and lubrication of such bolts is adjusted so that the level of pretension reached is about the same for different material strengths. Consequently, V_{A_b} and V_{F_u} are effectively taken as 0.0 and ρ_{A_b} and ρ_{F_u} are taken as 1.0 for all installation methods, except for the turn-of-nut method.

Application of Equations (13) to (18) for three different types of faying surfaces, namely, clean mill scale, blast clean surfaces and galvanized surfaces, two bolt grades (A325 and A490) and four methods of bolt installation, yields values of resistance factor for various levels of safety index. The summary of these calculations is presented in Tables 10 to 12 for A325 bolts and in Tables 13 to 15 for A490 bolts. Because DTI washers yield the same results for A325 and A490 bolts, the DTI washer statistics presented in Tables 10 to 12 are the same as those presented in Tables 13 to 15. Although F2280 grade (grade A490) TC bolts are used in practice, insufficient data are available to conduct a reliability analysis on this grade of TC bolt.

Tables 10 to 15 provide resistance factors for β values varying from 1.0 to 4.0. In addition, the safety index for resistance factors of 1.13 and 0.96 are provided. The value of 1.13 corresponds to ϕD_u in the 2005 AISC specification for no slip at service load, whereas the value of 0.96 corresponds to ϕD_u for no slip at factored load.

Table 10 – Safety Index and Resistance Factors for A325 Bolts and Clean Mill Scale Faying Surfaces ($\mu = 0.35$)

Calibrated Wrench		Turn-of-Nut		TC Bolts[1]		TC Bolts[2]		DTI washers	
β	ϕ	β	ϕ	β	ϕ	β	ϕ	β	ϕ
0.82	1.13	1.73	1.13	0.84	1.13	0.65	1.13	0.75	1.13
1.43	0.96	2.34	0.96	1.43	0.96	1.24	0.96	1.34	0.96
1.00	1.08	1.00	1.37	1.00	1.08	1.00	1.03	1.00	1.06
1.50	0.94	1.50	1.20	1.50	0.94	1.50	0.89	1.50	0.92
2.60	0.71	2.60	0.90	2.60	0.70	2.60	0.66	2.60	0.68
3.40	0.58	3.40	0.73	3.40	0.56	3.40	0.53	3.40	0.55
4.00	0.50	4.00	0.63	4.00	0.48	4.00	0.46	4.00	0.47

[1] TC bolts installed within two weeks after the seal on the bolt keg is broken.

[2] TC bolts installed with a delay greater than two weeks.

Table 11 – Safety Index and Resistance Factors for A325 Bolts and Blast Clean Faying Surfaces ($\mu = 0.50$)

Calibrated Wrench		Turn-of-Nut		TC Bolts[1]		TC Bolts[2]		DTI washers	
β	ϕ	β	ϕ	β	ϕ	β	ϕ	β	ϕ
1.74	1.13	2.78	1.13	1.69	1.13	1.48	1.13	1.60	1.13
2.47	0.96	3.52	0.96	2.37	0.96	2.16	0.96	2.28	0.96
1.00	1.34	1.00	1.70	1.00	1.34	1.00	1.27	1.00	1.31
1.50	1.19	1.50	1.52	1.50	1.18	1.50	1.13	1.50	1.16
2.00	1.07	2.60	1.18	2.60	0.91	2.60	0.86	2.60	0.89
3.40	0.78	3.40	0.98	3.40	0.75	3.40	0.72	3.40	0.74
4.00	0.69	4.00	0.87	4.00	0.66	4.00	0.63	4.00	0.65

[1] TC bolts installed within two weeks after the seal on the bolt keg is broken.

[2] TC bolts installed with a delay greater than two weeks.

Table 12 – Safety Index and Resistance Factors for A325 Bolts and Galvanized Faying Surfaces ($\mu = 0.35$)

Calibrated Wrench		Turn-of-Nut		TC Bolts[1]		TC Bolts[2]		DTI washers	
β	ϕ	β	ϕ	β	ϕ	β	ϕ	β	ϕ
-0.64	1.13	0.05	1.13	-0.58	1.13	-0.73	1.13	-0.64	1.13
-0.19	0.96	0.51	0.96	-0.13	0.96	-0.28	0.96	-0.20	0.96
1.00	0.63	1.00	0.80	1.00	0.63	1.00	0.60	1.00	0.62
1.50	0.53	1.50	0.67	1.50	0.53	1.50	0.50	1.50	0.52
2.60	0.36	2.60	0.46	2.60	0.36	2.60	0.34	2.60	0.35
3.40	0.27	3.40	0.34	3.40	0.27	3.40	0.26	3.40	0.26
4.00	0.22	4.00	0.28	4.00	0.22	4.00	0.21	4.00	0.21

[1] TC bolts installed within two weeks after the seal on the bolt keg is broken.

[2] TC bolts installed with a delay greater than two weeks.

Table 13 – Safety Index and Resistance Factors for A490 Bolts and Clean Mill Scale Faying Surfaces (μ = 0.35)

Calibrated Wrench		Turn-of-Nut		DTI washers	
β	ϕ	β	ϕ	β	ϕ
0.82	1.13	1.44	1.13	0.75	1.13
1.43	0.96	2.05	0.96	1.34	0.96
1.00	1.08	1.00	1.27	1.00	1.06
1.50	0.94	1.50	1.11	1.50	0.92
2.60	0.71	2.60	0.83	2.60	0.68
3.40	0.58	3.40	0.67	3.40	0.55
4.00	0.50	4.00	0.58	4.00	0.47

Table 14 – Safety Index and Resistance Factors for A490 Bolts and Blast Cleaned Faying Surfaces (μ = 0.50)

Calibrated Wrench		Turn-of-Nut		DTI washers	
β	ϕ	β	ϕ	β	ϕ
1.74	1.13	2.47	1.13	1.60	1.13
2.47	0.96	3.20	0.96	2.28	0.96
1.00	1.34	1.00	1.59	1.00	1.31
1.50	1.19	1.50	1.41	1.50	1.16
2.60	0.93	2.60	1.10	2.60	0.89
3.40	0.78	3.40	0.92	3.40	0.74
4.00	0.69	4.00	0.81	4.00	0.65

Table 15 – Safety Index and Resistance Factors for A490 Bolts and Galvanized Faying Surfaces (μ = 0.35)

Calibrated Wrench		Turn-of-Nut		DTI washers	
β	ϕ	β	ϕ	β	ϕ
-0.64	1.13	-0.16	1.13	-0.64	1.13
-0.19	0.96	0.29	0.96	-0.20	0.96
1.00	0.63	1.00	0.74	1.00	0.62
1.50	0.53	1.50	0.62	1.50	0.52
2.60	0.36	2.60	0.42	2.60	0.35
3.40	0.27	3.40	0.32	3.40	0.26
4.00	0.22	4.00	0.26	4.00	0.21

4. Assessment of the Consequence of Slip

Having calculated the resistance factor for different values of safety index β, a question remains, namely, what value of β is required? Galambos *et al*. (1982) recommended a value of β between 1.25 and 1.5 for no slip at service loads. The value of the safety index for no slip at factored loads must be determined with consideration to the consequence of slip at the factored load level, the ductility of the mode of failure considered, the reserve capacity in a joint after slip.

Although excessive deflection is a concern at service load level, it is only of concern at the factored load level if the deflections can give rise to second order effects of sufficient magnitude to cause failure of the structure. Second order effects in building structures can either take the form of P-Δ effects as gravity loads act on a laterally deformed gravity load carrying elements, or water ponding on roofs. This section presents a numerical investigation of water ponding on a long span roof. The effects of joint slip, inelastic response of the truss and large displacements are all taken into account in the analysis.

4.1 Water Ponding

Failure of roof structures due to water ponding provided the motivation for several research programs on ponding in the 1960's. As higher strength steels were being introduced into the building industry, the flexibility of roof and floor supporting members increased to the point where failures due to excessive accumulation of water on roofs started to happen. The failure mechanism due to ponding is now well understood. As water accumulates on a roof, the resulting deflections allow more water to accumulate, which results into more deflection. As the flexibility of the beams or trusses increases, a point is reached where the flexibility is too large, allowing for an excessive amount of water to accumulate, thus leading to flexural failure of the roof supporting members under the ponding action.

Assuming the deflected shape of simple beams to take the form of a half sine wave, Chinn (1965) proposed a critical beam stiffness beyond which the deflection of the beam under ponding load converges to a finite value, preventing excessive accumulation of rain water. Sawyer (1967) arrived at similar results by analyzing the differential equation of a beam on elastic support where the support stiffness is negative, that is to say, as the deflections increase the beam deflects even more. Chinn *et al.* (1969) made use of the differential equation method to validate the results of Sawyer and investigated more load conditions, all of which gave the same critical stiffness for a simple span beam.

Marino (1966) and Sawyer (1967) expanded the investigation of ponding in one-way systems to two-way roof systems. The half sine wave deflection assumed for simple span beams was retained for both the primary and secondary directions of a two-way system. Marino (1966) derived the deflection expression for the two-way roof and derived stiffness requirements for two-way systems. This work forms the foundation for the ponding requirements in the current AISC Specification (2005).

Design for ponding loads is covered in section B3 and Appendix 2 of AISC Specification (2005). It indicates that ponding can be ignored in roof structures with a slope of 2% (20mm per meter) or greater. When the slope of the roof is less than the minimum, sufficient stiffness must be provided to avoid instability due to accumulation of rain water. Chapter 8 of ASCE/SEI 7-05 provides a few equations of rain load estimation, which is essentially a strength concern. The rain load depends on the drainage system and the rainfall intensity. Chapter 2 of AISC Steel Design Guide 3 and the Steel Joist Institute Technical Digest No.3 (Heinzerling, 1971) outlines the design procedure adopted in the AISC Specification.

The effect of roof truss connection slip and the interaction between joint slippage and ponding have never been investigated. Joint slippage in roof trusses results in an effective reduction of stiffness. The additional deflection resulting from slippage in truss joints accentuates the ponding issue by providing more space for water accumulation. This sudden increase in roof deflection resulting from joint slippage was not considered in the original work that lead to the current guidelines for rain ponding. The purpose of the analysis presented in the following is to investigate the effect of joint slippage on the strength and stability of long span trusses.

4.2 Development of truss model

The analysis of a large span truss was conducted to determine the effect of joint slippage on deflection of the truss and ponding. The model incorporated non-linear effects such as, material yielding, joint slip, and water ponding resulting from large deflections. In order to account for the non-linear response of the truss, the general purpose finite element program ABAQUS was used for this investigation.

The non-linear finite element model was developed using the long span roof truss shown in Figure 6, provided by Cives Steel Company. The truss consists of a single 331.33 ft span and is subdivided into 17 panels varying in width from 10 ft to 26.67 ft. The total height of the truss is 39.67 ft. Although the selected long span truss is not susceptible to ponding problems because of the sloping top chord members it was used to develop the non-linear analysis procedure required to conduct a second order analysis to investigate ponding.

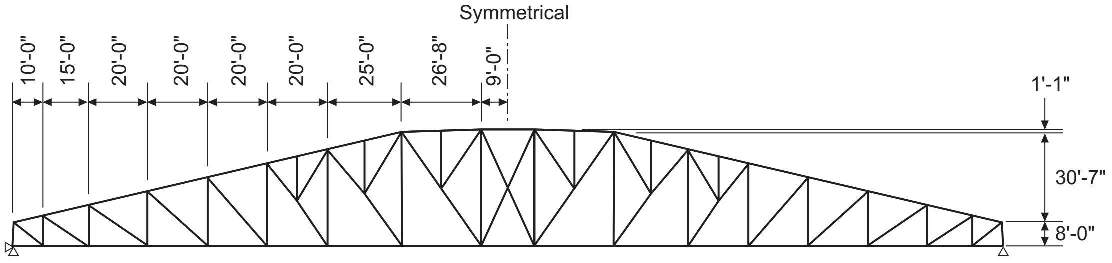


Figure 6 – Sample long span roof

The effect of ponding on roof truss stability was investigated on a modified version of the truss shown in Figure 6 and is illustrated in Figure 7. The web members were extended vertically to make the top chord horizontal. The effect of roof truss camber will be investigated later in this report. The assumption that a roof of this span length would be constructed without camber is a conservative assumption for this analysis. The truss members were designed to avoid instability of individual compression members or failure of tension members before overall instability of the roof truss.

The selected structure is modeled as a two-dimensional structure and is simply supported at the two end nodes of the lower chord as per the design drawings. It is assumed that the trusses are adequately restrained in the out-of-plane direction to prevent buckling of the analyzed trusses. The truss model was loaded on the elements of the upper chord along the whole length. The first order loads resulting from self-weight, mechanical load, service load etc., are uniformly distributed. The second order loads, snow or water ponding loads, are applied non-uniformly.

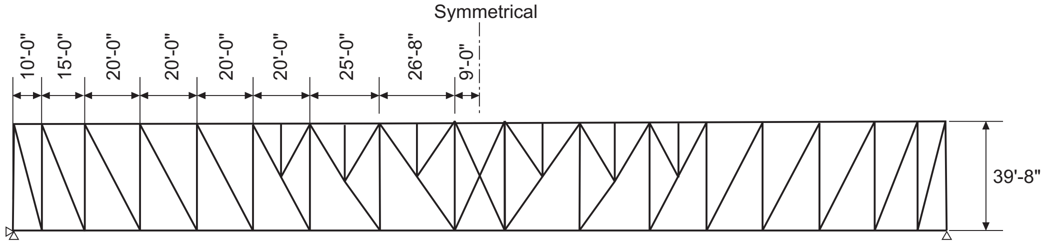
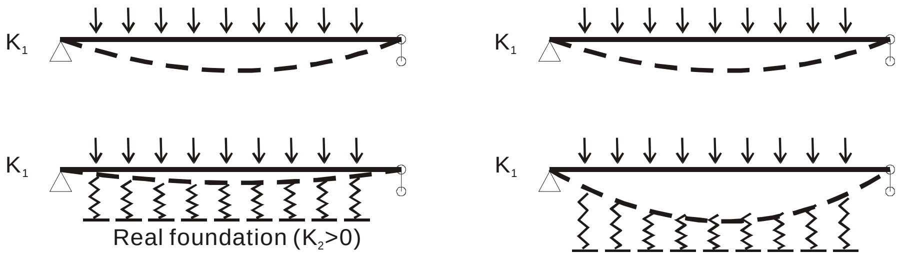


Figure 7 – Redesigned truss configuration

The magnitude of the water ponding load is proportional to the deflection of the truss. Since the ponding loads are not pre-defined before the analysis is conducted, i.e. they are solution dependent, they are simulated by a pseudo foundation with negative stiffness. Considering the example of a simply supported beam as shown in Figure 8, it is clear that the stiffness of the structural system is increased when the beam of stiffness K_1 is supported by an elastic foundation of positive stiffness K_2. The total stiffness (K_1+ K_2) of the beam results in smaller deflections under the applied load as indicated in Figure 8a. As illustrated in Figure 8b, the effect of ponding is to accelerate the rate of deflection. As proposed by Sawyer (1967), this effect can be simulated with a pseudo foundation of negative stiffness. The reduced total stiffness will result in increased deflections. The magnitude of the pseudo foundation stiffness K_2 is the product of the water density and the trusses spacing.



(a) Beam with positive stiffness spring elements

(b) Beam with negative stiffness spring elements

Figure 8 – Water ponding simulation using a pseudo foundation

The long span truss was modeled using 663 nodes and 261 beam B23 elements from ABAQUS. The B23 element is a cubic, two dimensional, Euler-Bernoulli beam element, which does not allow for shear deformation.

Each truss member was broken into three beam elements: the main element and two end elements. The main element represents the truss member between the two end connections. To simulate the end bolted connections a beam element was added to each end of the main element. The main elements were modeled following the shop drawings and the material properties consisted of a bilinear elastic-plastic material model with the yield strength taken as the nominal yield strength of A572 Grade 50 steel. The end elements were used to model the end connections to gusset plates. Although significant rotational restraint is usually encountered in gusset plate connections with multiple bolts, pinned connections were conservatively assumed for the finite element model. To minimize the curvature of the end elements, a cross section with larger moment of inertia is defined for all the end elements. End segments with a rectangular cross-section 61 mm x 1220 mm was arbitrarily adopted in this model.

The load versus elongation behavior of the bolt connections possesses four characteristic stages (Kulak *et al.* 1987), namely, pre-slip, slip, elastic bearing and inelastic bearing stages, as illustrated in Figure 9. Since the objective of this project is to investigate the effect of slip in bolted joints on the roof structure under ponding load, the in-plane elongation of the bolted connection was of primary concern, rather than localized stresses and out-of-plane bending. The load versus deformation behavior of the end elements is simulated by redefining the material properties for these elements. As shown in Figure 10, a connection with N bolts has stiffness and strength N times that of a single bolt connection. The stress versus strain behavior for the end elements should have a shape similar to that of the load versus elongation curve. The stress is obtained by dividing the load axis of the connection load versus deformation curve by the area of the end element. The strain is obtained by dividing the member deformation by the length of the end element. Both the compression and the tension responses were assumed to be the same for simplicity.

All the structural members, except the top chords, are composed of one main element and one or two end elements. The truss members that formed the top chord were modeled with two main elements and one end element for each main element. At any junction between a main element and an end element, two nodes, one for each element, were tied by multiple point constraint (MPC). For all the members, the rotational degree of freedom is released at the joints to simulate the pin connection.

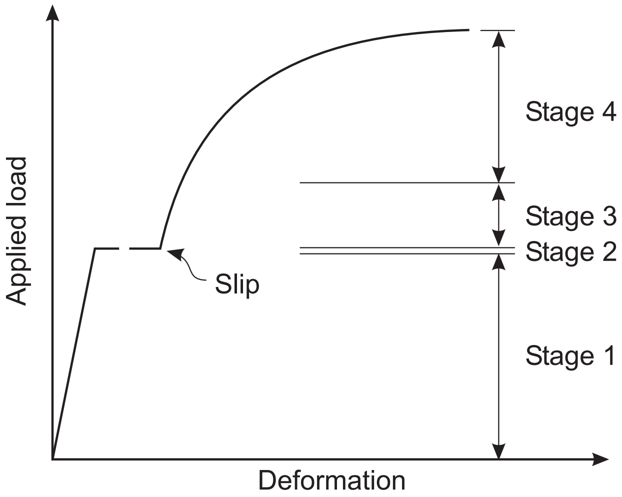


Figure 9 – Typical load versus deformation curve for joint with pre-tensioned bolts

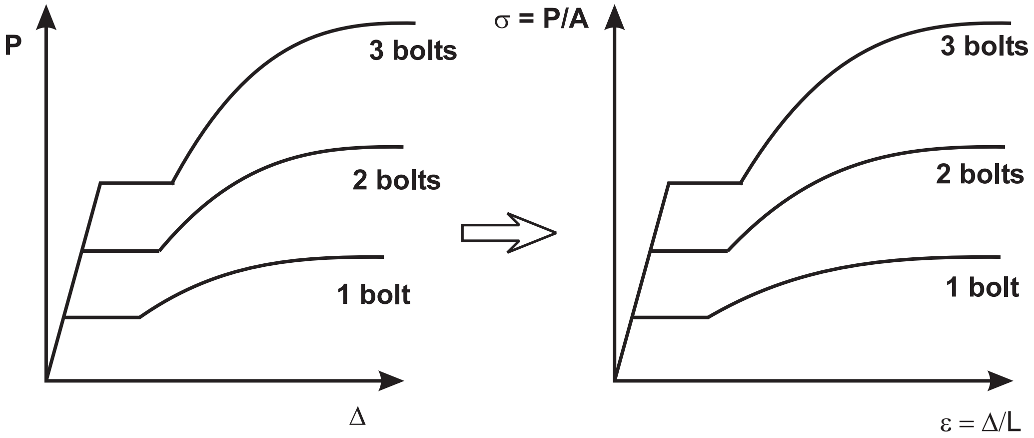


Figure 10 – Typical load versus elongation and stress versus strain curves for the bolted connection elements

4.3 Redesign strategy

The original trusses were designed for a sloping roof system as shown in Figure 6. Since the slope of the top chord is much larger than the limiting value of 2 percent beyond which ponding problems do not need to be considered, the truss shown in Figure 6 is obviously not susceptible to ponding. Therefore, the roof trusses were redesigned as a flat roof truss to investigate ponding and the effect of slip in joints on the ponding problems in a flat roof.

As indicated earlier, a flat roof configuration was obtained by moving the top chord panel points upward. Figure 7 shows the resulting configuration of the flat roof truss. Because of the resulting change in length and slope of several members of the truss, the cross-section of some of the members in the truss had to be changed. The cross-section of the members that saw an increase in axial force or an increase in length of compression members as a result of the changes in geometry were changed to meet the greater demand. The redesign is based on the member size of the original structure. Because the design loads for the truss were not known, the cross-section area of the redesigned members was increased by about the same ratio as the increase in member force as the geometry was changed and the truss loaded under a uniformly distributed load. Additionally, the moment of inertia of compression members was adjusted in a similar way to preclude premature buckling.

Because the objective of this investigation was to determine the effect of joint slippage on water ponding behavior, the number of bolts in each joint of the truss was selected to force as many connections as possible to slip before overall failure of the truss. Because of the static indeterminacy of the truss under consideration, any change in joint behavior as a result of a change in the number of bolts or any change in member size will result in a change of member forces. The redesign is therefore an iterative process. Although the number of bolts in the joints was changed for most connections to trigger slip in all the joints at the same time, it was not possible to get all the joints to slip simultaneously. The minimum number of bolts was limited to two bolts per joints and it was assumed that all bolts would be pretensioned by the same amount in all the joints, thus precluding slip in the joints of the lightly loaded members.

4.4 Critical flat-roof structure

4.4.1 Design

To investigate the worst condition of ponding, it is desirable to recreate the case that just meets the minimum design requirements. As discussed above, the existence of water ponding virtually reduces the structure stiffness for applied non-ponding load from K_1 to $K_1 + K_2$, where K_2 is negative. When the magnitude of K_2 is equal to K_1, sagging of the roof becomes infinitely large. To avoid this unstable ponding problem, K_1 is required to be larger than K_2 by a certain safety factor.

AISC (2005) presented two optional design methods: a simplified method and an improved design method. The simplified approach is used here since the truss being investigated is assumed to be part of a long roof, i.e. one way action prevails. The approach requires that

$$C_p + 0.9C_s \leq 0.25 \tag{18}$$

where C_p and C_s are flexibility constants for primary and secondary members and 0.25 represents an implicit safety factor of 4.

For the truss model investigated here, secondary members are not considered since it is expected that most of the deflections that are of concern will take place in the truss as a result of joint slip. Therefore,

$$C_p = \frac{\gamma\, s\, L^4}{\pi^4\, EI} \leq 0.25 \tag{19}$$

where

γ is density of the ponding material (water)
s is the truss spacing
L is structure span
E is the elastic modulus of steel
I is the equivalent moment of inertial of the structure

Equation (19) can be expressed in terms of K_1 and K_2 as:

$$-K_2 = \gamma\, s \leq 0.25\, K_1 = \frac{\pi^4\, EI}{4L^4} \tag{20}$$

Equating both sides of the equation leads to the critical case defined in the AISC Specification (2005). Since the existing truss structure consists of hundreds of members, it may need trial and error to modify K_1 to design the critical case. Hence, it is more convenient to change K_2, which is done by changing the truss spacing, *s*. For the structure under consideration, E and L are already known. The moment of inertia of the truss is obtained from the load versus midspan deflection curve obtained by loading a model of the truss where all the end elements have been omitted from the model. The critical truss spacing obtained from Equation (3) is 6.86 m (22.5 ft).

4.4.2 Relationship between total load and reference load

Assuming the loads on the structure totally come from the retained water, for any stable deflected shape as shown in Figure 11a, there are two load components: the first order load (the reference load) and second order load (the ponding load). The first order load reflects the height of water at the supports, i.e. the reference height, H_r, as shown in Figure 11b. The second order load results from sagging of the roof, namely, from the deflection Δ of the roof. If the deflected shape of the roof is assumed to be a half sine wave, it can be replaced by an equivalent uniformly distributed rain load of depth H_p as shown in Figure 11c. If the loads are expressed as a function of the water depth, the total load, H_{tot}, is then the sum of the reference load, H_r, and the ponding load, H_p. Then

$$H_r = H_{tot} - H_p = H_{tot} - \frac{2}{\pi}\Delta \tag{21}$$

where Δ is the midspan deflection.

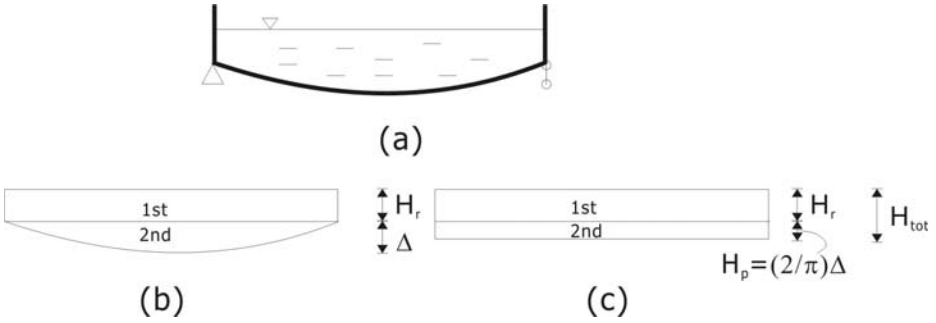


Figure 11 – Roof deflection and resulting load due to ponding

In other words, if the curve of the total load versus midspan deflection (H_{tot} vs. Δ) is known, the curve of the reference load versus midspan deflection (H_r vs. Δ) can be easily obtained. Figure 12 shows a comparison between the reference depth obtained directly from the finite element analysis and the reference depth calculated from the total deflection at midspan.

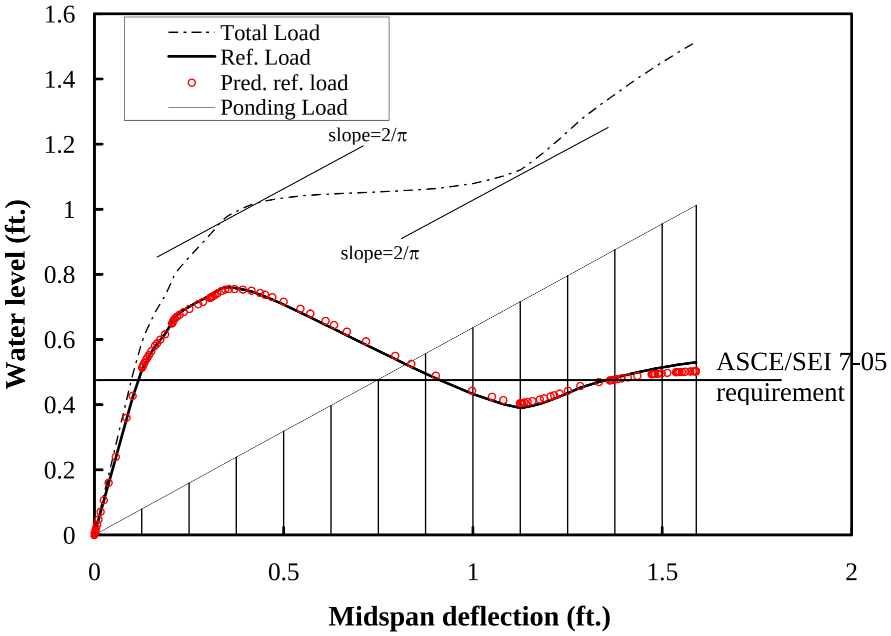


Figure 12 – Roof water level versus deflection and prediction (joint slip = 1/8 in.)

One may argue that plastic elongation and large displacement may affect the assumption of the sinusoidal shape deflection. In the current context, plastic elongation refers not only to plastic deformation of the truss members, but also the slip deformations taking place at the connections. The effect of plasticity was found to be negligible by comparing the analysis results of trusses with various magnitude of slip. Large displacements do not have much effect in early loading period. In the late stage of load, close to ultimate, the plasticity and large displacement would give a conservative estimate of H_r.

4.5 Peak reference load

The curve of total load versus deflection is easier to understand than the curve of reference load versus deflection since the total load reflects simply the volume of water accumulated on the roof. A comparison of the reference load, H_r, to the total provides an indication of the second order effect compared to the first order effect.

The reference load reaches its peak value when the slope of reference load versus displacement curve reaches zero. Differentiation of Equation (21) with respect to the midspan deflection, Δ, yields:

$$\frac{dH_r}{d\Delta} = \frac{d\left(H_{tot} - \frac{2}{\pi}\Delta\right)}{d\Delta} = \frac{dH_{tot}}{d\Delta} - \frac{2}{\pi} \tag{22}$$

This equation shows that this is again a stiffness problem. The peak reference load occurs at the point where the stiffness calculated based on the total load drops to $2/\pi$. Figure 12 illustrates this phenomenon: the crest and valley of the reference load take place at the $2/\pi$-slope points of the total load curve.

The load is usually expressed as a load per unit length rather than the water level. Equation (22) can be restated in terms of load per unit length as follows:

$$\frac{dH_r}{d\Delta} = \frac{dH_{tot}}{d\Delta} - \frac{2}{\pi} = \frac{d\left(w_{tot} / \gamma s\right)}{d\Delta} - \frac{2}{\pi} \tag{23}$$

The critical case is

$$\frac{dw_{tot}}{d\Delta} = \frac{2}{\pi}\gamma s \tag{24}$$

where $\frac{dw_{tot}}{d\Delta}$ is a function of $\frac{EI}{L^4}$, and Equation (24) then follows the same philosophy as Equation (20) from AISC Specification (2005), which consists of comparing the structure stiffness K_1 and the pseudo ponding stiffness K_2. Therefore, the key to ponding control, whether there is joint slip or not, is through stiffness control. The effect of joint slip on the effective truss stiffness is discussed later.

4.6 Ponding performance and failure modes

Ponding becomes a concern only when the peak reference load is reached before some other ultimate limit states since the structure is otherwise stiff enough to preclude any premature failure. In this investigation, it is assumed that the amount of rainwater is infinite and the reference height of water on the roof is limited by the height of the parapets. It is common practice to assume that drains and scuppers are clogged. This section investigates the ponding behavior of a roof truss for different parapet heights.

Case 1: High parapet ($H_{parapet}>H_{r,peak}$)

As precipitations accumulate on a roof, both the reference height, H_r, and the ponding height, H_p, increase (Figure 13a) until the peak reference load, $H_{r,peak}$, is reached (Figure 13b). $H_{r,peak}$ is the highest reference water level. If additional water is added on the roof, the structure can still hold the increased total load (Figure 12), but the reference water level, H_r, will start to drop as a result of accelerated sagging (Figure 13c). As more rainwater is added, H_r will keep dropping, but, as shown in Figure 12, the volume of water carried by the roof keeps increasing at a stable, but accelerated, rate. The descending curve observed in the reference height is due to the slip of joints in the truss. Once the bolts go into bearing, the water level at the parapets will increase again. The ultimate structure capacity therefore only depends on the strength of the members.

Case 2: Low parapet ($H_{parapet}<H_{r,peak}$)

In the previous scenario, it was assumed that the height of the parapets was sufficient to contain all precipitation so that no water can drain off the roof. If the parapet height is smaller than the peak reference height, the same loading path as in case 1 is obtained, except that it is cut off before $H_{r,peak}$ is reached. Since the parapet is lower than $H_{r,peak}$, the roof can hold water up to the top of the parapet (Fig. 13b). Subsequent rain will cause the roof to overflow, preventing any further sagging of the roof. The ultimate capacity of the structure will not be reached in this case and no failure is expected.

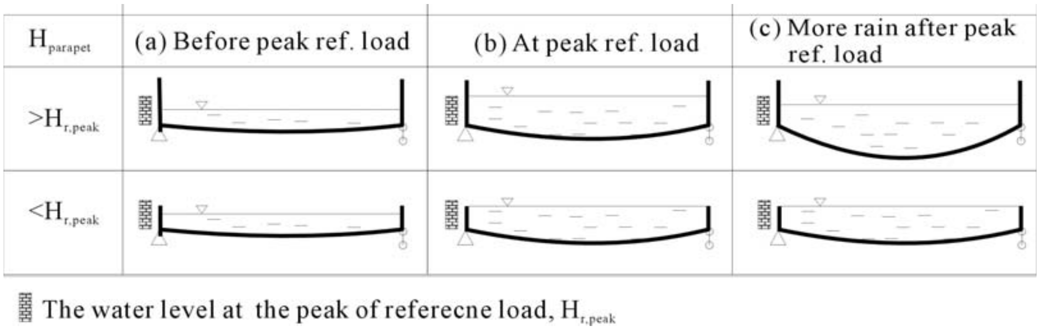


Figure 13 – Deflected shape of case 3

Case 3: Multiple sources of loads

Cases 1 and 2 illustrate the structure performance under water load only. There are other loads, such as the self-weight of the roof and other superimposed dead loads, that cause additional deflections. These non-fluid loads can be transformed to an equivalent water head, H_{other}. The main difference between this load and the weight of water is that the magnitude of the non-fluid load is not limited by the height of the parapet. These non-fluid loads cause deflections that promote collection of rainwater. Therefore, the non-water loads work as if the parapet is raised by an amount H_{other}. In other words, by increasing the parapet height to $H_{parapet} + H_{other}$, the loads from multiple sources can be transformed into an equivalent amount of water.

ASCE/SEI 7-05 requires that roofs with controlled drainage must be capable of supporting the rain from a storm. The nominal rain load is usually equal to a depth of water of 5.75 in. on the undeflected roof. Given that the structure illustrated in Figure 12 is able to support 0.75 ft of water (reference load in Fig. 7), measured at the edge of the roof, there is a reserve of capacity equivalent to approximately 3.25 in. of water. The roof truss considered in this example would therefore meet the ASCE code requirement.

4.7 Effect of connection slip on ponding behavior

The load versus deformation curve used to model the end elements of the truss members is based on the test data presented in the Guide to Design Criteria for Bolted and Riveted Joints (Kulak *et al.*1987). To investigate the effect of the amount of slip, the plateau corresponding to slip deformation (see Figure 14) is adjusted to reflect the amount of slip desired for the analysis. The amount of slip is a function of the clearance between the bolts and the bolt holes and the strength of the bolt connection is independent of the amount of slip. Therefore, for various slip distances, the pre- and post-slip behaviors (stages 1, 3 and 4 in Figure 9) of the curve are identical.

Although theoretically the amount of slip in a bolted joint could be as high as twice the bolt hole clearance, tests have shown that the amount of slip in a multi-bolt joint with regular size bolts is expected to be about half the bolt hole clearance (Kulak *et al.*, 1987). No test results were found for slip in plates with oversized holes. Therefore, for the investigation presented below, it was assumed that in joints with oversized holes, the amount of slip could be as high as twice the bolt hole clearance.

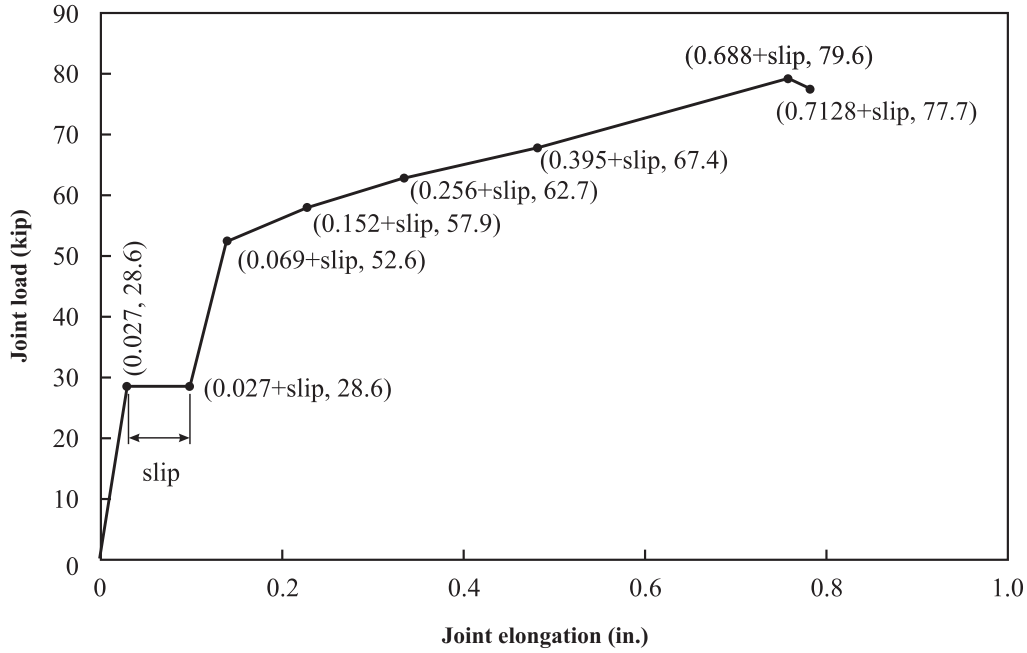


Figure 14 – Joint load versus elongation curve for one bolt

Case 1: No slipping (slip = 0)

The no slip condition will serve as a reference to assess the effect of slip on water ponding. In this case, it is assumed that all bolts are in bearing before any load is applied and, therefore, not slipping occurs when the slip load is reached. This behavior is achieved by eliminating the slip plateau in the connecting member model. The behavior of the truss under uniform loading is shown in Figure 15.

Since the slip load was intentionally set at a smaller value than the yield capacity of the bolted members, the load versus deflection curve does not show a plateau either. As indicated in Figure 15, the load keeps increasing, while the stiffness begins to reduce as the connections start to transfer load in bearing. Since bearing connections still provide considerable member stiffness, the structure stiffness in not likely to fall below the critical value as happened in Figure 13.

Figure 15 shows that about 80% of the connections went into bearing by the end of the analysis. The number of slip indicted in the figure indicates the number of connections that reached stage 2, namely, at least the slip load level. The number of bearing denotes the number of connections that have reached stage 3, i.e. the connections have slipped and gone into bearing. The number of slip and bearing represents the total number of connections that have reached either stage 2 or stage 3. In the case illustrated in Figure 15, the number of slip is zero due to the elimination of slipping plateau in the definition of the end elements.

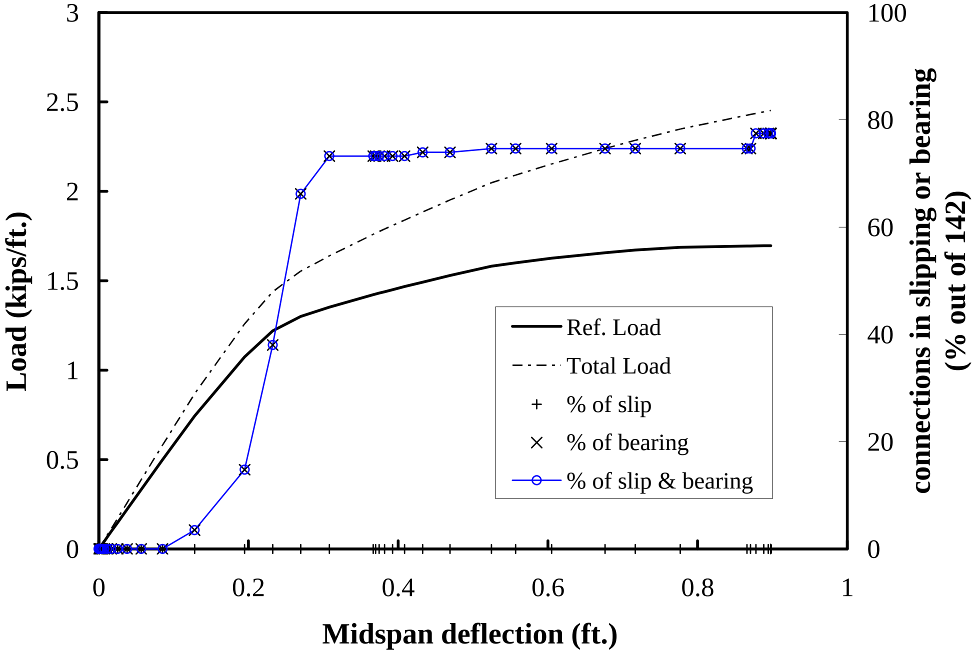


Figure 15 – Truss response for no slip in connections

Case 2: slip = 1/2 in.

This case was devised to simulate connections with oversized holes with holes 1/4 in. larger than the bolt diameter.

Compared to the no slip case, the large slip capacity of each joint ensures that a larger number of joints will be present in the overall behavior slip plateau displayed by the truss. Figure 16 illustrates the behavior of the truss under this extreme case. Because a significant number of joints are in stage 2 simultaneously (up to 60% of the joints), the truss loses its stiffness and the deflections increase without an increase in load for a midspan deflection of up to 18 in. (L/220).

It is expected that as the joints reach the bearing condition, the total load curve will start rising again. This is not shown in Figure 16 because the finite element analysis experienced convergence problems.

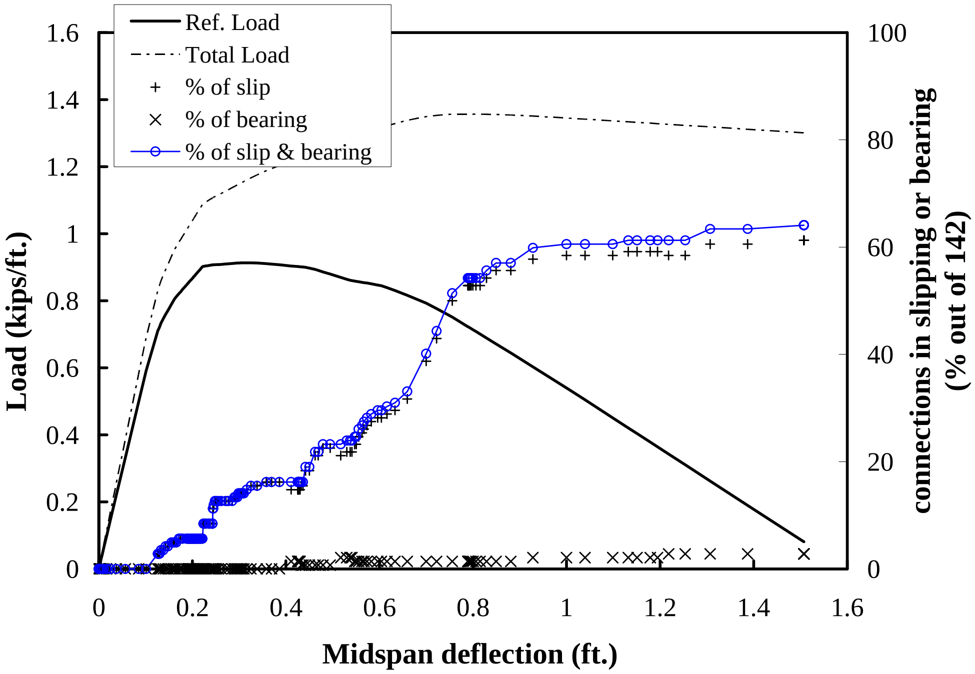


Figure 16 – Truss response for joint slip = 1/2 in.

Cases 3, 4 and 5: slip=1/32 in., 1/8 in. and 3/8 in.

Cases 3 and 4 attempt to simulate connections with regular size holes with 1/16 in. clearance. The slip used for Case 3 represents half a bolt hole clearance, which is the expected amount of slip in multi-bolt joints. Case 4, on the other hand, represents the situation where slip would be two times the bolt hole clearance, which represents an upper bound situation. Case 5 simulates oversized bolt holes with 3/16 in. clearance. Cases 3 to 5 are therefore intermediate cases between cases 1 and 2. Figures 17, 18 and 19 display the behavior of the truss for these three different slip conditions. As expected, when the number of joints located in stage 2 increases, the truss stiffness decreases and the decrease in reference load becomes more severe.

Figures 17 and 18 show that the number of slipping connections reaches a peak and then drops indicating that there are more connections that move from stage 2 to stage 3 than connections that move from stage 1 into stage 2.

Figure 19 shows similar features to Figure 16, namely, the truss deflection required to get the bolts into bearing is quite large and the total load curve plateaus and remains on a plateau until the end of the analysis at a midspan deflection slightly less than 1.2 ft. Although it is expected that the truss will regain some of its stiffness with more deflections, the finite element analysis stopped converging at the maximum deflection plotted in Figure 19.

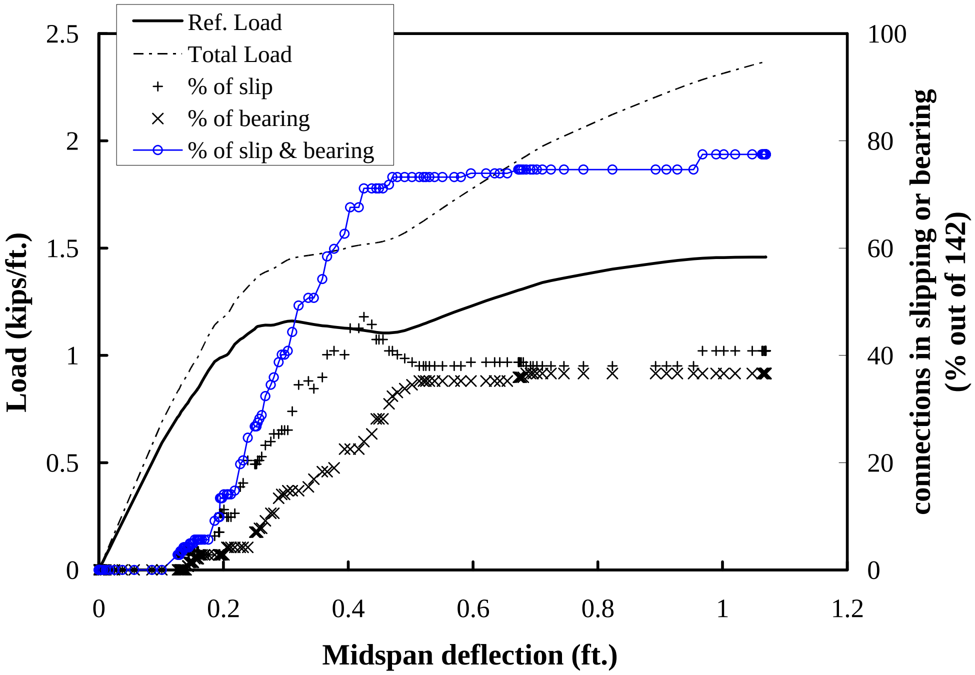


Figure 17 – Truss response for joint slip = 1/32 in.

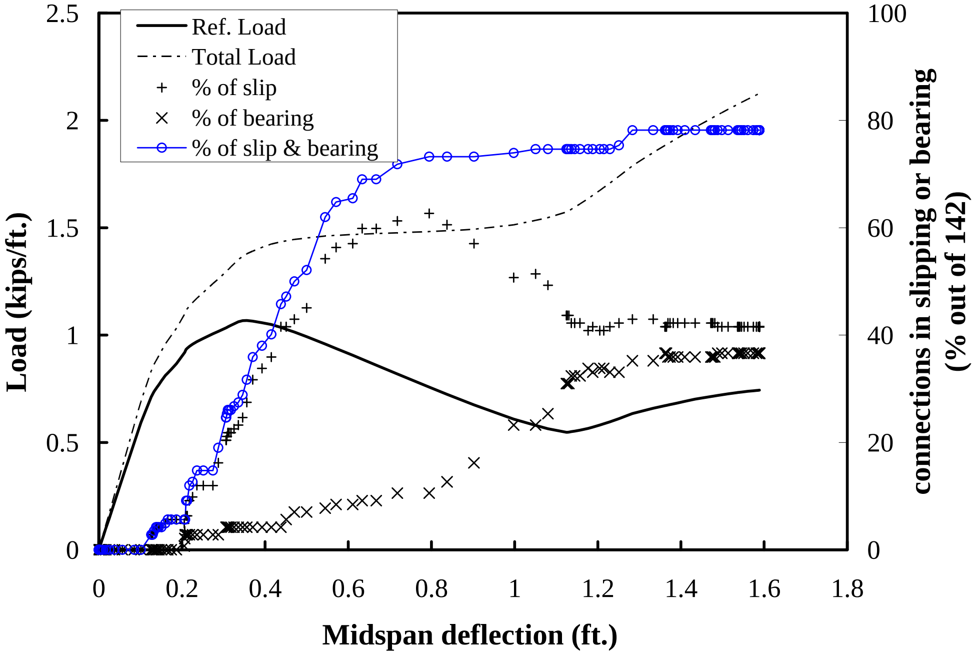


Figure 18 – Truss response for joint slip = 1/8 in.

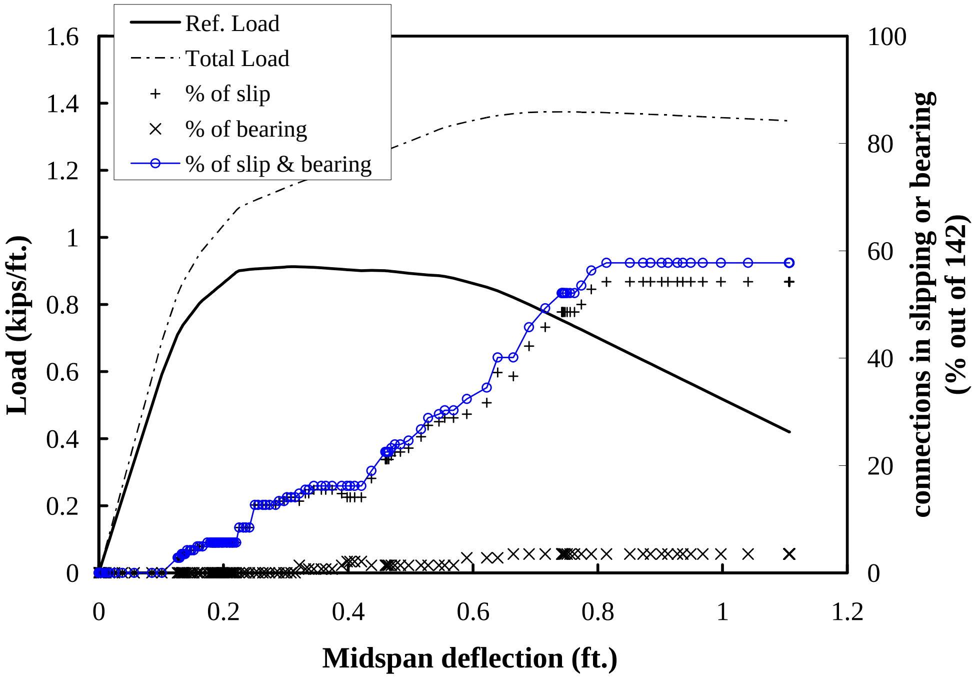


Figure 19 – Truss response for joint slip = 3/8 in.

Analysis of Cases 1 to 5

A summary of the analysis conducted on a long span truss with various magnitude of joint slip is presented in Figure 20 in terms of total load versus midspan deflection. The figure indicates that for three of the slip magnitudes illustrated in the figure the ultimate capacity of the roof truss, measured in terms of volume of water that can be carried by the roof, does not change with an increase in the magnitude of joint slip. However, there is a significant change in deflection at which the capacity is reached. For a slip of 1/8 in., twice the hole clearance for a regular size hole, the load curve plateau starts when a few connections have started to slip, and ends shortly after load transfer by bearing has started.

The curves for slips of 3/8 in. and 1/2 in. slip did not reach the same load level as the other three curves. It is expected that it would reach the same load level if the analysis had been able to converge.

The curves for the reference load are summarized in Figure 21. Similar phenomena to that observed in Figure 20 can also be observed from the reference load curve. A comparison of Figure 20 and Figure 21 indicates that although the volume of water on the roof keeps increasing as the joints slip, the water level at the parapet decreases. This phenomenon stops only when about half of the joints have stopped slipping and gone into bearing. Once bearing has been established in about 50% of the joints, the stiffness of the truss increases again and the reference load (height of water at the parapets) starts to increase.

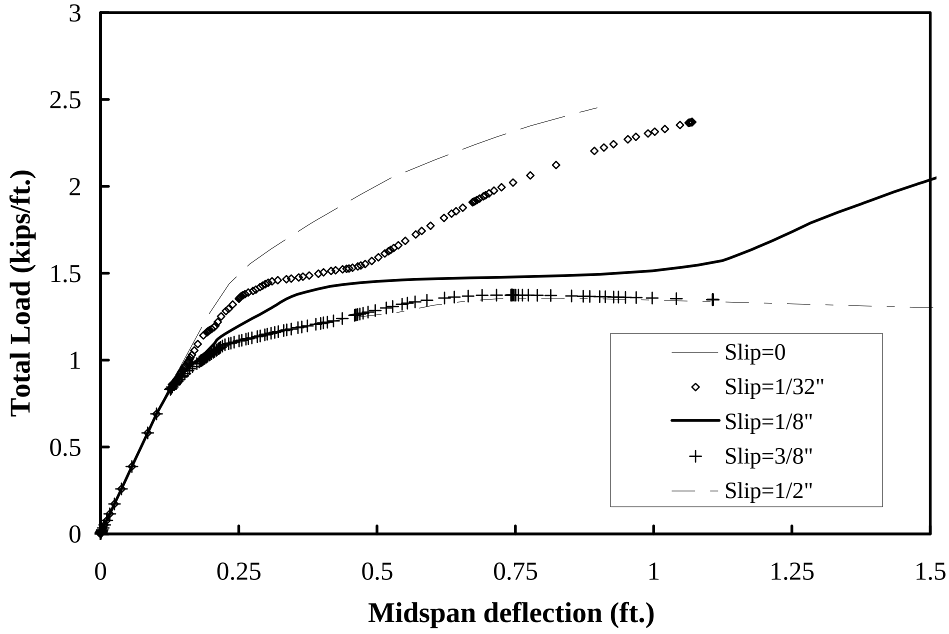


Figure 20 – Comparison of the total load for different slip magnitudes

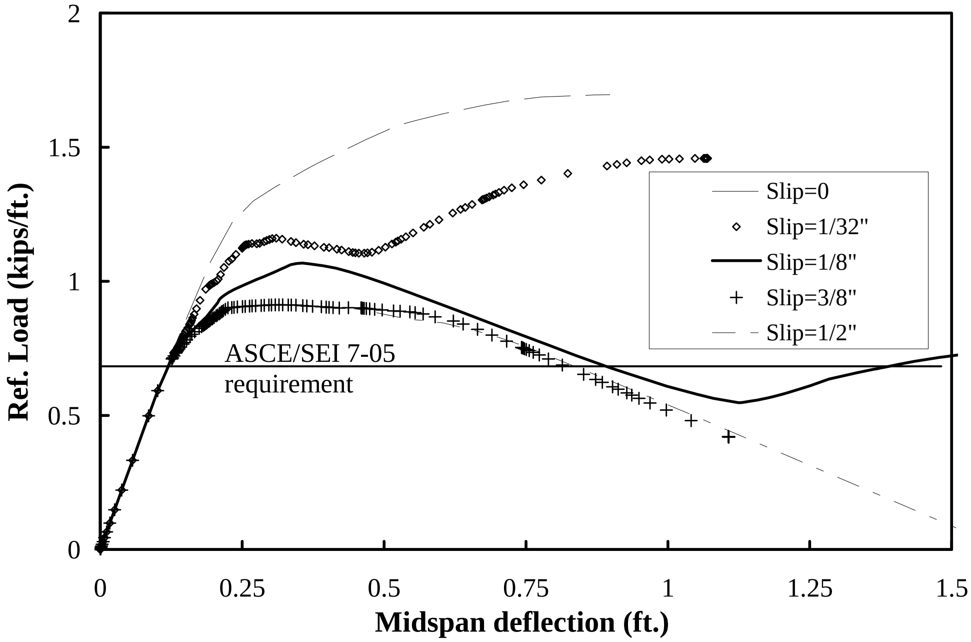


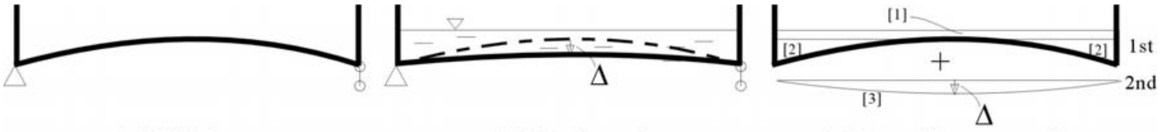
Figure 21 – Comparison of the reference load for different slip magnitudes

In reality, the connections in a structure are not likely to slip simultaneously. In the current investigation, the connections were designed to force simultaneous slippage in as many connections as possible. The overlap between slippage in some joints and load transfer in bearing in other joints would tend to reduce the impact of joint slippage since the stiffness is not lost in all joints at the same time. It should also be noted that the assumed slip magnitudes of 3/8 in. and 1/2 in. are excessive for multiple bolt joints.

Furthermore, a comparison of the analysis results with the ASCE/SEI 7-05 requirement indicates that the roof was able to contain the water required to be retained (typically the water from one storm) before any noticeable loss of stiffness.

4.8 Effect of camber

The finite element model of a cambered roof is very similar to that of the flat roof discussed above. When the roof truss is cambered, more water accumulates at the ends of the roof than at midspan. This is illustrated in Figure 22. Once again, the total load can be decomposed into a first and a second order load. The first order load, representing the load on the undeformed shape, is composed of the uniform load (load [1] in Figure 22c) and the complementary sine-shape load (load [2] in Figure 22c). The 2^{nd} order loads, loads due to deflection only, adopt a sine function configuration (the water volume between the dashed and solid lines in Figure 22b, or load [3] in Figure 22c). Load [2], which is independent of deflection, is applied to the structure in the first load step. The uniform load [1] is then gradually applied in load step 2 until failure. The second order load [3], simulated by a pseudo foundation, is produced with deflection in both steps. As soon as the deflection is at least as large as the camber, loads [2] and [3] constitute a uniform load block.



(a) Initial (b) Deflected (c) Load decomposition

Figure 22 – Rain load on roof truss with camber

Curves for the reference load and the total load, expressed in terms of water height, as a function of midspan deflection, are presented in Figures 23 and 24 where a negative deflection is measured upward. Except for a shift along the horizontal axis, the curves of total load presented in Figures 23 and 24 are identical to the curves presented in Figure 12 and 16, respectively, for the same truss without any camber. The curve of the reference load is plotted only from the non-cambered position (flat roof configuration). As expected, a comparison of the curves for a cambered truss with those for a flat roof truss indicates that the reference load reaches a higher value when the truss is cambered. For the flat roof truss with 0.5 in. slip, the maximum reference load is about 0.92 kip/ft (0.66 ft of water) whereas the maximum reference water level is about 1.02 ft for the cambered truss. However, in both cases the truss with minimum stiffness requirement meets the ASIC/SEI requirement for rain load carrying capacity.

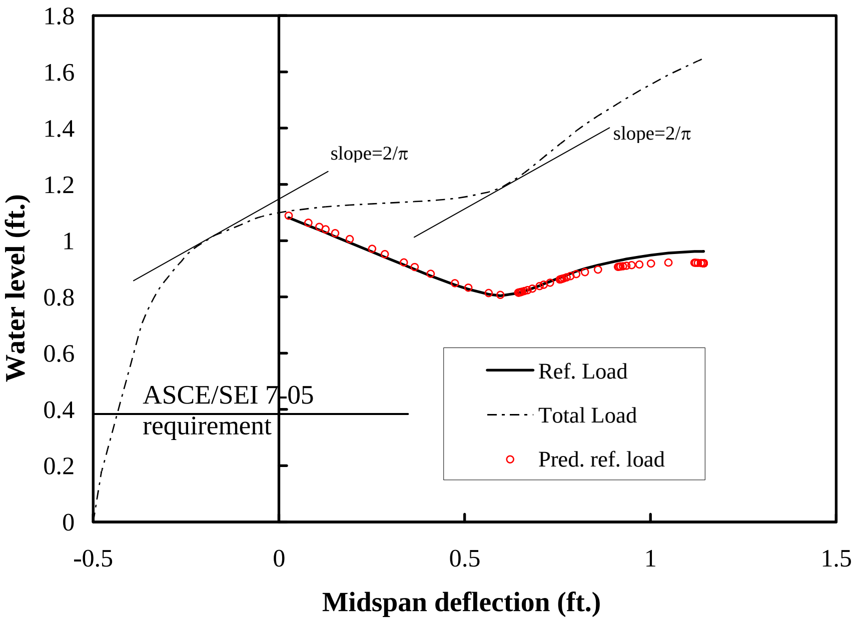


Figure 23 – Behavior of roof truss with initial camber (slip = 1/8 in.; camber = 6 in.)

The cambered truss configuration offers two advantages. First, it raises the threshold of ponding, $H_{r,peak}$. There is a ponding concern only if the initial loads are large enough to snap the roof through. Second, it delays the occurrence of sagging and, consequently, reduces the ponding load.

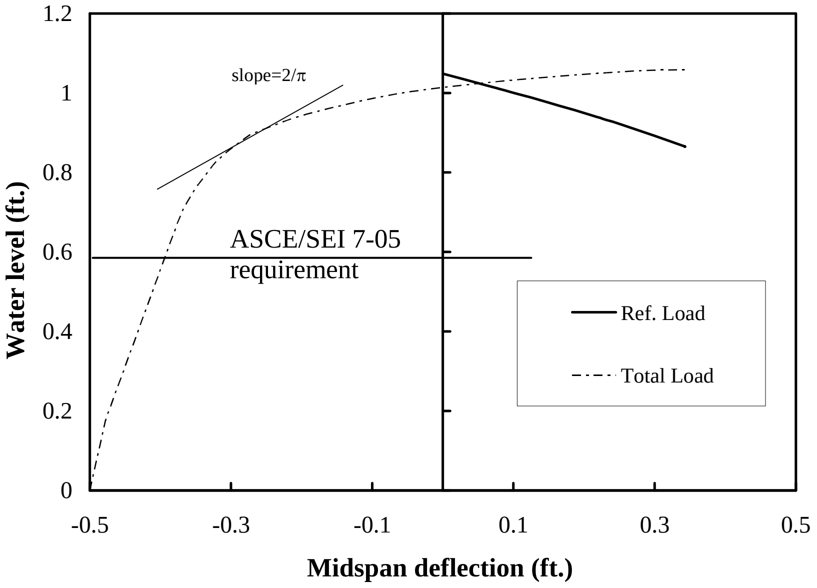


Figure 24 – Behavior of roof truss with initial camber (slip = 1/8 in.; camber = 6 in.)

5. Summary and Conclusions

5.1 Summary

A review of the literature on experimental data on slip critical joints was conducted to compile a database of test results on slip-critical joints with faying surfaces consisting of clean mill scale, sand blasted surfaces and galvanized surfaces. Results from bolt pretension measurements for bolts installed by the calibrated wrench method, turn-of-nut method, tension-control bolts and direct tension indicator washers were also reviewed. The test data were collected to conduct a reliability analysis to correlate the resistance factor with the reliability index for slip-critical joints.

The database of measured slip coefficients for clean mill scale and blast clean surfaces is sufficiently large to assess the probability of slip with confidence. On the other hand, the database of test results for hot-dip galvanized steel is small. An analysis of the database of test results indicated that a significant portion of the available test results could not be used in a reliability analysis, either because bolt pretension had not been measured directly, or the definition of the slip load was not consistent with the generally accepted definition, i.e. the load at significant slip rather than the load at first slip. The mean slip coefficient for clean mill scale, blast clean surfaces and galvanized surfaces was found to be 0.31, 0.52, and 0.20, respectively.

Recent test data on grade ASTM A588 steel indicated that the slip coefficient is significantly different from the value determined from earlier tests on the same grade of steel. The same data obtained from two different heats indicate that the slip coefficient is slightly higher than that used for other grades of steel with clean mill scale.

Test data from the University of Alberta and the University of Toronto on tension-control bolts indicated that bolt exposure time affects the level of pretension achieved in the bolts. Bolts installed immediately upon exposure of the bolts to the environment show a significantly higher pretension than bolts that have been exposed to the environment for more than two weeks before final installation of the bolts.

The resistance factor and corresponding safety index were calculated for the following cases: a) Joints with A325 bolts, clean mill scale, blast cleaned, and galvanized faying surfaces, and for bolts installed using the calibrated wrench method, turn-of-nut, TC bolts, or direct tension indicator washers; b) joints with A490 bolts, clean mill scale, blast cleaned, and galvanized faying surfaces, and for bolts installed using the calibrated wrench method or direct tension indicator washers.

The reliability analysis indicated that for any given resistance factor, the turn-of-nut method yields a significantly higher safety index than the calibrated wrench method, TC bolts, and DTI washers. Although this has always been recognized by design specification writers, the benefit of using the turn-of-nut method has never been pursued.

Although a reliability analysis was conducted for galvanized plates, the number of available test results is very limited and further testing is required to obtain an appropriate value of slip coefficient for slip critical joints with galvanized faying surfaces. Both the slip coefficient and the method of surface preparation to achieve the slip coefficient must be investigated. The latter is necessary since two distinct sets of slip coefficients were obtained from the reviewed test results.

The elastic stiffness has long been recognized as the main factor governing roof ponding problems. Based on the analysis of a 331 ft span truss, it was found that a truss that satisfies the current requirement for stiffness to prevent ponding instability can display a behavior similar to ponding instability, i.e. the roof deflection increases as the water level around the roof perimeter decreases. However, as deflections increase and the bolts in the truss joints go into bearing, the roof stabilizes and the water level around the roof perimeter can increase again. Deflection of these trusses can be controlled by controlling the parapet height. As long as the parapet is lower than the maximum reference height, $H_{r,peak}$, infinite rainfall will not lead to ponding instability.

It was shown that trusses with joint slip as large as two times the bolt hole clearance in regular size bolt holes can reach the same capacity as trusses without joint slip within a deflection of 1/240 of the span length. All the cases of joint slip investigated, up to a joint slip of 0.5 in., showed that the truss could safely carry the amount of water specified in ASCE/SEI 7-05, i.e., 5.75 in. of rain. The truss spacing used for this investigation was selected to meet the stiffness requirement of AISC (2005) for ponding consideration.

As expected, a cambered roof trusses have a greater resistance to ponding. Although both the cambered and uncambered trusses analyzed in this investigation showed the same strength and behavior, the reference load level, which relates to the water level around the perimeter of a roof, was found to be higher for the roof with camber than with the flat roof.

5.2 Selection of a safety index

The safety index and associated resistance factor for slip critical joints should be selected based on factors such as history of joint behavior, consequence of slip and remaining strength of the joint following joint slip.

There is sufficient experience with joints designed as slip-critical joints at service loads to assess a suitable safety index. Such joints have been used for many years without any indication of distress. For joints that use A325 bolts, the current design equation with a value of D_u = 1.13 ($D_u \equiv \phi$) results in a safety index of 0.82 for clean mill scale and 1.74 for blast cleaned faying surfaces with bolts installed using the calibrated wrench method. Since the behavior of joints with clean mill scale has never been a concern, a safety index of 1.0 seems to be appropriate for no slip at service load in these joints. The same value of safety index is also recommended for joints with blast clean faying surfaces. The resulting resistance factors for a safety index of 1.0 and various surface preparations and methods of installation are presented in Table 16.

Table 16 – Recommended resistance factor, ϕ, for no slip at service load ($\beta = 1.0$)

	Calibrated wrench		Turn-of-nut		TC bolts installed within two weeks		TC Bolts installed after two weeks		DTI Washers	
	A325	A490	A325	A490	A325	A490	A325	A490	A325	A490
CMS*	1.08	1.08	1.37	1.27	1.08	—	1.03	—	1.06	1.06
BC	1.34	1.34	1.70	1.59	1.34	—	1.27	—	1.31	1.31
Galv.	0.63	0.63	0.80	0.74	0.63	—	0.60	—	0.62	0.62

* CMS – clean mill scale; BC – blast clean; Galv. – galvanized

For joints designed for no slip at the factored load, there is no past experience to draw from. Table 17 shows that the current AISC specification provides a safety index varying from -0.13 (1.24 if we ignore galvanized surfaces) to 3.52. By comparison, the current value of safety index used for fracture of a tension member at the net section is 3.40. In order to rationalize a value of safety index appropriate for no slip under factored loads, one must look at the consequence of slip and the failure mode resulting from slip.

Table 17 – Safety index, β, resulting from current AISC design recommendation for no slip at factored load ($\phi D_u = 0.96$)

	Calibrated wrench		Turn-of-nut		TC bolts installed within two weeks		TC Bolts installed after two weeks		DTI Washers	
	A325	A490	A325	A490	A325	A490	A325	A490	A325	A490
CMS	1.43	1.43	2.34	2.05	1.43	—	1.24	—	1.34	1.34
BC	2.47	2.47	3.52	3.20	2.37	—	2.16	—	2.28	2.28
Galv.	-0.19	-0.19	0.51	0.29	-0.13	—	-0.28	—	-0.20	-0.20

Applications where no slip at factored load might be considered are: joints of long span trusses with oversized bolt holes; bolted built-up columns; and joints with thick fill plates. The analysis of a long span truss indicated that the consequence of slip with oversized holes is large, but stable, deflection of the truss. Load transfer in the truss joints takes place by shear of the bolts and bearing on the bolts on the gusset plates and bolted members. The truss investigated in this study was designed to be at the limit of the stiffness requirement from AISC Specification for preventing ponding. The truss satisfied the current ASCE/SEI design requirement without any significant reduction in stiffness. It is recalled that the analysis was conducted assuming maximum possible amount of slip in all the joints of a truss, namely, two times the bolt hole clearance for oversized holes. This magnitude of slip is believed to be unrealistically high. The analysis has shown that once slip has taken place, the truss was still able to carry increasing load once the bolts in part of the joints had gone into bearing.

The role of slip-critical joints in built-up columns is to prevent relative displacement of the elements making up the built-up member. As such, the joints must be able to transfer the shear flow between the elements of the built-up member. The consequence of slip in these joints is buckling of the column. The safety index in the current AISC Specification (2005) varies from a low value of 2.6 to a high value of 3.6 (Galambos, 2006). Although the consequence of slip is severe, it is expected that the number of bolts required in the joints would be small since they are designed to resist only the shear flow existing between the elements of the built-up member. A safety index of 2.6 is therefore recommended for the joints in built-up members. It is noted that the end connections between the compression built-up member and the structure need not be designed as slip-critical at factored loads. The end connections can be designed as bearing connections provided the spacing between the end connection and the first fasteners between the elements of the built-up section is sufficiently small to prevent buckling of the individual elements in the end zones before overall buckling of the column.

For joints with thick fill plates the consequence of slip is not well understood at this time. Available data on joints with fill plates cover plate thicknesses up to 3/4 in. only. A decrease in bolt shear strength of up to 20% was observed for fill plates with a thickness from 1/4 in. to 3/4 in. When the total thickness of fill plates exceeds 3/4 in. the fill plates must be developed. At this time there is insufficient information to assess the consequence of slip in joints with fill plate thickness greater than 3/4 in. It is therefore recommended that such fill plates be developed either by welding or by bolting to transfer the force in the fill plate to the main elements of the joint by friction, i.e., a slip-critical joint for the factored force in the fill plate. A safety index similar to that for built-up columns is also recommended.

A safety index of 2.6 is therefore recommended for the cases where no slip at the factored load level is desired. Table 18 presents the resistance factor required to obtain this level of safety for no slip at factored load.

Table 18 – Resistance factors for a safety index, β, of 2.6

	Calibrated wrench		Turn-of-nut		TC bolts installed within two weeks		TC Bolts installed after two weeks		DTI Washers	
	A325	A490	A325	A490	A325	A490	A325	A490	A325	A490
CMS	0.69	0.69	0.88	0.81	0.67	—	0.64	—	0.67	0.67
BC	0.93	0.93	1.18	1.10	0.91	—	0.86	—	0.89	0.89

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Appendix A

Slip Test Data

Author(s)	**Laub, W. H.; Phillips, J. R.**
Title	**The Effect of Fastener Material and Fastener Tension on the Allowable Bearing Stresses of Structural Joints**
Source	**Fritz Engineering Laboratory Report No. 243.2, Lehigh University, Bethlehem, PA, USA**
Year	**1954**
Ref. in Bolt Guide	**5.1**

Faying Surface *mill scale (cleaned)*

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
A-3	A307	3/4	1/16	1	2	2	2	44	160	0.278	A7	A
A-4	A307	3/4	1/16	1	2	2	2	39	160	0.243	A7	A
A-5	A325	3/4	1/16	1	2	2	2	133	463	0.288	A7	A
A-6	A325	3/4	1/16	1	2	2	2	136	463	0.293	A7	A
B-1	A325	3/4	1/16	1	2	2	2	89	463	0.192	A7	A
B-2	A325	3/4	1/16	1	2	2	2	89	463	0.192	A7	A
C-3	A325	3/4	1/16	1	2	2	2	167	463	0.361	A7	A
C-4	A325	3/4	1/16	1	2	2	2	140	463	0.303	A7	A
C-5	A325	3/4	1/16	1	2	2	2	145	463	0.313	A7	A
C-6	A325	3/4	1/16	1	2	2	2	145	633	0.228	A7	A
D-1	A307	7/8	1/16	1	2	2	2	109	285	0.383	A7	A
D-2	A307	7/8	1/16	1	2	2	2	80	285	0.281	A7	A
E-1	A307	7/8	1/16	1	2	2	2	53	285	0.188	A7	A
E-2	A307	7/8	1/16	1	2	2	2	87	285	0.305	A7	A
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Author(s)	**Steinhardt, O.; Möhler, K.**
Title	**Versuche zur Anwendung vorgespannter Schrauben im Stahlbau, I. Teil**
Source	**Deutscher Ausschuss für Stahlbau, Stahlbau Verlag, Cologne, Germany**
Year	**1954**
Ref. in Bolt Guide	**---**

Faying Surface Specimens A, B, C, and D

mill scale (cleaned with wire brush)

Specimen	Bolt Type	ϕ_B [mm]	HC [mm]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
A1a	8G	16	1	1	2	2	2	78	262	0.300	St 37	A
A1b	8G	16	1	1	2	2	2	96	262	0.367	St 37	A
A2a	8G	16	1	1	2	2	2	164	337	0.487	St 37	A
A2b	8G	16	1	1	2	2	2	171	337	0.507	St 37	A
A3a	8G	16	1	1	2	2	2	105	301	0.349	St 37	A
A3b	8G	16	1	1	2	2	2	115	301	0.382	St 37	A
A4a	8G	16	1	1	2	2	2	96	301	0.320	St 37	A
A4b	8G	16	1	1	2	2	2	114	301	0.379	St 37	A
A5a	8G	16	1	1	2	2	2	127	337	0.376	St 37	A
A5b	8G	16	1	1	2	2	2	144	337	0.428	St 37	A
A6a	8G	16	1	1	2	2	2	105	262	0.401	St 37	A
A6b	8G	16	1	1	2	2	2	105	262	0.401	St 37	A
A7a	8G	16	1	1	2	2	2	172	376	0.457	St 37	A
A7b	8G	16	1	1	2	2	2	183	376	0.488	St 37	A
A8a	8G	16	1	1	2	2	1	41	131	0.315	St 37	A
A8b	8G	16	1	1	2	2	1	44	131	0.337	St 37	A
A9a	8G	16	1	1	2	2	1	46	131	0.352	St 37	A
A9b	8G	16	1	1	2	2	1	60	131	0.457	St 37	A
A10a	8G	16	1	1	2	2	1	56	168	0.332	St 37	A
A10b	8G	16	1	1	2	2	1	61	168	0.361	St 37	A
A11a	8G	16	1	1	2	2	1	50	168	0.297	St 37	A
A11b	8G	16	1	1	2	2	1	53	168	0.315	St 37	A
A12a	8G	16	1	1	2	2	2	103	376	0.274	St 37	A
A13a	8G	16	1	1	2	2	2	113	376	0.300	St 37	A
A14a	8G	16	1	1	2	2	2	125	376	0.331	St 37	A
A15a	8G	16	1	1	2	2	2	133	376	0.355	St 37	A
A15b	8G	16	1	1	2	2	2	135	376	0.360	St 37	A
A16a	8G	16	1	1	2	2	2	141	376	0.376	St 37	A
A16b	8G	16	1	1	2	2	2	145	376	0.386	St 37	A
A17a	8G	16	1	1	2	2	2	121	376	0.321	St 37	A
A17b	8G	16	1	1	2	2	2	132	376	0.352	St 37	A
A18a	8G	16	1	1	2	2	2	138	376	0.368	St 37	A
A18b	8G	16	1	1	2	2	2	145	376	0.386	St 37	A
A19a	8G	16	1	1	2	2	2	130	311	0.419	St 37	A
A19b	8G	16	1	1	2	2	2	135	311	0.435	St 37	A
A20a	8G	16	1	1	2	2	2	125	311	0.400	St 37	A
A20b	8G	16	1	1	2	2	2	129	311	0.416	St 37	A
A21a	8G	16	1	1	2	2	2	96	277	0.346	St 37	A
A21b	8G	16	1	1	2	2	2	105	277	0.379	St 37	A
A22a	8G	16	1	1	2	2	2	96	277	0.348	St 37	A
A22b	8G	16	1	1	2	2	2	129	277	0.465	St 37	A
A23a	8G	16	1	1	2	2	2	97	277	0.351	St 37	A
A23b	8G	16	1	1	2	2	2	110	277	0.397	St 37	A

Specimen	Bolt Type	ϕ_B [mm]	HC [mm]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
A24a	8G	16	1	1	2	2	2	131	337	0.390	St 37	A
A24b	8G	16	1	1	2	2	2	131	337	0.390	St 37	A
A25a	8G	16	1	1	2	2	2	123	337	0.364	St 37	A
A25b	8G	16	1	1	2	2	2	144	337	0.428	St 37	A
A26a	8G	16	1	1	2	2	2	145	337	0.431	St 37	A
A26b	8G	16	1	1	2	2	2	148	337	0.440	St 37	A
A27a	8G	16	1	1	2	2	2	81	311	0.262	St 37	A
A27b	8G	16	1	1	2	2	2	90	311	0.290	St 37	A
A28a	8G	16	1	1	2	2	2	84	311	0.271	St 37	A
A28b	8G	16	1	1	2	2	2	103	311	0.331	St 37	A
A29a	8G	16	1	1	2	2	2	57	277	0.206	St 37	A
A29b	8G	16	1	1	2	2	2	84	277	0.305	St 37	A
A30a	8G	16	1	1	2	2	2	71	277	0.255	St 37	A
A30b	8G	16	1	1	2	2	2	83	277	0.301	St 37	A
A31a	8G	16	1	1	2	2	2	72	277	0.259	St 37	A
A31b	8G	16	1	1	2	2	2	77	277	0.280	St 37	A
B1a	8G	16	1	1	2	2	2	116	376	0.308	St 37	A
B1b	8G	16	1	1	2	2	2	126	376	0.334	St 37	A
B2a	8G	16	1	1	2	2	2	123	376	0.326	St 37	A
B2b	8G	16	1	1	2	2	2	142	376	0.378	St 37	A
B3a	8G	16	1	1	2	2	2	117	376	0.311	St 37	A
B3b	8G	16	1	1	2	2	2	126	376	0.334	St 37	A
B4a	10K	16	1	1	2	2	2	145	451	0.322	St 37	A
B4b	10K	16	1	1	2	2	2	151	451	0.335	St 37	A
B5a	10K	16	1	1	2	2	2	156	451	0.346	St 37	A
B5b	10K	16	1	1	2	2	2	176	451	0.389	St 37	A
B6a	10K	16	1	1	2	2	2	164	451	0.363	St 37	A
B6b	10K	16	1	1	2	2	2	179	451	0.396	St 37	A
B7a	8G	16	1	1	2	2	2	84	277	0.305	St 37	A
B7b	8G	16	1	1	2	2	2	96	277	0.348	St 37	A
B8a	8G	16	1	1	2	2	2	85	277	0.309	St 37	A
B8b	8G	16	1	1	2	2	2	91	277	0.330	St 37	A
B9a	8G	16	1	1	2	2	2	84	277	0.305	St 37	A
B9b	8G	16	1	1	2	2	2	86	277	0.312	St 37	A
B10a	10K	16	1	1	2	2	2	149	277	0.539	St 37	A
B10b	10K	16	1	1	2	2	2	158	277	0.571	St 37	A
B11a	8G	16	1	1	2	2	2	90	376	0.240	St 37	A
B11b	8G	16	1	1	2	2	2	92	376	0.245	St 37	A
B12a	8G	16	1	1	2	2	2	91	376	0.243	St 37	A
B12b	8G	16	1	1	2	2	2	99	376	0.264	St 37	A
B13a	8G	16	1	1	2	2	2	90	311	0.290	St 37	A
B13b	8G	16	1	1	2	2	2	105	311	0.337	St 37	A
B14a	8G	16	1	1	2	2	2	95	311	0.306	St 37	A
B14b	8G	16	1	1	2	2	2	104	311	0.334	St 37	A
B15a	10K	16	1	1	2	2	2	217	388	0.559	St 37	A
B15b	10K	16	1	1	2	2	2	200	388	0.516	St 37	A
B16a	10K	16	1	1	2	2	2	182	388	0.471	St 37	A
B16b	10K	16	1	1	2	2	2	191	388	0.493	St 37	A
B17a	10K	16	1	1	2	2	2	165	388	0.425	St 37	A
B17b	10K	16	1	1	2	2	2	169	388	0.435	St 37	A
B18a	10K	16	1	1	2	2	2	175	388	0.450	St 37	A
B18b	10K	16	1	1	2	2	2	178	388	0.458	St 37	A
B19a	10K	16	1	1	2	2	2	168	388	0.433	St 37	A
B19b	10K	16	1	1	2	2	2	180	388	0.463	St 37	A

Specimen	Bolt Type	ϕ_B [mm]	HC [mm]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
C1	8G	22	1	1	2	2	2	75	379	0.197	St 37	A
C2	8G	22	1	1	2	2	2	145	379	0.383	St 37	A
C3	8G	22	1	1	2	2	2	77	379	0.202	St 37	A
C4	8G	22	1	1	2	2	2	136	542	0.252	St 37	A
C5	8G	22	1	1	2	2	2	239	542	0.442	St 37	A
C6	8G	22	1	1	2	2	2	116	542	0.214	St 37	A
C7	8G	22	1	1	2	2	2	74	379	0.194	St 37	A
C8	8G	22	1	1	2	2	2	114	379	0.301	St 37	A
C9	8G	22	1	1	2	2	2	76	378	0.200	St 37	A
C10	8G	22	1	1	2	2	2	108	542	0.199	St 37	A
C12	8G	22	1	1	2	2	2	97	542	0.179	St 37	A
C13	8G	22	1	1	2	2	2	112	542	0.207	St 37	A
C14	8G	22	1	1	2	2	2	133	542	0.246	St 37	A
C15	8G	22	1	1	2	2	2	120	542	0.221	St 37	A
C16	8G	22	1	1	2	2	2	162	693	0.234	St 37	A
C17	8G	22	1	1	2	2	2	161	693	0.232	St 37	A
C18	8G	22	1	1	2	2	2	147	693	0.212	St 37	A
C19	8G	22	1	1	2	2	2	69	379	0.181	St 37	A
C20	8G	22	1	1	2	2	2	115	542	0.212	St 37	A
C21	8G	22	1	1	2	2	2	154	693	0.222	St 37	A
C22	8G	22	1	3	2	6	2	852	1,825	0.467	St 37	A
C23	8G	22	1	3	2	6	2	607	1,825	0.333	St 37	A
C24	8G	22	1	3	2	6	2	730	1,825	0.400	St 37	A
C25	8G	22	1	3	2	6	2	852	1,825	0.467	St 37	A
C26	8G	22	1	3	2	6	2	360	1,825	0.197	St 37	A
C27	8G	22	1	3	2	6	2	453	1,825	0.248	St 37	A
C28	8G	22	1	3	2	6	2	360	1,825	0.197	St 37	A
C29	8G	22	1	3	2	6	2	360	1,825	0.197	St 37	A
D1	8G	16	1	1	2	2	2	88	277	0.319	St 37	A
D2	8G	16	1	1	2	2	2	68	277	0.245	St 37	A
D3	8G	16	1	1	2	2	2	126	277	0.454	St 37	A
D4	10K	16	1	1	2	2	2	180	388	0.463	St 37	A
D5	10K	16	1	1	2	2	2	148	388	0.382	St 37	A
D6	10K	16	1	1	2	2	2	189	388	0.488	St 37	A
D7	8G	16	1	1	2	2	2	132	277	0.479	St 37	A
D8	8G	16	1	1	2	2	2	99	277	0.358	St 37	A
D9	8G	16	1	1	2	2	2	99	277	0.358	St 37	A
D10	10K	16	1	1	2	2	2	210	388	0.541	St 37	A
D11	10K	16	1	1	2	2	2	203	388	0.524	St 37	A
D12	10K	16	1	1	2	2	2	223	388	0.574	St 37	A
D13	12K	16	1	1	2	2	2	245	468	0.524	St 37	A
D14	12K	16	1	1	2	2	2	257	468	0.549	St 37	A
D15	12K	16	1	1	2	2	2	277	468	0.591	St 37	A
D16	12K	16	1	1	2	2	2	200	468	0.428	St 37	A
D17	12K	16	1	1	2	2	2	203	468	0.434	St 37	A
D18	12K	16	1	1	2	2	2	213	468	0.455	St 37	A
D19	8G	16	1	1	2	2	2	109	277	0.394	St 37	A
D20	8G	16	1	1	2	2	2	174	346	0.502	St 37	A
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Note: Pretension was determined by applied torque and not measured directly.

Author(s) **Steinhardt, O.; Möhler, K.**
Title **Versuche zur Anwendung vorgespannter Schrauben im Stahlbau, I. Teil**
Source **Deutscher Ausschuss für Stahlbau, Stahlbau Verlag, Cologne, Germany**
Year **1954**
Ref. in Bolt Guide **---**

Faying Surface Specimens E and F
sand-blasted

Specimen	Bolt	ϕ_B	HC	n_L	n_R	n	m	F_s	P	μ	Plate	Surface
	Type	[mm]	[mm]	[—]	[—]	[—]	[—]	[kN]	[kN]	[—]	Grade	Class
E1a	8G	16	1	1	2	2	2	170	277	0.613	St 37	B
E1b	8G	16	1	1	2	2	2	159	277	0.574	St 37	B
E2a	8G	16	1	1	2	2	2	162	277	0.585	St 37	B
E2b	8G	16	1	1	2	2	2	172	277	0.621	St 37	B
E3a	8G	16	1	1	2	2	2	155	277	0.560	St 37	B
E3b	8G	16	1	1	2	2	2	157	277	0.567	St 37	B
F1	8G	22	1	1	2	2	2	233	379	0.617	St 37	B
F2	8G	22	1	1	2	2	2	286	379	0.756	St 37	B
F3	8G	22	1	1	2	2	2	279	379	0.736	St 37	B
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Note: Pretension was determined by applied torque and not measured directly.

Author(s) **Steinhardt, O.; Möhler, K.**
Title **Versuche zur Anwendung vorgespannter Schrauben im Stahlbau, I. Teil**
Source **Deutscher Ausschuss für Stahlbau, Stahlbau Verlag, Cologne, Germany**
Year **1954**
Ref. in Bolt Guide **---**

Faying Surface Specimens G, H, and J
flame-blasted

Specimen	Bolt	ϕ_B	HC	n_L	n_R	n	m	F_s	P	μ	Plate	Surface
	Type	[mm]	[mm]	[—]	[—]	[—]	[—]	[kN]	[kN]	[—]	Grade	Class
G1a	8G	16	1	1	2	2	2	215	376	0.572	St 37	B
G1b	8G	16	1	1	2	2	2	225	376	0.598	St 37	B
G2a	8G	16	1	1	2	2	2	170	376	0.451	St 37	B
G2b	8G	16	1	1	2	2	2	205	376	0.545	St 37	B
G3a	8G	16	1	1	2	2	2	176	376	0.467	St 37	B
G3b	8G	16	1	1	2	2	2	200	376	0.532	St 37	B
G4a	8G	16	1	1	2	2	2	203	376	0.540	St 37	B
G4b	8G	16	1	1	2	2	2	226	376	0.600	St 37	B
G5a	8G	16	1	1	2	2	2	177	376	0.470	St 37	B
G5b	8G	16	1	1	2	2	2	208	376	0.553	St 37	B
G6a	8G	16	1	1	2	2	2	215	376	0.572	St 37	B
G6b	8G	16	1	1	2	2	2	215	376	0.572	St 37	B
G7a	8G	16	1	1	2	2	2	193	376	0.514	St 37	B
G7b	8G	16	1	1	2	2	2	220	376	0.585	St 37	B
G8a	8G	16	1	1	2	2	2	173	376	0.459	St 37	B
G8b	8G	16	1	1	2	2	2	219	376	0.582	St 37	B
G9a	8G	16	1	1	2	2	2	191	311	0.615	St 37	B
G9b	8G	16	1	1	2	2	2	200	311	0.643	St 37	B
G10a	8G	16	1	1	2	2	2	180	311	0.577	St 37	B
G10b	8G	16	1	1	2	2	2	190	311	0.612	St 37	B
G11a	8G	16	1	1	2	2	2	169	311	0.542	St 37	B
G11b	8G	16	1	1	2	2	2	226	311	0.725	St 37	B
G12a	8G	16	1	1	2	2	2	187	311	0.602	St 37	B
G12b	8G	16	1	1	2	2	2	223	311	0.716	St 37	B
G13a	8G	16	1	1	2	2	2	181	311	0.580	St 37	B
G13b	8G	16	1	1	2	2	2	194	311	0.624	St 37	B
G14a	8G	16	1	1	2	2	2	171	311	0.549	St 37	B
G14b	8G	16	1	1	2	2	2	193	311	0.621	St 37	B
G15a	8G	16	1	1	2	2	2	164	311	0.526	St 37	B
G15b	8G	16	1	1	2	2	2	213	311	0.684	St 37	B
G16a	8G	16	1	1	2	2	2	171	311	0.549	St 37	B
G16b	8G	16	1	1	2	2	2	172	311	0.552	St 37	B
G17a	8G	16	1	1	2	2	2	142	311	0.457	St 37	B
G17b	8G	16	1	1	2	2	2	157	311	0.504	St 37	B
G18a	8G	16	1	1	2	2	2	162	311	0.520	St 37	B
G18b	8G	16	1	1	2	2	2	166	311	0.533	St 37	B
G19a	8G	16	1	1	2	2	2	181	311	0.580	St 37	B
G19b	8G	16	1	1	2	2	2	232	311	0.747	St 37	B
G20a	8G	16	1	1	2	2	2	181	311	0.580	St 37	B
G20b	8G	16	1	1	2	2	2	201	311	0.646	St 37	B
G21a	8G	16	1	1	2	2	2	149	311	0.479	St 37	B
G21b	8G	16	1	1	2	2	2	233	311	0.750	St 37	B
G22a	8G	16	1	1	2	2	2	304	608	0.500	St 37	B

Specimen	Bolt	ϕ_B	HC	n_L	n_R	n	m	F_s	P	μ	Plate	Surface
	Type	[mm]	[mm]	[—]	[—]	[—]	[—]	[kN]	[kN]	[—]	Grade	Class
G22b	8G	16	1	1	2	2	2	363	608	0.597	St 37	B
G23a	8G	16	1	1	2	2	2	308	608	0.506	St 37	B
G23b	8G	16	1	1	2	2	2	343	608	0.565	St 37	B
H1a	8G	16	1	1	2	2	2	193	376	0.514	St 37	B
H1b	8G	16	1	1	2	2	2	221	376	0.587	St 37	B
H2a	8G	16	1	1	2	2	2	179	311	0.574	St 37	B
H2b	8G	16	1	1	2	2	2	182	311	0.586	St 37	B
H3a	8G	16	1	1	2	2	2	189	311	0.608	St 37	B
H3b	8G	16	1	1	2	2	2	199	311	0.640	St 37	B
H4a	8G	16	1	1	2	2	2	168	311	0.539	St 37	B
H4b	8G	16	1	1	2	2	2	181	311	0.583	St 37	B
J1	8G	22	1	1	2	2	2	186	542	0.344	St 37	B
J2	8G	22	1	1	2	2	2	181	542	0.335	St 37	B
J3	8G	22	1	1	2	2	2	216	542	0.399	St 37	B
J4	8G	22	1	1	2	2	2	1,097	608	1.803	St 37	B
J5	8G	22	1	1	2	2	2	1,219	608	2.005	St 37	B
J6	8G	22	1	1	2	2	2	1,097	608	1.803	St 37	B
J7	8G	22	1	1	2	2	2	1,219	608	2.005	St 37	B
J8	8G	22	1	3	2	6	2	1,097	1,825	0.601	St 37	B
J9	8G	22	1	3	2	6	2	852	1,825	0.467	St 37	B
J10	8G	22	1	3	2	6	2	1,097	1,825	0.601	St 37	B
J11	8G	22	1	3	2	6	2	1,158	1,825	0.634	St 37	B
J12	8G	22	1	3	2	6	2	1,097	1,825	0.601	St 37	B
J13	8G	22	1	3	2	6	2	852	1,825	0.467	St 37	B
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Note: Pretension was determined by applied torque and not measured directly.

Author(s) **Steinhardt, O.; Möhler, K.**
Title **Versuche zur Anwendung vorgespannter Schrauben im Stahlbau, I. Teil**
Source **Deutscher Ausschuss für Stahlbau, Stahlbau Verlag, Cologne, Germany**
Year **1954**
Ref. in Bolt Guide **---**

Faying Surface Specimens K1 - K9 and K14 - K30
peened, derusted (different procedures; some specimens only around the bolt holes, others over entire surface; some intensive, some normal)

Specimen	Bolt Type	ϕ_B [mm]	HC [mm]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
K1a	8G	16	1	1	2	2	2	115	311	0.369	St 37	Unclassified
K1b	8G	16	1	1	2	2	2	142	311	0.457	St 37	"
K2a	8G	16	1	1	2	2	2	110	311	0.353	St 37	"
K2b	8G	16	1	1	2	2	2	115	311	0.369	St 37	"
K3a	8G	16	1	1	2	2	2	123	311	0.394	St 37	"
K3b	8G	16	1	1	2	2	2	131	311	0.422	St 37	"
K4a	8G	16	1	1	2	2	2	152	376	0.404	St 37	"
K4b	8G	16	1	1	2	2	2	173	376	0.459	St 37	"
K5a	8G	16	1	1	2	2	2	174	376	0.462	St 37	"
K5b	8G	16	1	1	2	2	2	191	376	0.509	St 37	"
K6a	8G	16	1	1	2	2	2	183	311	0.590	St 37	"
K6b	8G	16	1	1	2	2	2	183	311	0.590	St 37	"
K7a	8G	16	1	1	2	2	2	125	311	0.400	St 37	"
K7b	8G	16	1	1	2	2	2	127	311	0.407	St 37	"
K8a	8G	16	1	1	2	2	2	120	311	0.385	St 37	"
K8b	8G	16	1	1	2	2	2	126	311	0.404	St 37	"
K9a	8G	16	1	1	2	2	2	144	376	0.384	St 37	"
K9b	8G	16	1	1	2	2	2	146	376	0.389	St 37	"
K14a	8G	16	1	1	2	2	2	100	311	0.322	St 37	"
K14b	8G	16	1	1	2	2	2	120	311	0.385	St 37	"
K15a	8G	16	1	1	2	2	2	123	311	0.394	St 37	"
K15b	8G	16	1	1	2	2	2	136	311	0.438	St 37	"
K16a	8G	16	1	1	2	2	2	130	311	0.419	St 37	"
K16b	8G	16	1	1	2	2	2	133	311	0.429	St 37	"
K17a	8G	16	1	1	2	2	2	124	311	0.397	St 37	"
K17b	8G	16	1	1	2	2	2	130	311	0.419	St 37	"
K18a	12K	16	1	1	2	2	2	189	451	0.420	St 37	"
K18b	12K	16	1	1	2	2	2	204	451	0.452	St 37	"
K19a	12K	16	1	1	2	2	2	201	451	0.446	St 37	"
K19b	12K	16	1	1	2	2	2	220	451	0.487	St 37	"
K20a	12K	16	1	1	2	2	2	193	451	0.428	St 37	"
K20b	12K	16	1	1	2	2	2	213	451	0.472	St 37	"
K21a	8G	16	1	1	2	2	2	126	301	0.418	St 37	"
K21b	8G	16	1	1	2	2	2	161	301	0.535	St 37	"
K22a	8G	16	1	1	2	2	2	145	376	0.386	St 37	"
K22b	8G	16	1	1	2	2	2	174	376	0.462	St 37	"
K23a	8G	16	1	1	2	2	2	106	311	0.340	St 37	"
K23b	8G	16	1	1	2	2	2	125	311	0.400	St 37	"
K24a	8G	16	1	1	2	2	2	96	376	0.256	St 37	"
K24b	8G	16	1	1	2	2	2	103	376	0.274	St 37	"
K25a	8G	16	1	1	2	2	2	96	376	0.256	St 37	"
K25b	8G	16	1	1	2	2	2	100	376	0.266	St 37	"
K26a	8G	16	1	1	2	2	2	122	311	0.391	St 37	"

Specimen	Bolt	ϕ_B	HC	n_L	n_R	n	m	F_s	P	μ	Plate	Surface
	Type	[mm]	[mm]	[—]	[—]	[—]	[—]	[kN]	[kN]	[—]	Grade	Class
K26b	8G	16	1	1	2	2	2	141	311	0.454	St 37	Unclassified
K27a	8G	16	1	1	2	2	2	172	376	0.457	St 37	"
K27b	8G	16	1	1	2	2	2	201	376	0.535	St 37	"
K28a	8G	16	1	1	2	2	2	183	376	0.488	St 37	"
K28b	8G	16	1	1	2	2	2	201	376	0.535	St 37	"
K29a	8G	22	1	3	2	6	2	877	1,825	0.481	St 37	"
K30a	8G	22	1	3	2	6	2	779	1,825	0.427	St 37	"
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Note: Pretension was determined by applied torque and not measured directly.

The "standard" surface "was obtained by traversing the width of the joint plate with a sharp nosed cutting tool, maintaining a constant cutting speed, cross traverse and depth of cut. This surface was chosen ... because its CLA value of roughness, …, was not far removed from that of 'as received' plates." (p. 543)

Author(s)	**Hechtman, R. A.; Young, D. R.; Chin, A. G.; Savikko, E. R.**
Title	**Slip of Joints under Static Loads**
Source	**Transactions ASCE, Vol. 120, pp. 1335-1352**
Year	**1955**
Ref. in Bolt Guide	**5.3**

Faying Surface *Specimens 10 - 39, 57 - 68, 77 - 139*
mill scale (wire brushed, oil and grease removed)
Specimens 54 - 56
mill scale completely removed by sandblasting (cleaned)
Specimens 74 - 76
mill scale? (subpunched and reamed holes in lap plates -> slightly dished)

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
10	4140	1	1/16	2	2	4	2	551	1605	0.343	A7	A
11	4140	1	1/16	2	2	4	2	543	1594	0.340	A7	A
12A	4140	1	1/16	2	2	4	2	537	1605	0.335	A7	A
12B	4140	1	1/16	2	2	4	2	612	1605	0.382	A7	A
13	4140	1	1/16	2	2	4	2	481	1605	0.300	A7	A
14	4140	1	1/16	2	2	4	2	691	1612	0.429	A7	A
15A	4140	1	1/16	2	2	4	2	604	1637	0.369	A7	A
15B	4140	1	1/16	2	2	4	2	615	1594	0.386	A7	A
16	4140	1	1/16	2	2	4	2	652	1591	0.410	A7	A
17	4140	1	1/16	2	2	4	2	526	1587	0.331	A7	A
18	4140	1	1/16	2	2	4	2	738	1580	0.467	A7	A
19	4140	1	1/16	2	2	4	2	604	1598	0.378	A7	A
20	4140	1	1/16	2	2	4	2	705	1587	0.444	A7	A
21	4140	1	1/16	2	2	4	2	680	1598	0.425	A7	A
31	4140	1	1/16	2	2	4	2	350	861	0.406	A7	A
32	4140	1	1/16	2	2	4	2	324	861	0.377	A7	A
33	4140	1	1/16	2	2	4	2	294	847	0.347	A7	A
37	4140	1	1/16	2	2	4	2	445	1270	0.350	A7	A
38	4140	1	1/16	2	2	4	2	565	1299	0.435	A7	A
39	4140	1	1/16	2	2	4	2	453	1260	0.360	A7	A
54	4140	1	1/16	2	2	4	2	733	1623	0.452	A7	B
55	4140	1	1/16	2	2	4	2	629	1591	0.396	A7	B
56	4140	1	1/16	2	2	4	2	968	1591	0.608	A7	B
57	4140	1	1/16	2	2	4	2	473	1274	0.371	A7	A
58	4140	1	1/16	2	2	4	2	520	1327	0.392	A7	A
59	4140	1	1/16	2	2	4	2	506	1309	0.387	A7	A
63	4140	1	1/16	3	2	6	2	826	2263	0.365	A7	A
64	4140	1	1/16	3	2	6	2	793	2279	0.348	A7	A
65	4140	1	1/16	3	2	6	2	910	2268	0.401	A7	A
66	4140	1	1/16	4	2	8	2	1018	3018	0.337	A7	A
67	4140	1	1/16	4	2	8	2	962	3018	0.319	A7	A
68	4140	1	1/16	4	2	8	2	968	3032	0.319	A7	A
74	4140	1	1/16	2	2	4	2	576	1598	0.361	A7	A
75	4140	1	1/16	2	2	4	2	540	1587	0.340	A7	A
76	4140	1	1/16	2	2	4	2	562	1616	0.348	A7	A
77	4140	1	1/16	2	2	4	2	467	1509	0.310	A7	A
78	4140	1	1/16	2	2	4	2	475	1516	0.314	A7	A
79A	4140	1	1/16	2	2	4	2	593	1516	0.391	A7	A
79B	4140	1	1/16	2	2	4	2	501	1502	0.333	A7	A
80	4140	1	1/16	2	2	4	2	559	1505	0.372	A7	A
81	4140	1	1/16	2	2	4	2	428	1509	0.284	A7	A

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
82	4140	1	1/16	2	2	4	2	520	1516	0.343	A7	A
101	A325	1	1/16	2	2	4	2	526	1502	0.350	A7	A
102	A325	1	1/16	2	2	4	2	461	1502	0.307	A7	A
103	A325	1	1/16	2	2	4	2	422	1495	0.283	A7	A
104	4140	1	1/16	2	2	4	2	559	1509	0.371	A7	A
105	4140	1	1/16	2	2	4	2	571	1502	0.380	A7	A
106	4140	1	1/16	2	2	4	2	571	1516	0.376	A7	A
107	A325	1	1/16	2	2	4	2	557	1850	0.301	A7	A
108	A325	1	1/16	2	2	4	2	517	1875	0.276	A7	A
109	A325	1	1/16	2	2	4	1	228	925	0.246	A7	A
119	4140	1	1/16	2	2	4	1	324	756	0.429	A7	A
120	4140	1	1/16	2	2	4	1	389	756	0.514	A7	A
121	4140	1	1/16	2	2	4	1	338	751	0.451	A7	A
122	4140	1	1/16	2	2	4	1	302	761	0.397	A7	A
123	4140	1	1/16	2	2	4	1	296	761	0.389	A7	A
124	4140	1	1/16	2	2	4	1	312	753	0.414	A7	A
128A	A325	1	1/16	2	2	4	2	464	1473	0.315	A7	A
128B	A325	1	1/16	2	2	4	2	394	1516	0.260	A7	A
129	A325	1	1/16	2	2	4	2	375	1502	0.250	A7	A
130	A325	1	1/16	2	2	4	2	478	1505	0.318	A7	A
131	A325	1	1/16	2	2	4	2	478	1516	0.315	A7	A
132	A325	1	1/16	2	2	4	2	383	1505	0.255	A7	A
133	A325	1	1/16	2	2	4	2	414	1530	0.271	A7	A
137	A325	1	1/16	2	2	4	2	610	1854	0.329	A7	A
138	A325	1	1/16	2	2	4	2	624	1865	0.334	A7	A
139	A325	1	1/16	2	2	4	2	596	1868	0.319	A7	A
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Notes:

Specimens 48 - 50 had red lead painted faying surfaces (wire brushed, cleaned mill scale)
Specimens 51 - 53 had varnished faying surfaces (wire brushed, cleaned mill scale)
All these specimens (48 - 53, total of 6) slipped from the start of loading

All specimens tested in tension, except Specimens 104 - 106 (3) in compression and 119 - 124 (6) in torsion

Author(s)	**Vasishth, U. C.; Lu, Z.-A., Vasarhelyi, D. D.**
Title	**A Study of the Nominla Coefficient of Friction in Structural Steel Joints …**
Source	**8th Progress Report, University of Washington, Seattle**
Year	**1957**
Ref. in Bolt Guide	**---**

Faying Surface *Several*

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
B0S6	—	—	—	—	—	—	—	—	—	0.220	—	A
40	—	—	—	—	—	—	—	—	—	0.380	—	A
41	—	—	—	—	—	—	—	—	—	0.350	—	A
S10-2	—	—	—	—	—	—	—	—	—	0.520	—	A
S11-2	—	—	—	—	—	—	—	—	—	0.480	—	A
S12-2	—	—	—	—	—	—	—	—	—	0.470	—	A
S12-5	—	—	—	—	—	—	—	—	—	0.310	—	Lacquered
S13-2	—	—	—	—	—	—	—	—	—	0.460	—	A
S13-5	—	—	—	—	—	—	—	—	—	0.310	—	Lacquered
S14-2	—	—	—	—	—	—	—	—	—	0.600	—	A
S14-5	—	—	—	—	—	—	—	—	—	0.300	—	Lacquered
S15-2	—	—	—	—	—	—	—	—	—	0.400	—	A
S15-5	—	—	—	—	—	—	—	—	—	0.200	—	Lacquered
S16-2	—	—	—	—	—	—	—	—	—	0.380	—	A
S16-5	—	—	—	—	—	—	—	—	—	0.300	—	Lacquered
S17-2	—	—	—	—	—	—	—	—	—	0.180	—	A
S-72	—	—	—	—	—	—	—	—	—	0.300	—	A
S-74	—	—	—	—	—	—	—	—	—	0.290	—	Lacquered
S-82	—	—	—	—	—	—	—	—	—	0.300	—	A
S-84	—	—	—	—	—	—	—	—	—	0.290	—	Lacquered
S-92	—	—	—	—	—	—	—	—	—	0.210	—	A
S-94	—	—	—	—	—	—	—	—	—	0.360	—	Lacquered
C6-1	—	—	—	—	—	—	—	—	—	0.275	—	A
C6-3	—	—	—	—	—	—	—	—	—	0.289	—	A
C6-4	—	—	—	—	—	—	—	—	—	0.322	—	A
C6-6	—	—	—	—	—	—	—	—	—	0.308	—	A
C6-8	—	—	—	—	—	—	—	—	—	0.265	—	A
C6-9	—	—	—	—	—	—	—	—	—	0.297	—	A
C6-10	—	—	—	—	—	—	—	—	—	0.299	—	A
C6-11	—	—	—	—	—	—	—	—	—	0.291	—	A
C6-12	—	—	—	—	—	—	—	—	—	0.276	—	A
C6-13	—	—	—	—	—	—	—	—	—	0.302	—	A
C6-14	—	—	—	—	—	—	—	—	—	0.284	—	A
C6-15	—	—	—	—	—	—	—	—	—	0.298	—	A
C6-16	—	—	—	—	—	—	—	—	—	0.233	—	A
C6-17	—	—	—	—	—	—	—	—	—	0.296	—	A
C6-18	—	—	—	—	—	—	—	—	—	0.280	—	A
C6-19	—	—	—	—	—	—	—	—	—	0.306	—	A
C6-20	—	—	—	—	—	—	—	—	—	0.312	—	A
C6-21	—	—	—	—	—	—	—	—	—	0.287	—	A
C6-22	—	—	—	—	—	—	—	—	—	0.309	—	A
C6-23	—	—	—	—	—	—	—	—	—	0.291	—	A
C6-24	—	—	—	—	—	—	—	—	—	0.257	—	A
C6-26	—	—	—	—	—	—	—	—	—	0.247	—	A
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Author(s)	**Beano, S. Y.; Vasarhelyi, D. D.**
Title	**The Effect of Various Treatment of the Faying Surface and of the Misalignment of Holes on the Coefficient of Friction and Efficiency of Bolted Joints**
Source	**M.Sc. Thesis, University of Washington, Seattle**
Year	**1958**
Ref. in Bolt Guide	**12.7**

Faying Surface

Specimens P, ZU, ZX, X5 and X6
red lead (dry assemble)
Specimens X7 and X8
red lead (wet assemble)
Specimens X1, X2 and X15
red lead with subsequent fire cleaning and wire brushing
Specimens X3, X4, X13 and X14
red lead with subsequent sand blasting
Specimen X9
mill scale removed by fire cleaning and wire brushing
Specimen X10
mill scale removed by sand blasting
Specimens X11 and X12

red lead (dry) plus 2nd coat of red lead (wet assemble)

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
P-16	A325	3/4	1/16	3	4	12	2	200	—	0.073	A7	Unclassified
P-30	A325	3/4	1/16	3	4	12	2	200	—	0.073	A7	"
ZU1	A325	7/8	1/16	4	1	4	2	89	—	0.077	A7	"
ZU2	A325	7/8	1/16	4	1	4	2	89	—	0.077	A7	"
ZX1	A325	7/8	1/16	4	1	4	2	89	—	0.077	A7	"
ZX2	A325	7/8	1/16	4	1	4	2	89	—	0.077	A7	"
X1	A325	1	1/16	2	2	4	2	467	—	0.219	A7	"
X2	A325	1	1/16	2	2	4	2	489	—	0.229	A7	"
X3	A325	1	1/16	2	2	4	2	890	—	0.417	A7	"
X4	A325	1	1/16	2	2	4	2	890	—	0.417	A7	"
X5	A325	1	1/16	2	2	4	2	133	—	0.063	A7	"
X6	A325	1	1/16	2	2	4	2	222	—	0.064	A7	"
X7	A325	1	1/16	2	2	4	2	689	—	0.323	A7	"
X8	A325	1	1/16	2	2	4	2	623	—	0.292	A7	"
X9	A325	1	1/16	2	2	4	2	912	—	0.428	A7	B
X10	A325	1	1/16	2	2	4	2	956	—	0.448	A7	B
X11	A325	1	1/16	2	2	4	2	200	—	0.094	A7	Unclassified
X12	A325	1	1/16	2	2	4	2	231	—	0.108	A7	"
X13	A325	1	1/16	2	2	4	2	814	—	0.381	A7	"
X14	A325	1	1/16	2	2	4	2	814	—	0.381	A7	"
X15	A325	1	1/16	2	2	4	2	445	—	0.208	A7	"
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Note: Some of the bolt holes were intentionally misaligned, but no significant effect on slip was observed

Author(s)	**Hojarczyk, S.; Kasinski, J.; Nawrot, T.**
Title	**Load Slip Characteristics of High Strength Bolted Structural Joints Protected from Corrosion by Various Sprayed Coatings**
Source	**Proceedings, Jubilee Symposium on High Strength Bolts, London, pp. 61-66**
Year	**1959**
Ref. in Bolt Guide	**5.37**

Faying Surface *Specimens 1 - 3 and 19 - 21*
mill scale (wire-brushed and cleaned)
Specimens 4 - 6
red lead paint (one coat) on mill scale surfaces
Specimen 7-9
zinc sprayed (0.20 mm) on sandblasted surfaces
Specimens 10 - 12
aluminium sprayed (0.25 mm) on sandblasted surfaces
Specimens 13 - 15
Chrome nickel sprayed (0.50 mm) on sandblasted surfaces
Specimens 16 - 18 and 22 - 24
sandblasted

Specimen	Bolt Type	ϕ_B [mm]	HC [mm]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
7	35SG	22	4	1	2	2	2	172	602	0.285	St 37	Unclassified
8	35SG	22	4	1	2	2	2	270	602	0.448	St 37	"
9	35SG	22	4	1	2	2	2	275	602	0.456	St 37	"
10	35SG	22	4	1	2	2	2	216	602	0.358	St 37	"
11	35SG	22	4	1	2	2	2	211	602	0.350	St 37	"
12	35SG	22	4	1	2	2	2	250	602	0.415	St 37	"
13	35SG	22	4	1	2	2	2	235	602	0.391	St 37	"
14	35SG	22	4	1	2	2	2	265	602	0.440	St 37	"
15	35SG	22	4	1	2	2	2	240	602	0.399	St 37	"
19	35SG	22	4	1	2	2	2	103	602	0.171	St 37	A
20	35SG	22	4	1	2	2	2	177	602	0.293	St 37	A
21	35SG	22	4	1	2	2	2	206	602	0.342	St 37	A
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Note: 35SG bolts: f_y = 720 MPa, f_u = 810 MPa
St 37 plates: f_y = 250 MPa, f_u = 360 MPa
Specimens 1 - 3 not pretensioned
Specimens 4 - 6, 16 - 18 and 22 - 24 did not show clear slip

Author(s) **Steinhardt, O.; Möhler, K.**
Title **Versuche zur Anwendung vorgespannter Schrauben im Stahlbau, II. Teil**
Source **Deutscher Ausschuss für Stahlbau, Stahlbau Verlag, Cologne, Germany**
Year **1959**
Ref. in Bolt Guide **5.5**

Faying Surface *Specimens A1 - A3*
mill scale cleaned with wire brush
Specimens A4 - A15, B1 - B3, C, D1, D3, D4, F, G, J
flame-blasted (single pass longitudinally)
Specimens B4 - B6
flame-blasted (double pass longitudinally)
Specimens B7 - B9
flame-blasted (single pass at angle (45°))
Specimens D2, D5
flame-blasted (main plates), sand-blasted (lap plates)
Specimens E
sand-blasted
Specimens H
hot-dip galvanized

Specimen	Bolt Type	ϕ_B [mm]	HC [mm]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
A1a	10K	16	1	1	2	2	2	121	311	0.388	St 52	A
A1b	10K	16	1	1	2	2	2	119	311	0.381	St 52	A
A2a	10K	16	1	1	2	2	2	139	311	0.448	St 52	A
A2b	10K	16	1	1	2	2	2	121	311	0.388	St 52	A
A3a	10K	16	1	1	2	2	2	145	311	0.467	St 52	A
A3b	10K	16	1	1	2	2	2	139	311	0.448	St 52	A
A4a	10K	16	1	1	2	2	2	189	311	0.608	St 52	B
A4b	10K	16	1	1	2	2	2	191	311	0.615	St 52	B
A5a	10K	16	1	1	2	2	2	211	311	0.678	St 52	B
A5b	10K	16	1	1	2	2	2	206	311	0.662	St 52	B
A6a	10K	16	1	1	2	2	2	199	311	0.640	St 52	B
A6b	10K	16	1	1	2	2	2	198	311	0.637	St 52	B
A7a	10K	22	1	1	2	2	2	441	609	0.725	St 52	B
A7b	10K	22	1	1	2	2	2	432	609	0.709	St 52	B
A8a	10K	22	1	1	2	2	2	461	609	0.757	St 52	B
A8b	10K	22	1	1	2	2	2	471	609	0.773	St 52	B
A9a	10K	22	1	1	2	2	2	427	609	0.701	St 52	B
A9b	10K	22	1	1	2	2	2	420	609	0.689	St 52	B
A10a	10K	22	1	1	2	2	2	476	609	0.781	St 52	B
A10b	10K	22	1	1	2	2	2	471	609	0.773	St 52	B
A11a	10K	22	1	1	2	2	2	471	609	0.773	St 52	B
A11b	10K	22	1	1	2	2	2	491	609	0.805	St 52	B
A12a	10K	22	1	1	2	2	2	441	609	0.725	St 52	B
A12b	10K	22	1	1	2	2	2	476	609	0.781	St 52	B
A13a	10K	22	1	1	2	2	2	452	609	0.743	St 52	B
A13b	10K	22	1	1	2	2	2	477	609	0.783	St 52	B
A14a	10K	22	1	1	2	2	2	441	609	0.725	St 52	B
A14b	10K	22	1	1	2	2	2	481	609	0.789	St 52	B
A15a	10K	22	1	1	2	2	2	525	727	0.722	St 52	B
A15b	10K	22	1	1	2	2	2	530	727	0.729	St 52	B
B1a	8G	16	1	1	2	2	2	189	311	0.608	St 52	B

Specimen	Bolt Type	ϕ_B [mm]	HC [mm]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
B1b	8G	16	1	1	2	2	2	191	311	0.615	St 52	B
B2a	8G	16	1	1	2	2	2	211	311	0.678	St 52	B
B2b	8G	16	1	1	2	2	2	206	311	0.662	St 52	B
B3a	8G	16	1	1	2	2	2	199	311	0.640	St 52	B
B3b	8G	16	1	1	2	2	2	198	311	0.637	St 52	B
B4a	8G	16	1	1	2	2	2	252	311	0.810	St 52	B
B4b	8G	16	1	1	2	2	2	258	311	0.829	St 52	B
B5a	8G	16	1	1	2	2	2	244	311	0.785	St 52	B
B5b	8G	16	1	1	2	2	2	250	311	0.804	St 52	B
B6a	8G	16	1	1	2	2	2	253	311	0.813	St 52	B
B6b	8G	16	1	1	2	2	2	265	311	0.851	St 52	B
B7a	8G	16	1	1	2	2	2	243	311	0.782	St 52	B
B7b	8G	16	1	1	2	2	2	260	311	0.835	St 52	B
B8a	8G	16	1	1	2	2	2	249	311	0.801	St 52	B
B8b	8G	16	1	1	2	2	2	259	311	0.832	St 52	B
B9a	8G	16	1	1	2	2	2	244	311	0.785	St 52	B
B9b	8G	16	1	1	2	2	2	265	311	0.851	St 52	B
C11a	10K	16	1	1	3	3	2	291	487	0.598	St 37/52	B
C11b	10K	16	1	1	3	3	2	329	487	0.674	St 37/52	B
C12a	10K	16	1	1	3	3	2	279	487	0.572	St 37/52	B
C12b	10K	16	1	1	3	3	2	306	487	0.628	St 37/52	B
C21a	10K	16	1	2 + 1		3	2	283	487	0.580	St 37/52	B
C21b	10K	16	1	2 + 1		3	2	347	487	0.713	St 37/52	B
C22a	10K	16	1	2 + 1		3	2	240	487	0.493	St 37/52	B
C22b	10K	16	1	2 + 1		3	2	257	487	0.527	St 37/52	B
C23a	10K	16	1	2 + 1		3	2	226	487	0.463	St 37/52	B
C23b	10K	16	1	2 + 1		3	2	280	487	0.574	St 37/52	B
C31a	10K	16	1	3	1	3	2	292	487	0.600	St 37/52	B
C31b	10K	16	1	3	1	3	2	299	487	0.614	St 37/52	B
C32a	10K	16	1	3	1	3	2	250	487	0.513	St 37/52	B
C32b	10K	16	1	3	1	3	2	292	487	0.600	St 37/52	B
D11a	10K	16	1	1	2	2	2	162	325	0.498	St 37	B
D11b	10K	16	1	1	2	2	2	175	325	0.537	St 37	B
D12a	10K	16	1	1	2	2	2	172	325	0.528	St 37	B
D12b	10K	16	1	1	2	2	2	172	325	0.528	St 37	B
D13a	10K	16	1	1	2	2	2	162	325	0.498	St 37	B
D13b	10K	16	1	1	2	2	2	162	325	0.498	St 37	B
D21a	10K	16	1	1	2	2	2	172	325	0.528	St 37	B
D21b	10K	16	1	1	2	2	2	172	325	0.528	St 37	B
D22a	10K	16	1	1	2	2	2	193	325	0.595	St 37	B
D22b	10K	16	1	1	2	2	2	193	325	0.595	St 37	B
D23a	10K	16	1	1	2	2	2	162	325	0.498	St 37	B
D23b	10K	16	1	1	2	2	2	162	325	0.498	St 37	B
D31a	10K	16	1	1	2	2	2	174	325	0.534	St 37	B
D31b	10K	16	1	1	2	2	2	191	325	0.589	St 37	B
D32a	10K	16	1	1	2	2	2	185	325	0.571	St 37	B
D32b	10K	16	1	1	2	2	2	196	325	0.604	St 37	B
D33a	10K	16	1	1	2	2	2	193	325	0.595	St 37	B
D33b	10K	16	1	1	2	2	2	209	325	0.643	St 37	B
D41a	10K	16	1	1	2	2	2	162	325	0.498	St 37	B
D41b	10K	16	1	1	2	2	2	177	325	0.543	St 37	B
D42a	10K	16	1	1	2	2	2	174	325	0.534	St 37	B
D42b	10K	16	1	1	2	2	2	169	325	0.519	St 37	B

Specimen	Bolt Type	ϕ_B [mm]	HC [mm]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
D43a	10K	16	1	1	2	2	2	174	325	0.534	St 37	B
D43b	10K	16	1	1	2	2	2	171	325	0.525	St 37	B
D51a	10K	16	1	1	2	2	2	162	325	0.498	St 37	B
D51b	10K	16	1	1	2	2	2	177	325	0.543	St 37	B
D52a	10K	16	1	1	2	2	2	179	325	0.550	St 37	B
D52b	10K	16	1	1	2	2	2	179	325	0.550	St 37	B
D53a	10K	16	1	1	2	2	2	178	325	0.546	St 37	B
D53b	10K	16	1	1	2	2	2	192	325	0.592	St 37	B
E7a	10K	20	1	1	3	3	2	340	753	0.452	St 48	B
E7b	10K	20	1	1	3	3	2	358	753	0.475	St 48	B
E8a	10K	20	1	1	3	3	2	361	753	0.479	St 48	B
E8b	10K	20	1	1	3	3	2	368	753	0.488	St 48	B
E9a	10K	20	1	1	3	3	2	447	753	0.594	St 52	B
E9b	10K	20	1	1	3	3	2	456	753	0.605	St 52	B
E10a	10K	20	1	1	3	3	2	440	753	0.585	St 52	B
E10b	10K	20	1	1	3	3	2	451	753	0.599	St 52	B
F1a	8G	16	1	1	2	2	1	99	156	0.637	St 37	B
F1b	8G	16	1	1	2	2	1	108	156	0.694	St 37	B
F2a	8G	16	1	1	2	2	1	85	156	0.549	St 37	B
F2b	8G	16	1	1	2	2	1	88	156	0.567	St 37	B
F3a	8G	16	1	1	2	2	1	96	156	0.618	St 37	B
F3b	8G	16	1	1	2	2	1	98	156	0.631	St 37	B
F4a	8G	16	1	1	2	2	1	103	156	0.662	St 37	B
F4b	8G	16	1	1	2	2	1	112	156	0.719	St 37	B
F5a	8G	16	1	1	2	2	1	96	156	0.618	St 37	B
F5b	8G	16	1	1	2	2	1	103	156	0.662	St 37	B
F6a	8G	16	1	1	2	2	1	105	156	0.675	St 37	B
F6b	8G	16	1	1	2	2	1	108	156	0.694	St 37	B
G1a	?	16	1	5	2	10	2	1,000	1,556	0.642	?	B
G1b	?	16	1	5	2	10	2	1,280	1,556	0.823	?	B
G2a	?	16	1	2	5	10	2	1,046	1,556	0.672	?	B
G2b	?	16	1	2	5	10	2	1,158	1,556	0.744	?	B
G3a	?	16	1	1	2	2	2	220	311	0.706	?	B
G3b	?	16	1	1	2	2	2	231	311	0.741	?	B
H11a	10K	22	1	1	2	2	1	37	313	0.119	?	C
H11b	10K	22	1	1	2	2	1	47	313	0.150	?	C
H12a	10K	22	1	1	2	2	2	99	627	0.158	?	C
H12b	10K	22	1	1	2	2	2	120	627	0.191	?	C
H21a	10K	22	1	1	2	2	1	43	313	0.138	?	C
H21b	10K	22	1	1	2	2	1	45	313	0.144	?	C
H22a	10K	22	1	1	2	2	2	88	627	0.141	?	C
H22b	10K	22	1	1	2	2	2	106	627	0.169	?	C
J1aa	10K	16	1	1	3	3	2	245	482	0.509	St 37	B
J1ab	10K	16	1	1	3	3	2	301	482	0.625	St 37	B
J1ba	10K	16	1	1	3	3	2	269	482	0.558	St 37	B
J1bb	10K	16	1	1	3	3	2	279	482	0.578	St 37	B
J2aa	10K	16	1	1 + 2		3	2	270	482	0.560	St 37	B
J2ab	10K	16	1	1 + 2		3	2	270	482	0.560	St 37	B
J2ba	10K	16	1	1 + 2		3	2	263	482	0.545	St 37	B
J2bb	10K	16	1	1 + 2		3	2	263	482	0.545	St 37	B
J3aa	10K	16	1	3	1	3	2	251	482	0.521	St 37	B
J3ab	10K	16	1	3	1	3	2	251	482	0.521	St 37	B
J3ba	10K	16	1	3	1	3	2	262	482	0.543	St 37	B

Specimen	Bolt Type	ϕ_B [mm]	HC [mm]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
J3bb	10K	16	1	3	1	3	2	275	482	0.570	St 37	B
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Note: Pretension was determined by applied torque and not measured directly.

Author(s)	**van Douwen, A. A.; de Back, j.; Bouwman, L. P.**
Title	**Connections with H.S. Bolts - the Friction Factor under Influence of Different Tightening Methods of the Bolts and of Different Conditions of the Contact Surfaces**
Source	**Report No. 6-59-9-VB-3, Stevin Laboratory, Dep. of Civil Engineering, Technical University, Delft, the Netherlands**
Year	**1959**
Ref. in Bolt Guide	**5.4**

Faying Surface

Specimens x1 - x4 (where x stands for A through H)
flame-cleaned
Specimens x5 - x8 (where x stands for A through H) and K1 - N10
shot-blasted
Specimens x9 - x12 (where x stands for A through H)
untreated

Specimen	Bolt Type	ϕ_B [mm]	HC [mm]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
A1	10K	16	1	1	1	1	2	89	175	0.511	—	B?
A2	10K	16	1	1	1	1	2	89	186	0.479	—	B?
A3	A325	16	1	1	1	1	2	80	159	0.506	—	B?
A4	A325	16	1	1	1	1	2	94	163	0.578	—	B?
A5	10K	16	1	1	1	1	2	91	177	0.517	—	B
A6	10K	16	1	1	1	1	2	115	214	0.539	—	B
A7	A325	16	1	1	1	1	2	92	169	0.544	—	B
A8	A325	16	1	1	1	1	2	77	145	0.530	—	B
A9	10K	16	1	1	1	1	2	90	208	0.432	—	A
A10	10K	16	1	1	1	1	2	86	196	0.438	—	A
A11	A325	16	1	1	1	1	2	106	232	0.458	—	A
A12	A325	16	1	1	1	1	2	97	208	0.467	—	A
B1	10K	16	1	1	1	1	2	100	182	0.546	—	B?
B2	10K	16	1	1	1	1	2	103	194	0.530	—	B?
B3	A325	16	1	1	1	1	2	89	196	0.455	—	B?
B4	A325	16	1	1	1	1	2	86	188	0.458	—	B?
B5	10K	16	1	1	1	1	2	105	204	0.514	—	B
B6	10K	16	1	1	1	1	2	97	184	0.524	—	B
B7	A325	16	1	1	1	1	2	104	210	0.495	—	B
B8	A325	16	1	1	1	1	2	92	178	0.519	—	B
B9	10K	16	1	1	1	1	2	91	206	0.440	—	A
B10	10K	16	1	1	1	1	2	105	237	0.444	—	A
B11	A325	16	1	1	1	1	2	91	208	0.436	—	A
B12	A325	16	1	1	1	1	2	66	155	0.427	—	A
D1	10K	22	1	1	1	1	2	162	408	0.397	—	B?
D2	10K	22	1	1	1	1	2	146	357	0.409	—	B?
D3	A325	22	1	1	1	1	2	122	312	0.390	—	B?
D4	A325	22	1	1	1	1	2	114	308	0.369	—	B?
D5	10K	22	1	1	1	1	2	191	430	0.445	—	B
D6	10K	22	1	1	1	1	2	181	383	0.472	—	B
D7	A325	22	1	1	1	1	2	142	337	0.422	—	B
D8	A325	22	1	1	1	1	2	172	318	0.540	—	B
D9	10K	22	1	1	1	1	2	123	383	0.321	—	A
D10	10K	22	1	1	1	1	2	103	336	0.307	—	A
D11	A325	22	1	1	1	1	2	123	400	0.306	—	A
D12	A325	22	1	1	1	1	2	83	304	0.274	—	A
E1	10K	22	1	1	1	1	2	118	265	0.444	—	B?
E2	10K	22	1	1	1	1	2	200	498	0.402	—	B?
E3	A325	22	1	1	1	1	2	108	308	0.350	—	B?
E4	A325	22	1	1	1	1	2	176	538	0.327	—	B?
E5	10K	22	1	1	1	1	2	177	378	0.468	—	B

Specimen	Bolt Type	ϕ_B [mm]	HC [mm]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
E6	10K	22	1	1	1	1	2	226	465	0.485	—	B
E7	A325	22	1	1	1	1	2	185	368	0.504	—	B
E8	A325	22	1	1	1	1	2	210	445	0.471	—	B
E9	10K	22	1	1	1	1	2	93	316	0.295	—	A
E10	10K	22	1	1	1	1	2	123	392	0.313	—	A
E11	A325	22	1	1	1	1	2	93	339	0.275	—	A
E12	A325	22	1	1	1	1	2	113	397	0.284	—	A
G1	10K	16	1	3	1	3	2	201	522	0.385	—	B?
G2	10K	16	1	3	1	3	2	226	514	0.439	—	B?
G3	A325	16	1	3	1	3	2	167	510	0.327	—	B?
G4	A325	16	1	3	1	3	2	186	455	0.409	—	B?
G5	10K	16	1	3	1	3	2	245	475	0.517	—	B
G6	10K	16	1	3	1	3	2	240	520	0.462	—	B
G7	A325	16	1	3	1	3	2	231	491	0.470	—	B
G8	A325	16	1	3	1	3	2	211	563	0.375	—	B
G9	10K	16	1	3	1	3	2	167	485	0.344	—	A
G10	10K	16	1	3	1	3	2	147	494	0.298	—	A
G11	A325	16	1	3	1	3	2	181	613	0.296	—	A
G12	A325	16	1	3	1	3	2	201	651	0.309	—	A
H1	10K	16	1	3	1	3	2	172	416	0.413	—	B?
H2	10K	16	1	3	1	3	2	265	526	0.504	—	B?
H3	A325	16	1	3	1	3	2	201	655	0.307	—	B?
H4	A325	16	1	3	1	3	2	147	459	0.321	—	B?
H5	10K	16	1	3	1	3	2	270	604	0.446	—	B
H6	10K	16	1	3	1	3	2	289	581	0.498	—	B
H7	A325	16	1	3	1	3	2	250	614	0.407	—	B
H8	A325	16	1	3	1	3	2	231	591	0.390	—	B
H9	10K	16	1	3	1	3	2	211	591	0.357	—	A
H10	10K	16	1	3	1	3	2	264	702	0.376	—	A
H11	A325	16	1	3	1	3	2	162	645	0.251	—	A
H12	A325	16	1	3	1	3	2	181	583	0.311	—	A
K1	10K	16	1	3	1	3	2	81	182	0.446	—	B
K2	10K	16	1	1	1	1	2	90	208	0.434	—	B
K3	10K	16	1	1	1	1	2	80	190	0.423	—	B
K4	10K	16	1	1	1	1	2	73	228	0.319	—	B
K5	10K	16	1	1	1	1	2	90	206	0.436	—	B
K6	A325	16	1	1	1	1	2	67	200	0.333	—	B
K7	A325	16	1	1	1	1	2	55	149	0.368	—	B
K8	A325	16	1	1	1	1	2	67	163	0.413	—	B
K9	A325	16	1	1	1	1	2	56	153	0.369	—	B
K10	A325	16	1	1	1	1	2	56	155	0.361	—	B
L1	10K	16	1	1	1	1	2	129	194	0.662	—	B
L2	10K	16	1	1	1	1	2	109	226	0.485	—	B
L3	10K	16	1	1	1	1	2	110	198	0.554	—	B
L4	10K	16	1	1	1	1	2	126	163	0.771	—	B
L5	10K	16	1	1	1	1	2	107	175	0.612	—	B
L6	A325	16	1	1	1	1	2	115	212	0.542	—	B
L7	A325	16	1	1	1	1	2	107	173	0.619	—	B
L8	A325	16	1	1	1	1	2	90	159	0.568	—	B
L9	A325	16	1	1	1	1	2	81	165	0.494	—	B
L10	A325	16	1	1	1	1	2	98	180	0.546	—	B
M1	10K	16	1	1	3	3	2	231	534	0.432	—	B
M2	10K	16	1	1	3	3	2	284	540	0.527	—	B
M3	10K	16	1	1	3	3	2	280	491	0.570	—	B
M4	10K	16	1	1	3	3	2	299	583	0.513	—	B
M5	10K	16	1	1	3	3	2	368	567	0.649	—	B

Specimen	Bolt Type	ϕ_B [mm]	HC [mm]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
M6	A325	16	1	1	3	3	2	281	557	0.504	—	B
M7	A325	16	1	1	3	3	2	331	565	0.585	—	B
M8	A325	16	1	1	3	3	2	323	522	0.618	—	B
M9	A325	16	1	1	3	3	2	343	553	0.621	—	B
M10	A325	16	1	1	3	3	2	284	596	0.477	—	B
N1	10K	16	1	1	3	3	2	221	520	0.425	—	B
N2	10K	16	1	1	3	3	2	221	475	0.465	—	B
N3	10K	16	1	1	3	3	2	245	555	0.442	—	B
N4	10K	16	1	1	3	3	2	240	530	0.454	—	B
N5	10K	16	1	1	3	3	2	240	520	0.462	—	B
N6	A325	16	1	1	3	3	2	223	545	0.408	—	B
N7	A325	16	1	1	3	3	2	224	510	0.438	—	B
N8	A325	16	1	1	3	3	2	220	512	0.429	—	B
N9	A325	16	1	1	3	3	2	202	492	0.410	—	B
N10	A325	16	1	1	3	3	2	191	532	0.360	—	B
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Note Testing of specimens K1 - N10 was carried out with the two main plates having slightly different thicknesses

Author(s) **Johnson, L. G.; Cannon, J. C.; Spooner, L. A.**
Title **High-Tensile Preloaded Bolted Joints for Development of Full Plastic Moments**
Source **British Welding Journal, Vol, 7, No. 9, pp. 560 - 569**
Year **1960**
Ref. in Bolt Guide **—**

Faying Surface *Dirt, grease, rust, and mill scale removed by cleaning and wire brushing*

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
2	A325	3/4	1/16	2	3	6	1	371	756	0.49	A36	B?
6	A325	3/4	1/16	2	4	8	1	523	1164	0.49	A7	B?
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Author(s) **Foreman, R. T.; Rumpf, J. L.**
Title **Static Tension Tests of Compact Bolted Joints**
Source **Transactions ASCE, Vol. 126, Part 2, pp. 228 - 254**
Year **1961**
Ref. in Bolt Guide **4.5**

Faying Surface *mill scale (degreased)*

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
B1	A325	7/8	1/16	5	6	30	2	5,507	12,908	0.427	A7	A
B2	A325	7/8	1/16	5	5	25	2	4,657	10,773	0.432	A7	A
B3	A325	7/8	1/16	5	4	20	2	4,052	8,629	0.470	A7	A
B4	A325	7/8	1/16	5	5	23	2	3,781	9,688	0.390	A7	A
B5	A325	7/8	1/16	5	5	20	2	2,709	8,442	0.321	A7	A
B6	A325	7/8	1/16	6	3	18	2	2,994	7,579	0.395	A7	A
A3	A325	1	1/16	4	4	16	2	3,750	8,611	0.435	A7	A
G1	A325	1-1/8	1/16	4	3	12	2	4,092	8,327	0.491	A7	A
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Note: Specimen B4: no bolts in slots r3/l2, r3/l4 *r = row*
Specimen B5: no bolts in slots r2/l2, r2/l4, r3/l3, r4/l2, r4/l4 *l = line*

Author(s)	**Bendigo, R. A.; Hansen, R. M.; Rumpf, J. L.**
Title	**Long Bolted Joints**
Source	**Journal of the Structural Division, Vol. 89, ST 6, pp. 187-213**
Year	**1963**
Ref. in Bolt Guide	**4.6**

Faying Surface *Specimens D31 - D101 and L2 - L10*
semi-polished (mill scale removed with power tool)
Specimens D701 - D1001 and D10 - D16
mill scale (wire brushed, oil and grease removed)

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
D31	A325	7/8	1/16	2	3	6	2	783	2,615	0.299	A7	A
D41	A325	7/8	1/16	2	4	8	2	1,041	3,516	0.296	A7	A
D51	A325	7/8	1/16	2	5	10	2	1,548	4,439	0.349	A7	A
D61	A325	7/8	1/16	2	6	12	2	1,503	5,316	0.283	A7	A
D71	A325	7/8	1/16	2	7	14	2	1,592	6,202	0.257	A7	A
D81	A325	7/8	1/16	2	8	16	2	2,491	7,117	0.350	A7	A
D91	A325	7/8	1/16	2	9	18	2	1,801	8,070	0.223	A7	A
D101	A325	7/8	1/16	2	10	20	2	2,526	8,985	0.281	A7	A
D701	A325	7/8	1/16	2	7	14	2	3,203	5,667	0.565	A7	A
D801	A325	7/8	1/16	2	8	16	2	2,713	6,832	0.397	A7	A
D901	A325	7/8	1/16	2	9	18	2	3,848	7,446	0.517	A7	A
D1001	A325	7/8	1/16	2	10	20	2	4,492	8,629	0.521	A7	A
D10	A325	7/8	1/16	2	10	20	2	4,003	8,149	0.491	A7	A
D13A	A325	7/8	1/16	2	13	26	2	3,523	10,478	0.336	A7	A
D13	A325	7/8	1/16	2	13	26	2	4,270	10,616	0.402	A7	A
D16	A325	7/8	1/16	2	16	32	2	5,524	12,810	0.431	A7	A
L2	A325	7/8	1/16	2	2	4	1	276	865	0.319	A7	A
L5	A325	7/8	1/16	2	5	10	1	476	2,153	0.221	A7	A
L7	A325	7/8	1/16	2	7	14	1	867	3,033	0.286	A7	A
L10	A325	7/8	1/16	2	10	20	1	1,557	4,323	0.360	A7	A
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Note: Specimens 48 - 50 had red lead painted faying surfaces (wire brushed, cleaned mill scale)
Specimens 51 - 53 had varnished faying surfaces (wire brushed, cleaned mill scale)
All these specimens (48 - 53) slipped from the start of loading

Author(s)	**Fisher, J. W.; Ramseier, P. O.; Beedle, L. S.**
Title	**Strength of A440 Steel Joints Fastened with A325 Bolts**
Source	**Publications IABSE, Vol. 23, pp. 135-158**
Year	**1963**
Ref. in Bolt Guide	**4.7**

Faying Surface *mill scale (wire brushed, oil and grease removed)*

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
E41a	A325	7/8	1/16	2	4	8	2	1,165	3,637	0.320	A440	A
E41b	A325	7/8	1/16	2	4	8	2	881	3,644	0.242	A440	A
E41c	A325	7/8	1/16	2	4	8	2	1,156	3,580	0.323	A440	A
E41e	A325	7/8	1/16	2	4	8	2	1,254	3,672	0.342	A440	A
E41f	A325	7/8	1/16	2	4	8	2	1,201	3,437	0.349	A440	A
E41g	A325	7/8	1/16	2	4	8	2	1,254	3,644	0.344	A440	A
E41	A325	7/8	1/16	2	4	8	2	1,112	3,459	0.322	A440	A
E71	A325	7/8	1/16	2	7	14	2	1,779	6,015	0.296	A440	A
E101	A325	7/8	1/16	2	10	20	2	2,731	8,700	0.314	A440	A
E131	A325	7/8	1/16	2	13	26	2	3,665	11,125	0.329	A440	A
E161	A325	7/8	1/16	2	16	32	2	4,573	13,721	0.333	A440	A
E46	A325	7/8	1/16	6	4	24	2	3,550	10,440	0.340	A440	A
E74	A325	7/8	1/16	4	7	28	2	4,057	12,106	0.335	A440	A
E741	A325	7/8	1/16	4	7	28	2	3,025	12,031	0.251	A440	A
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Note: Nester (1966) reported four additional results from this ref.: E721 μ=0.28, E163 μ=0.27, E722 μ=0.24, E164 μ=0.29.

Author(s) **Chesson, E.; Munse, W. H.**
Title **Studies of the Behavior of High-Strength Bolts and Bolted Joints**
Source **University of Illinois Bulletin 469, Vol. 62, No. 26, October**
Year **1964**
Ref. in Bolt Guide **4.9**

Faying Surface *as-rolled (mill scale), loose mat. Removed, degreased*

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
5	A325	3/4	1/16	2	2	4	2	—	—	0.320	A7	A
6	A325	3/4	1/16	2	2	4	2	—	—	0.350	A7	A
7	A325	3/4	1/8	2	2	4	2	—	—	0.280	A7	A
8	A325	3/4	1/16	2	2	4	2	—	—	0.200	A7	A
9	A325	1	1/16	2	2	4	2	—	—	0.240	A7	A
A2	A325	3/4	1/8	2	2	4	2	—	—	0.250	A7	A
A3	A325	3/4	1/8	2	2	4	2	—	—	0.280	A7	A
B1	A325	3/4	1/8	2	2	4	2	—	—	0.240	A7	A
B2	A325	3/4	1/8	2	2	4	2	—	—	0.260	A7	A
B3	A325	3/4	1/8	2	2	4	2	—	—	0.230	A7	A
C1	A325	5/8	1/16	2	2	4	2	—	—	0.200	A7	A
D1	A325	3/4	1/8	2	2	4	2	—	—	0.230	A7	A
D2	A325	3/4	1/8	2	2	4	2	—	—	0.100	A7	A
D3	A325	3/4	1/8	2	2	4	2	—	—	0.180	A7	A

		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Note: All specimens were fatigue tested with the first cycle slip being measured

Author(s) **Chen, C.-C.; Vasarhelyi, D. D.**
Title **Bolted Joints with Main Plates of Different Thicknesses**
Source **Report, Department of Civil Engineering, University of Washington**
Year **1965**
Ref. in Bolt Guide **5.14**

Faying Surface *All specimens with original mill scale*

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
A-1	A325	3/4	1/16	3	3	9	2	623	2,322	0.268	A7	A
A-2	A325	3/4	1/16	3	3	9	2	623	2,322	0.268	A7	A
A-3	A325	3/4	1/16	3	4	12	2	1,023	3,096	0.330	A7	A
A-4	A325	3/4	1/16	3	3	9	2	667	2,322	0.287	A7	A
A-5	A325	3/4	1/16	3	4	12	2	1,023	3,096	0.330	A7	A
A-6	A325	3/4	1/16	3	4	12	2	1,156	3,309	0.349	A7	A
A-7	A325	3/4	1/16	3	5	15	2	1,290	3,870	0.333	A7	A
A-8	A325	3/4	1/16	3	5	15	2	1,379	4,083	0.338	A7	A
A-9	A325	3/4	1/16	3	5	15	2	1,512	4,297	0.352	A7	A
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Note: 18 more tests were conducted with thinner main plates (one side) to simulate not quite perfect fabrication conditions (Specimens B and C). These test results are shown below.

In the paper (J of Str Div, Vol. 93, ST 6, 1967) to the report, the "normal" clamping force was reported as 25 kips/bolt, instead of the 29 kips/bolt reported here => higher friction coeff. are obtained with data from paper.

B-1	A325	3/4	1/16	3	3	9	2	618	2,322	0.266	A7	A
B-2	A325	3/4	1/16	3	3	9	2	623	2,322	0.268	A7	A
B-3	A325	3/4	1/16	3	4	12	2	1,045	3,096	0.338	A7	A
B-4	A325	3/4	1/16	3	3	9	2	556	2,322	0.239	A7	A
B-5	A325	3/4	1/16	3	4	12	2	890	3,096	0.287	A7	A
B-6	A325	3/4	1/16	3	4	12	2	979	3,309	0.296	A7	A
B-7	A325	3/4	1/16	3	5	15	2	1,183	3,870	0.306	A7	A
B-8	A325	3/4	1/16	3	5	15	2	1,263	4,083	0.309	A7	A
B-9	A325	3/4	1/16	3	5	15	2	1,419	4,297	0.330	A7	A
C-1	A325	3/4	1/16	3	3	9	2	623	2,322	0.268	A7	A
C-2	A325	3/4	1/16	3	3	9	2	623	2,322	0.268	A7	A
C-3	A325	3/4	1/16	3	4	12	2	934	3,096	0.302	A7	A
C-4	A325	3/4	1/16	3	3	9	2	480	2,322	0.207	A7	A
C-5	A325	3/4	1/16	3	4	12	2	756	3,096	0.244	A7	A
C-6	A325	3/4	1/16	3	4	12	2	845	3,309	0.255	A7	A
C-7	A325	3/4	1/16	3	5	15	2	979	3,870	0.253	A7	A
C-8	A325	3/4	1/16	3	5	15	2	1,156	4,083	0.283	A7	A
C-9	A325	3/4	1/16	3	5	15	2	1,334	4,297	0.311	A7	A

Author(s)	**Douty, R. T.; McGuire, W.**
Title	**High Strength Bolted Moment Connections**
Source	**Journal of the Structural Division, Vol. 91, pp. 101 - 128**
Year	**1965**
Ref. in Bolt Guide	**—**

Faying Surface *blast cleaned*

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
B10.1	A325	3/4	1/16	2	4	8	1	484	—	0.487	A7	B
B10.2	A325	3/4	1/16	2	4	8	1	596	—	0.599	A7	B
B10.3	A325	3/4	1/16	2	4	8	1	610	—	0.613	A7	B
B11	A325	3/4	1/16	2	3	6	1	396	—	0.659	A7	B
B13.1	A325	7/8	1/16	2	3	6	1	494	—	0.476	A7	B
B13.2	A490	7/8	1/16	2	3	6	1	546	—	0.527	A7	B
B13.3	A490	7/8	1/16	2	3	6	1	587	—	0.560	A7	B
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Note: Bending tests; no data on pretension loads; surface preparation and slip coefficients not in paper, but data found in Barakat et al. (1984) "Slip Resistance of High Strength Bolted Joints - Literature Review"

Author(s)	**Klöppel, K.; Seeger, T.**
Title	**Sicherheit und Bemessung von HV-Verbindungen aus St 37 und St 52 nach Versuchen unter Dauerbelastung und ruhender Belastung**
Source	**Institut für Statik und Stahlbau, Technische Hochschule Darmstadt**
Year	**1965**
Ref. in Bolt Guide	**5.18**

Faying Surface *All specimens, but Specimens II-9, II-10 and II-16*
sand-blasted (without and with exposure after sand-blasting)
Specimens II-9, II-10 and II-16
as-received, dry mill-scale

Specimen	Bolt Type	ϕ_B [mm]	HC [mm]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
I-37-1	10K	16	1	1	2	2	2	232	388	0.596	St 37	B
I-37-2	10K	16	1	1	2	2	2	271	388	0.697	St 37	B
I-37-3	10K	16	1	1	2	2	2	230	388	0.591	St 37	B
I-37-4	10K	16	1	1	2	2	2	245	388	0.631	St 37	B
I-37-5	10K	16	1	1	2	2	2	201	388	0.518	St 37	B
I-37-6	10K	16	1	1	2	2	2	215	388	0.553	St 37	B
I-52-1	10K	16	1	1	2	2	2	273	388	0.702	St 52	B
I-52-2	10K	16	1	1	2	2	2	274	388	0.705	St 52	B
I-52-3	10K	16	1	1	2	2	2	286	388	0.737	St 52	B
I-52-4	10K	16	1	1	2	2	2	279	388	0.717	St 52	B
I-52-5	10K	16	1	1	2	2	2	235	388	0.606	St 52	B
I-52-6	10K	16	1	1	2	2	2	249	388	0.641	St 52	B
II-1	10K	24	1	3	2	6	2	1,638	2,602	0.630	St 52	B
II-2	10K	24	1	3	2	6	2	1,668	2,602	0.641	St 52	B
II-3	10K	24	1	3	2	6	2	1,668	2,602	0.641	St 52	B
II-4	10K	24	1	3	2	6	2	1,275	2,602	0.490	St 52	B
II-5	10K	24	1	3	2	6	2	1,570	2,602	0.603	St 52	B
II-6	10K	24	1	3	2	6	2	1,364	2,602	0.524	St 52	B
II-7	10K	24	1	3	2	6	2	1,462	2,602	0.562	St 52	B
II-8	10K	24	1	3	2	6	2	1,638	2,602	0.630	St 52	B
II-9	10K	24	1	3	2	6	2	1,177	2,602	0.452	St 52	A
II-10	10K	24	1	3	2	6	2	1,216	2,602	0.468	St 52	A
II-11	10K	24	1	3	2	6	2	1,648	2,602	0.633	St 52	B
II-12	10K	24	1	3	2	6	2	1,599	2,602	0.615	St 52	B
II-13	10K	24	1	3	2	6	2	1,315	2,602	0.505	St 52	B
II-14	10K	24	1	3	2	6	2	1,447	2,602	0.556	St 52	B
II-16	10K	24	1	3	2	6	2	1,001	2,602	0.385	St 52	A
III-1	10K	12	1	1	2	2	2	114	204	0.558	St 37	B
III-2	10K	12	1	1	2	2	2	116	204	0.567	St 37	B
III-3	10K	12	1	1	2	2	2	118	204	0.577	St 37	B
III-4	10K	12	5	1	2	2	2	115	204	0.563	St 37	B
III-5	10K	12	5	1	2	2	2	108	204	0.529	St 37	B
III-6	10K	12	5	1	2	2	2	104	204	0.510	St 37	B
IV-1	10K	16	1	1	2	2	2	174	388	0.447	St 37	B
IV-2	10K	16	1	1	2	2	2	174	388	0.447	St 37	B
IV-3	10K	16	1	1	2	2	2	178	388	0.457	St 37	B
IV-4	10K	16	5	1	2	2	2	173	388	0.444	St 37	B
IV-5	10K	16	5	1	2	2	2	177	388	0.455	St 37	B
IV-6	10K	16	5	1	2	2	2	170	388	0.437	St 37	B
V-1	10K	24	1	1	2	2	2	526	867	0.606	St 37	B
V-2	10K	24	1	1	2	2	2	490	867	0.564	St 37	B

Specimen	Bolt Type	ϕ_B [mm]	HC [mm]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
V-3	10K	24	5	1	2	2	2	460	867	0.531	St 37	B
V-4	10K	24	5	1	2	2	2	422	867	0.486	St 37	B
V-5	10K	24	5	1	2	2	2	461	867	0.532	St 37	B
V-6	10K	24	5	1	2	2	2	504	867	0.581	St 37	B
VI-1	10K	27	1	1	1	1	2	270	573	0.471	St 37	B
VI-2	10K	27	1	1	1	1	2	271	573	0.473	St 37	B
VI-3	10K	27	1	1	1	1	2	263	573	0.459	St 37	B
VI-4	10K	27	5	1	1	1	2	250	573	0.437	St 37	B
VI-5	10K	27	5	1	1	1	2	259	573	0.452	St 37	B
VI-6	10K	27	5	1	1	1	2	258	573	0.450	St 37	B
VII-1	10K	12	1	1	6	6	2	336	612	0.548	St 37	B
VII-2	10K	12	5	1	6	6	2	293	612	0.479	St 37	B
VII-3	10K	12	5	1	6	6	2	299	612	0.489	St 37	B
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Note: Pretension in Specimens I and II was determined by applied torque and not measured directly.
Specimen II-15 showed gradual slip

Author(s) **Prynne, P.**
Title **Fundamental of Use of High Strength Bolts in Structural Connections**
Source **Civil Engineering and Public Works Review, Vol. 60, No. 704/705, pp. 375-383/542-545**
Year **1965**
Ref. in Bolt Guide **—**

Faying Surface Specimens 101 - 603
"standard" (see note at bottom)
Specimens 604 - 607
as received (cleaned mill scale?)

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
101	Not stated	7/8	1/8	1	1	1	1	49	149	0.329	Mild Steel	A
102	"	7/8	1/8	1	1	1	1	47	154	0.303	Mild Steel	A
103	"	7/8	1/8	1	1	1	1	44	151	0.289	Mild Steel	A
104	"	7/8	1/8	1	1	1	1	45	143	0.315	Mild Steel	A
201	"	7/8	1/8	1	1	1	1	109	136	0.801	Mild Steel	A
202	"	7/8	1/8	1	1	1	1	74	140	0.529	Mild Steel	A
203	"	7/8	1/8	1	1	1	1	79	143	0.552	Mild Steel	A
204	"	7/8	1/8	1	1	1	1	44	141	0.312	Mild Steel	A
205	"	7/8	1/8	1	1	1	1	56	145	0.386	Mild Steel	A
206	"	7/8	1/8	1	1	1	1	91	139	0.655	Mild Steel	A
207	"	7/8	1/8	1	1	1	1	48	141	0.340	Mild Steel	A
208	"	7/8	1/8	1	1	1	1	60	128	0.469	Mild Steel	A
301	"	7/8	1/8	2	1	2	1	119	267	0.444	Mild Steel	A
302	"	7/8	1/8	2	1	2	1	125	271	0.460	Mild Steel	A
303	"	7/8	1/8	2	1	2	1	122	259	0.469	Mild Steel	A
304	"	7/8	1/8	2	1	2	1	118	261	0.450	Mild Steel	A
305	"	7/8	1/8	2	1	2	1	114	269	0.422	Mild Steel	A
306	"	7/8	1/8	2	1	2	1	118	255	0.461	Mild Steel	A
307	"	7/8	1/8	2	1	2	1	98	271	0.360	Mild Steel	A
308	"	7/8	1/8	2	1	2	1	125	269	0.463	Mild Steel	A
309	"	7/8	1/8	2	1	2	1	129	263	0.489	Mild Steel	A
310	"	7/8	1/8	2	1	2	1	118	263	0.447	Mild Steel	A
401	"	7/8	1/8	2	1	2	1	123	273	0.449	Mild Steel	A
402	"	7/8	1/8	2	1	2	1	121	261	0.462	Mild Steel	A
403	"	7/8	1/8	2	1	2	1	120	271	0.441	Mild Steel	A
404	"	7/8	1/8	2	1	2	1	118	279	0.421	Mild Steel	A
501	"	7/8	1/8	1	1	1	2	95	277	0.342	Mild Steel	A
502	"	7/8	1/8	1	1	1	2	84	263	0.318	Mild Steel	A
503	"	7/8	1/8	1	1	1	2	68	255	0.266	Mild Steel	A
504	"	7/8	1/8	1	1	1	2	95	273	0.347	Mild Steel	A
505	"	7/8	1/8	1	1	1	2	88	269	0.326	Mild Steel	A
506	"	7/8	1/8	1	1	1	2	102	269	0.378	Mild Steel	A
601	"	7/8	1/8	2	1	2	2	207	518	0.400	Mild Steel	A
602	"	7/8	1/8	2	1	2	2	238	538	0.443	Mild Steel	A
603	"	7/8	1/8	2	1	2	2	197	502	0.393	Mild Steel	A
604	???	7/8	1/8	2	1	2	2	231	494	0.468	Mild Steel	A
605	???	7/8	1/8	2	1	2	2	253	478	0.529	Mild Steel	A
606	???	7/8	1/8	2	1	2	2	238	510	0.467	Mild Steel	A
607	???	7/8	1/8	2	1	2	2	239	510	0.469	Mild Steel	A
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Note: The "standard" surface "was obtained by traversing the width of the joint plate with a sharp nosed cutting tool, maintaining a constant cutting speed, cross traverse and depth of cut. This surface was chosen ... because its CLA value of roughness, …, was not far removed from that of 'as received' plates." (p. 543)

Author(s) **Brookhart, G. C.; Siddiqi, I. H.; Vasarhelyi, D. D.**
Title **The Effect of Galvanizing and Other Surface Treatments of High Tensile Bolts and Bolted Joints**
Source **Dep. of Civil Eng., University of Washington, Seattle**
Year **1966**
Ref. in Bolt Guide **5.9**

Faying Surface

Specimens 1 and 2 — *Galvanized (hot-dip)*
Specimens 3 — *Zinc painted*

Specimens 4 — *Metallized (hot sprayed)*
Specimens 5 — *Mill scale*

Specimens 6 and 7 — *Vinyl (2 types)*
Specimens 8 — *Rust ban*

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
1A1	A325	1	1/16	2	2	4	2	320	1,551	0.206	Not stated	C
1A2	A325	1	1/16	2	2	4	2	334	1,551	0.215	"	C
1A3	A325	1	1/16	2	2	4	2	405	1,551	0.261	"	C
1A4	A325	1	1/16	2	2	4	2	378	1,551	0.244	"	C
1C1	A325	1	1/16	2	2	4	4	365	1,551	0.235	"	C
1C2	A325	1	1/16	2	2	4	4	365	1,551	0.235	"	C
1C3	A325	1	1/16	2	2	4	4	391	1,551	0.252	"	C
2A1	A325	1	1/16	2	2	4	2	267	1,320	0.202	"	C
2A2	A325	1	1/16	2	2	4	2	254	1,320	0.192	"	C
2A3	A325	1	1/16	2	2	4	2	311	1,320	0.236	"	C
3A1	A326	1	1/16	2	2	4	2	534	1,551	0.344	"	Unclassified
3A2	A327	1	1/16	2	2	4	2	467	1,551	0.301	"	"
3A3	A328	1	1/16	2	2	4	2	387	1,551	0.249	"	"
4A1	A329	1	1/16	2	2	4	2	271	1,551	0.175	"	"
4A2	A330	1	1/16	2	2	4	2	649	1,551	0.419	"	"
4A3	A331	1	1/16	2	2	4	2	810	1,551	0.522	"	"
5A1	A332	1	1/16	2	2	4	2	480	1,551	0.310	"	A
5A2	A333	1	1/16	2	2	4	2	356	1,551	0.229	"	A
5A3	A334	1	1/16	2	2	4	2	418	1,551	0.269	"	A
5C1	A335	1	1/16	2	2	4	4	467	1,551	0.301	"	A
5C2	A336	1	1/16	2	2	4	4	503	1,551	0.324	"	A
5C3	A337	1	1/16	2	2	4	4	494	1,551	0.318	"	A
6A1	A338	1	1/16	2	2	4	2	423	1,551	0.272	"	Unclassified
6A2	A339	1	1/16	2	2	4	2	434	1,551	0.280	"	"
6A3	A340	1	1/16	2	2	4	2	445	1,551	0.287	"	"
7A1	A341	1	1/16	2	2	4	2	434	1,551	0.280	"	"
7A2	A342	1	1/16	2	2	4	2	411	1,551	0.265	"	"
7A3	A343	1	1/16	2	2	4	2	407	1,551	0.262	"	"
8A1	A344	1	1/16	2	2	4	2	890	1,551	0.573	"	"
8A2	A345	1	1/16	2	2	4	2	471	776	0.608	"	"
8A3	A346	1	1/16	2	2	4	2	456	776	0.588	"	"
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Author(s) **Kuperus, A.**
Title **The Ratio between the Slip Factor of Fe 52 and Fe 37**
Source **Report No. 6-66-3-VB-13, Stevin Laboratory, Dep. of Civil Engineering,**
Technical University, Delft, the Netherlands
Year **1966**
Ref. in Bolt Guide **5.8**

Faying Surface *Specimens UT*
untreate (Rust removed with wire brush before assembly)
Specimens SB
shot-blasted

Specimen	Bolt Type	ϕ_B [mm]	HC [mm]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
UT-Fe37-0-1	10K	20	—	1	1	1	2	—	—	0.38	Fe37	A
UT-Fe37-0-2	10K	20	—	1	1	1	2	—	—	0.36	Fe37	A
UT-Fe37-0-3	10K	20	—	1	1	1	2	—	—	0.39	Fe37	A
UT-Fe37-0-4	10K	20	—	1	1	1	2	—	—	0.27	Fe37	A
UT-Fe37-5-1	10K	20	—	1	1	1	2	—	—	0.36	Fe37	A
UT-Fe37-5-2	10K	20	—	1	1	1	2	—	—	0.38	Fe37	A
UT-Fe37-5-3	10K	20	—	1	1	1	2	—	—	0.41	Fe37	A
UT-Fe37-5-4	10K	20	—	1	1	1	2	—	—	0.32	Fe37	A
UT-Fe37-14-1	10K	20	—	1	1	1	2	—	—	0.49	Fe37	A
UT-Fe37-14-2	10K	20	—	1	1	1	2	—	—	0.48	Fe37	A
UT-Fe37-14-3	10K	20	—	1	1	1	2	—	—	0.48	Fe37	A
UT-Fe37-14-4	10K	20	—	1	1	1	2	—	—	0.45	Fe37	A
UT-Fe37-60-1	10K	20	—	1	1	1	2	—	—	0.58	Fe37	A
UT-Fe37-60-2	10K	20	—	1	1	1	2	—	—	0.56	Fe37	A
UT-Fe37-60-3	10K	20	—	1	1	1	2	—	—	0.53	Fe37	A
UT-Fe37-60-4	10K	20	—	1	1	1	2	—	—	0.54	Fe37	A
UT-Fe52-0-1	10K	20	—	1	1	1	2	—	—	0.22	Fe52	A
UT-Fe52-0-2	10K	20	—	1	1	1	2	—	—	0.25	Fe52	A
UT-Fe52-0-3	10K	20	—	1	1	1	2	—	—	0.25	Fe52	A
UT-Fe52-0-4	10K	20	—	1	1	1	2	—	—	0.27	Fe52	A
UT-Fe52-5-1	10K	20	—	1	1	1	2	—	—	0.29	Fe52	A
UT-Fe52-5-2	10K	20	—	1	1	1	2	—	—	0.27	Fe52	A
UT-Fe52-5-3	10K	20	—	1	1	1	2	—	—	0.27	Fe52	A
UT-Fe52-5-4	10K	20	—	1	1	1	2	—	—	0.27	Fe52	A
UT-Fe52-14-1	10K	20	—	1	1	1	2	—	—	0.39	Fe52	A
UT-Fe52-14-2	10K	20	—	1	1	1	2	—	—	0.32	Fe52	A
UT-Fe52-14-3	10K	20	—	1	1	1	2	—	—	0.36	Fe52	A
UT-Fe52-14-4	10K	20	—	1	1	1	2	—	—	0.33	Fe52	A
UT-Fe52-60-1	10K	20	—	1	1	1	2	—	—	0.58	Fe52	A
UT-Fe52-60-2	10K	20	—	1	1	1	2	—	—	0.46	Fe52	A
UT-Fe52-60-3	10K	20	—	1	1	1	2	—	—	0.47	Fe52	A
UT-Fe52-60-4	10K	20	—	1	1	1	2	—	—	0.55	Fe52	A
SB-Fe37-0-1	10K	20	—	1	1	1	2	—	—	0.55	Fe37	B
SB-Fe37-0-2	10K	20	—	1	1	1	2	—	—	0.57	Fe37	B
SB-Fe37-0-3	10K	20	—	1	1	1	2	—	—	0.49	Fe37	B
SB-Fe37-0-4	10K	20	—	1	1	1	2	—	—	0.55	Fe37	B
SB-Fe37-0-5	10K	20	—	1	1	1	2	—	—	0.65	Fe37	B
SB-Fe37-0-6	10K	20	—	1	1	1	2	—	—	0.65	Fe37	B
SB-Fe37-0-7	10K	20	—	1	1	1	2	—	—	0.59	Fe37	B
SB-Fe37-0-8	10K	20	—	1	1	1	2	—	—	0.65	Fe37	B
SB-Fe37-0-9	10K	20	—	1	1	1	2	—	—	0.45	Fe37	B
SB-Fe37-0-10	10K	20	—	1	1	1	2	—	—	0.56	Fe37	B
SB-Fe37-0-11	10K	20	—	1	1	1	2	—	—	0.49	Fe37	B

Specimen	Bolt Type	ϕ_B [mm]	HC [mm]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
SB-Fe37-0-12	10K	20	—	1	1	1	2	—	—	0.51	Fe37	B
SB-Fe37-0-13	10K	20	—	1	1	1	2	—	—	0.51	Fe37	B
SB-Fe37-0-14	10K	20	—	1	1	1	2	—	—	0.52	Fe37	B
SB-Fe37-0-15	10K	20	—	1	1	1	2	—	—	0.52	Fe37	B
SB-Fe37-0-16	10K	20	—	1	1	1	2	—	—	0.53	Fe37	B
SB-Fe37-7-1	10K	20	—	1	1	1	2	—	—	0.46	Fe37	B
SB-Fe37-7-2	10K	20	—	1	1	1	2	—	—	0.53	Fe37	B
SB-Fe37-7-3	10K	20	—	1	1	1	2	—	—	0.51	Fe37	B
SB-Fe37-7-4	10K	20	—	1	1	1	2	—	—	0.44	Fe37	B
SB-Fe37-7-5	10K	20	—	1	1	1	2	—	—	0.55	Fe37	B
SB-Fe37-7-6	10K	20	—	1	1	1	2	—	—	0.56	Fe37	B
SB-Fe37-7-7	10K	20	—	1	1	1	2	—	—	0.53	Fe37	B
SB-Fe37-7-8	10K	20	—	1	1	1	2	—	—	0.58	Fe37	B
SB-Fe37-7-9	10K	20	—	1	1	1	2	—	—	0.42	Fe37	B
SB-Fe37-7-10	10K	20	—	1	1	1	2	—	—	0.51	Fe37	B
SB-Fe37-7-11	10K	20	—	1	1	1	2	—	—	0.49	Fe37	B
SB-Fe37-7-12	10K	20	—	1	1	1	2	—	—	0.43	Fe37	B
SB-Fe37-7-13	10K	20	—	1	1	1	2	—	—	0.55	Fe37	B
SB-Fe37-7-14	10K	20	—	1	1	1	2	—	—	0.55	Fe37	B
SB-Fe37-7-15	10K	20	—	1	1	1	2	—	—	0.50	Fe37	B
SB-Fe37-7-16	10K	20	—	1	1	1	2	—	—	0.55	Fe37	B
SB-Fe37-21-1	10K	20	—	1	1	1	2	—	—	0.50	Fe37	B
SB-Fe37-21-2	10K	20	—	1	1	1	2	—	—	0.48	Fe37	B
SB-Fe37-21-3	10K	20	—	1	1	1	2	—	—	0.55	Fe37	B
SB-Fe37-21-4	10K	20	—	1	1	1	2	—	—	0.54	Fe37	B
SB-Fe37-21-5	10K	20	—	1	1	1	2	—	—	0.52	Fe37	B
SB-Fe37-21-6	10K	20	—	1	1	1	2	—	—	0.60	Fe37	B
SB-Fe37-21-7	10K	20	—	1	1	1	2	—	—	0.55	Fe37	B
SB-Fe37-21-8	10K	20	—	1	1	1	2	—	—	0.62	Fe37	B
SB-Fe37-21-9	10K	20	—	1	1	1	2	—	—	0.52	Fe37	B
SB-Fe37-21-10	10K	20	—	1	1	1	2	—	—	0.52	Fe37	B
SB-Fe37-21-11	10K	20	—	1	1	1	2	—	—	0.54	Fe37	B
SB-Fe37-21-12	10K	20	—	1	1	1	2	—	—	0.51	Fe37	B
SB-Fe37-21-13	10K	20	—	1	1	1	2	—	—	0.57	Fe37	B
SB-Fe37-21-14	10K	20	—	1	1	1	2	—	—	0.55	Fe37	B
SB-Fe37-21-15	10K	20	—	1	1	1	2	—	—	0.54	Fe37	B
SB-Fe37-21-16	10K	20	—	1	1	1	2	—	—	0.53	Fe37	B
SB-Fe52-0-1	10K	20	—	1	1	1	2	—	—	0.60	Fe52	B
SB-Fe52-0-2	10K	20	—	1	1	1	2	—	—	0.70	Fe52	B
SB-Fe52-0-3	10K	20	—	1	1	1	2	—	—	0.62	Fe52	B
SB-Fe52-0-4	10K	20	—	1	1	1	2	—	—	0.70	Fe52	B
SB-Fe52-0-5	10K	20	—	1	1	1	2	—	—	0.77	Fe52	B
SB-Fe52-0-6	10K	20	—	1	1	1	2	—	—	0.74	Fe52	B
SB-Fe52-0-7	10K	20	—	1	1	1	2	—	—	0.73	Fe52	B
SB-Fe52-0-8	10K	20	—	1	1	1	2	—	—	0.78	Fe52	B
SB-Fe52-0-9	10K	20	—	1	1	1	2	—	—	0.64	Fe52	B
SB-Fe52-0-10	10K	20	—	1	1	1	2	—	—	0.53	Fe52	B
SB-Fe52-0-11	10K	20	—	1	1	1	2	—	—	0.57	Fe52	B
SB-Fe52-0-12	10K	20	—	1	1	1	2	—	—	0.63	Fe52	B
SB-Fe52-0-13	10K	20	—	1	1	1	2	—	—	0.60	Fe52	B
SB-Fe52-0-14	10K	20	—	1	1	1	2	—	—	0.56	Fe52	B
SB-Fe52-0-15	10K	20	—	1	1	1	2	—	—	0.61	Fe52	B
SB-Fe52-0-16	10K	20	—	1	1	1	2	—	—	0.61	Fe52	B
SB-Fe52-7-1	10K	20	—	1	1	1	2	—	—	0.54	Fe52	B
SB-Fe52-7-2	10K	20	—	1	1	1	2	—	—	0.54	Fe52	B
SB-Fe52-7-3	10K	20	—	1	1	1	2	—	—	0.430	Fe52	B
SB-Fe52-7-4	10K	20	—	1	1	1	2	—	—	0.560	Fe52	B

Specimen	Bolt Type	ϕ_B [mm]	HC [mm]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
SB-Fe52-7-5	10K	20	—	1	1	1	2	—	—	0.49	Fe52	B
SB-Fe52-7-6	10K	20	—	1	1	1	2	—	—	0.57	Fe52	B
SB-Fe52-7-7	10K	20	—	1	1	1	2	—	—	0.58	Fe52	B
SB-Fe52-7-8	10K	20	—	1	1	1	2	—	—	0.58	Fe52	B
SB-Fe52-7-9	10K	20	—	1	1	1	2	—	—	0.52	Fe52	B
SB-Fe52-7-10	10K	20	—	1	1	1	2	—	—	0.54	Fe52	B
SB-Fe52-7-11	10K	20	—	1	1	1	2	—	—	0.59	Fe52	B
SB-Fe52-7-12	10K	20	—	1	1	1	2	—	—	0.57	Fe52	B
SB-Fe52-7-13	10K	20	—	1	1	1	2	—	—	0.53	Fe52	B
SB-Fe52-7-14	10K	20	—	1	1	1	2	—	—	0.57	Fe52	B
SB-Fe52-7-15	10K	20	—	1	1	1	2	—	—	0.58	Fe52	B
SB-Fe52-7-16	10K	20	—	1	1	1	2	—	—	0.57	Fe52	B
SB-Fe52-21-1	10K	20	—	1	1	1	2	—	—	0.59	Fe52	B
SB-Fe52-21-2	10K	20	—	1	1	1	2	—	—	0.61	Fe52	B
SB-Fe52-21-3	10K	20	—	1	1	1	2	—	—	0.48	Fe52	B
SB-Fe52-21-4	10K	20	—	1	1	1	2	—	—	0.52	Fe52	B
SB-Fe52-21-5	10K	20	—	1	1	1	2	—	—	0.59	Fe52	B
SB-Fe52-21-6	10K	20	—	1	1	1	2	—	—	0.57	Fe52	B
SB-Fe52-21-7	10K	20	—	1	1	1	2	—	—	0.62	Fe52	B
SB-Fe52-21-8	10K	20	—	1	1	1	2	—	—	0.62	Fe52	B
SB-Fe52-21-9	10K	20	—	1	1	1	2	—	—	0.57	Fe52	B
SB-Fe52-21-10	10K	20	—	1	1	1	2	—	—	0.65	Fe52	B
SB-Fe52-21-11	10K	20	—	1	1	1	2	—	—	0.58	Fe52	B
SB-Fe52-21-12	10K	20	—	1	1	1	2	—	—	0.59	Fe52	B
SB-Fe52-21-13	10K	20	—	1	1	1	2	—	—	0.65	Fe52	B
SB-Fe52-21-14	10K	20	—	1	1	1	2	—	—	0.64	Fe52	B
SB-Fe52-21-15	10K	20	—	1	1	1	2	—	—	0.69	Fe52	B
SB-Fe52-21-16	10K	20	—	1	1	1	2	—	—	0.64	Fe52	B
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Note: The shot-blasted specimens were left in open storage from 0 to 21 days before testing. It is reported that the test specimens that had rust on them were brushed clean. The test specimens consisted of double lap splice joints. The bolt pretension was established from axial deformation and calibration. Slip was established by the drop in load and visual inspection of the joints. Two

Author(s)	**Nester, E. E.**
Title	**Influence of Variation of the Contact Area upon the Slip Resistance of a Bolted Joint**
Source	**M.Sc. Thesis, Report No. 318.1, Fritz Engineering Laboratory, Lehigh University**
Year	**1966**
Ref. in Bolt Guide	**—**
Faying Surface	*All specimens mill scale (wire brushed and cleaned with solvent)*

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
CA1-1	A325	7/8	1/16	4	1	4	2	457	1,285	0.356	A36	A
CA1-2	A325	7/8	1/16	4	1	4	2	366	1,292	0.283	A36	A
CA1-3	A325	7/8	1/16	4	1	4	2	501	1,285	0.390	A36	A
CA2-1	A325	7/8	1/16	4	1	4	2	374	1,288	0.290	A36	A
CA2-2	A325	7/8	1/16	4	1	4	2	412	1,292	0.319	A36	A
CA2-3	A325	7/8	1/16	4	1	4	2	374	1,288	0.290	A36	A
CA3-1	A325	7/8	1/16	4	1	4	2	371	1,409	0.264	A36	A
CA3-2	A325	7/8	1/16	4	1	4	2	286	1,288	0.222	A36	A
CA3-3	A325	7/8	1/16	4	1	4	2	283	1,306	0.217	A36	A
CA4-1	A325	7/8	1/16	4	1	4	2	264	1,288	0.205	A36	A
CA4-2	A325	7/8	1/16	4	1	4	2	256	1,295	0.197	A36	A
CA4-3	A325	7/8	1/16	4	1	4	2	302	1,295	0.233	A36	A
CA5-1	A325	7/8	1/16	4	1	4	2	331	1,292	0.256	A36	A
CA5-2	A325	7/8	1/16	4	1	4	2	334	1,285	0.260	A36	A
CA5-3	A325	7/8	1/16	4	1	4	2	375	1,281	0.293	A36	A
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Note: CA1 no, CA2 ϕ1-3/4 in., CA3 ϕ2-5/8 in., CA4 ϕ3-1/2 in., CA5 ϕ4-3/8 in. washers between plates (all washers 1/2 in. thick)

Author(s)	**Sterling, G. H.; Fisher, J. W.**
Title	**A440 Steel Joints Connected by A490 Bolts**
Source	**Journal of the Structural Division, Vol. 92, ST3, pp. 101-118**
Year	**1966**
Ref. in Bolt Guide	**5.6**

Faying Surface *mill scale (oil and grease removed)*

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
K42a	A490	7/8	1/16	2	4	8	2	1,557	4,270	0.365	A440	A
K42b	A490	7/8	1/16	2	4	8	2	1,397	4,234	0.330	A440	A
K42c	A490	7/8	1/16	2	4	8	2	1,486	4,092	0.363	A440	A
K42d	A490	7/8	1/16	2	4	8	2	1,704	4,242	0.402	A440	A
K131	A490	7/8	1/16	1	13	13	2	2,411	7,540	0.320	A440	A
K132	A490	7/8	1/16	1	13	13	2	2,580	7,540	0.342	A440	A
K133	A490	7/8	1/16	1	13	13	2	2,438	7,529	0.324	A440	A
K191	A490	7/8	1/16	1	19	19	2	3,763	11,071	0.340	A440	A
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Author(s) **Vasarhelyi, D. D.; Chiang, K. C.**
Title **Coefficient of Friction in Joints of Various Steels**
Source **Journal of the Structural Division, ASCE, Vol. 93, ST 4, pp. 227 - 243**
Year **1967**
Ref. in Bolt Guide **5.15**

Faying Surface *All specimens with original mill scale*

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
C6-A-1A	A325	1	1/16	2	2	4	2	445	1,576	0.282	A36	A
C6-A-1B	A325	1	1/16	2	2	4	2	445	1,541	0.289	A36	A
C6-A-2A	A325	1	1/16	2	2	4	2	356	1,532	0.232	A440	A
C6-A-2B	A325	1	1/16	2	2	4	2	356	1,619	0.220	A440	A
C6-A-3A	A325	1	1/16	2	2	4	2	445	1,595	0.279	T1	A
C6-A-3B	A325	1	1/16	2	2	4	2	445	1,586	0.281	T1	A
C6-A-4A	A325	1	1/16	2	2	4	2	356	1,646	0.216	A36-A440	A
C6-A-4B	A325	1	1/16	2	2	4	2	445	1,608	0.277	A36-A440	A
C6-A-5A	A325	1	1/16	2	2	4	2	356	1,591	0.224	A36-T1	A
C6-A-5B	A325	1	1/16	2	2	4	2	445	1,586	0.281	A36-T1	A
C6-A-6A	A325	1	1/16	2	2	4	2	445	1,617	0.275	A440-T1	A
C6-A-6B	A325	1	1/16	2	2	4	2	489	1,595	0.307	A440-T1	A
C6-A-7A	A325	1	1/16	2	2	4	2	489	1,571	0.312	A7	A
C6-A-7B	A325	1	1/16	2	2	4	2	534	1,554	0.343	A7	A
C6-A-8A	A325	1	1/16	2	2	4	2	489	1,588	0.308	A7	A
C6-A-8B	A325	1	1/16	2	2	4	2	578	1,546	0.374	A7	A
C6-B-1A	A325	1	1/16	2	2	4	2	356	1,592	0.223	A7	A
C6-B-1B	A325	1	1/16	2	2	4	2	400	1,596	0.251	A7	A
C6-B-2A	A325	1	1/16	2	2	4	2	445	1,594	0.279	A7	A
C6-B-2B	A325	1	1/16	2	2	4	2	445	1,619	0.275	A7	A
C6-C-1A	A325	1	1/16	2	2	4	4	534	1,504	0.355	A7	A
C6-C-1B	A325	1	1/16	2	2	4	4	445	1,459	0.305	A7	A
C6-C-2A	A325	1	1/16	2	2	4	4	356	1,521	0.234	A7	A
C6-C-2B	A325	1	1/16	2	2	4	4	356	1,527	0.233	A7	A
C6-D-1A	A325	1	1/16	2	2	4	4	400	1,492	0.268	A7	A
C6-D-1B	A325	1	1/16	2	2	4	4	400	1,499	0.267	A7	A
C6-D-2A	A325	1	1/16	2	2	4	4	267	1,539	0.173	A7	A
C6-D-2B	A325	1	1/16	2	2	4	4	267	1,342	0.199	A7	A
C6-D-2C	A325	1	1/16	2	2	4	4	445	1,433	0.310	A7	A
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Note: 18 additional tests were conducted with thinner main plates (one side) to simulate not quite perfect fabrication conditions (Specimens B and C). These test results are not included, since they investigate a rather special parameter.

A-4 and A-6 are the same tests (designation used twice for comparison reasons)

Author(s)	**Allan, R. N.; Fisher, J. W.**
Title	**Bolted Joints with Oversize or Slotted Holes**
Source	**Journal of the Structural Division, Vol. 94, ST9, pp. 2061-2080**
Year	**1968**
Ref. in Bolt Guide	**4.26**

Faying Surface *mill scale (loose mill scale and burrs removed)*

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
OH1-1	A325	1	1/16	2	4	8	2	1,399	4,907	0.285	A36	A
OH1-2	A325	1	1/16	2	4	8	2	1,457	4,964	0.293	A36	A
OH1-3	A325	1	1/16	2	4	8	2	1,434	5,074	0.283	A36	A
OH2-1	A325	1	1/4	2	4	8	2	1,221	4,651	0.263	A36	A
OH2-2	A325	1	1/4	2	4	8	2	1,079	3,754	0.287	A36	A
OH2-3	A325	1	1/4	2	4	8	2	1,312	4,221	0.311	A36	A
OH3-1	A325	1	1/4	2	4	8	2	1,274	4,405	0.289	A36	A
OH3-2	A325	1	1/4	2	4	8	2	1,188	4,292	0.277	A36	A
OH3-3	A325	1	1/4	2	4	8	2	1,156	4,212	0.275	A36	A
OH4-1	A325	1	5/16	2	4	8	2	1,179	4,471	0.264	A36	A
OH4-2	A325	1	5/16	2	4	8	2	1,128	4,726	0.239	A36	A
OH4-3	A325	1	5/16	2	4	8	2	1,050	4,742	0.221	A36	A
SH1-1	A325	1	SH_{par}	2	4	8	2	825	4,484	0.184	A36	A
SH1-2	A325	1	SH_{par}	2	4	8	2	885	4,662	0.190	A36	A
SH1-3	A325	1	SH_{par}	2	4	8	2	1,054	4,888	0.216	A36	A
SH2-1	A325	1	SH_{per}	2	4	8	2	1,103	5,105	0.216	A36	A
SH2-2	A325	1	SH_{per}	2	4	8	2	979	5,111	0.191	A36	A
SH2-3	A325	1	SH_{per}	2	4	8	2	1,168	4,677	0.250	A36	A
SH3-1	A325	1	SH_{per}	2	4	8	2	1,001	5,057	0.198	A36	A
SH3-2	A325	1	SH_{per}	2	4	8	2	934	4,229	0.221	A36	A
SH3-3	A325	1	SH_{per}	2	4	8	2	952	4,272	0.223	A36	A
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Note: Hole Clearance: SH_{par} = slotted hole parallel to line of load

SH_{per} = slotted hole perpendicular to line of load

Author(s) **Fisher, J. W.; Kulak, G. L.**
Title **Test of Bolted Butt Splices**
Source **Journal of the Structural Division, ASCE, Vol. 94, ST 11, pp. 2609 - 2619**
Year **1968**
Ref. in Bolt Guide **5.25**

Faying Surface *All specimens blast-cleaned (oil and grease removed)*

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
F191	A325	1-1/8	1/16	19	1	19	2	3,647	13,184	0.277	A514	B
F192	A325	1-1/8	1/16	19	1	19	2	3,941	12,744	0.309	A514	B
F131	A325	1-1/8	1/16	13	1	13	2	3,292	9,969	0.330	A514	B
F111	A325	1-1/8	1/16	11	1	11	2	2,669	8,171	0.327	A514	B
HJ131	A325	7/8	1/16	13	1	13	2	2,002	5,690	0.352	A36/A440	B
HJ132	A325	7/8	1/16	13	1	13	2	1,979	6,129	0.323	A36/A440	B
HJ133	A490	7/8	1/16	13	1	13	2	3,292	7,344	0.448	A440/A514	B
HJ135	A325	7/8	1/16	13	1	13	2	1,744	5,470	0.319	A440/A514	B
HJ136	A325	7/8	1/16	13	1	13	2	2,144	5,289	0.405	A440/A514	B
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Author(s) **Kennedy, D. J. L.; Sanderson, R. A.**
Title **Fatigue Behavior of High Strength Bolted Galvanized Joints**
Source **M.Sc. Thesis, Dep. of Civil Engineering, University of Toronto**
Year **1968**
Ref. in Bolt Guide **—**

Faying Surface *Specimens M*
mill scale (as received)
Specimens G
galvanized (in 835°F bath, not roughened)

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
M-2	A325	1/2	1/16	2	2	4	2	152	584	0.260	*	A
M-3	A325	1/2	1/16	2	2	4	2	154	574	0.268	*	A
M-4	A325	1/2	1/16	2	2	4	2	140	600	0.234	*	A
M-5	A325	1/2	1/16	2	2	4	2	148	558	0.266	*	A
M-6	A325	1/2	1/16	2	2	4	2	156	608	0.256	*	A
M-7	A325	1/2	1/16	2	2	4	2	152	573	0.266	*	A
M-8	A325	1/2	1/16	2	2	4	2	131	568	0.230	*	A
M-9	A325	1/2	1/16	2	2	4	2	142	579	0.246	*	A
M-10	A325	1/2	1/16	2	2	4	2	171	639	0.267	*	A
M-11	A325	1/2	1/16	2	2	4	2	157	640	0.245	*	A
M-12	A325	1/2	1/16	2	2	4	2	152	641	0.238	*	A
M-13	A325	1/2	1/16	2	2	4	2	158	641	0.247	*	A
M-14	A325	1/2	1/16	2	2	4	2	168	641	0.263	*	A
M-15	A325	1/2	1/16	2	2	4	2	152	642	0.237	*	A
M-16	A325	1/2	1/16	2	2	4	2	192	641	0.300	*	A
G-1	A325	1/2	1/16	2	2	4	2	64	564	0.114	*	C
G-2	A325	1/2	1/16	2	2	4	2	75	697	0.107	*	C
G-3	A325	1/2	1/16	2	2	4	2	112	694	0.162	*	C
G-4	A325	1/2	1/16	2	2	4	2	144	697	0.207	*	C
G-5	A325	1/2	1/16	2	2	4	2	96	697	0.138	*	C
G-6	A325	1/2	1/16	2	2	4	2	112	699	0.160	*	C
G-7	A325	1/2	1/16	2	2	4	2	80	699	0.114	*	C
G-8	A325	1/2	1/16	2	2	4	2	96	697	0.138	*	C
G-9	A325	1/2	1/16	2	2	4	2	128	697	0.184	*	C
M-21	A325	1/2	1/16	2	2	4	2	152	641	0.238	*	A
M-22	A325	1/2	1/16	2	2	4	2	156	641	0.244	*	A
M-23	A325	1/2	1/16	2	2	4	2	184	644	0.286	*	A
M-24	A325	1/2	1/16	2	2	4	2	153	644	0.237	*	A
M-26	A325	1/2	1/16	2	2	4	2	156	646	0.242	*	A
M-27	A325	1/2	1/16	2	2	4	2	156	642	0.243	*	A
M-28	A325	1/2	1/16	2	2	4	2	160	646	0.248	*	A
M-29	A325	1/2	1/16	2	2	4	2	156	644	0.242	*	A
G-10	A325	1/2	1/16	2	2	4	2	122	697	0.175	*	C
G-11	A325	1/2	1/16	2	2	4	2	112	697	0.161	*	C
G-12	A325	1/2	1/16	2	2	4	2	104	703	0.148	*	C
G-13	A325	1/2	1/16	2	2	4	2	112	699	0.160	*	C
G-14	A325	1/2	1/16	2	2	4	2	88	705	0.125	*	C
G-15	A325	1/2	1/16	2	2	4	2	124	701	0.177	*	C
G-16	A325	1/2	1/16	2	2	4	2	84	701	0.120	*	C
G-17	A325	1/2	1/16	2	2	4	2	97	705	0.137	*	C
G-18	A325	1/2	1/16	2	2	4	2	120	703	0.171	*	C
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Note: * Plate Grade: CAN/CSA G40.8 Grade A
Specimens M-1 - M-16 and G-1 - G-9 tested in tension
Specimens M-20 - M-30 and G-10 - G-18 tested in compression
The slip load was defined as the load at which the bolts were all in bearing for the mill scale specimens, and at the load for a slip of 0.01" for the galvanized specimens.

Author(s)	**Kulak, G. L.; Fisher, J. W.**
Title	**A514 Stell Joints Fastended by A490 Bolts**
Source	**Journal of the Structural Division, ASCE, Vol. 94, ST 10, pp. 2303 - 2323**
Year	**1968**
Ref. in Bolt Guide	**5.12**

Faying Surface *All specimens blast-cleaned (oil and grease removed)*

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
F42a	A325	1-1/8	1/16	4	2	8	2	1,761	4,911	0.359	A514	B
F42b	A325	1-1/8	1/16	4	2	8	2	1,477	4,982	0.296	A514	B
F42c	A325	1-1/8	1/16	4	2	8	2	1,450	4,875	0.297	A514	B
F42d	A325	1-1/8	1/16	4	2	8	2	1,521	5,017	0.303	A514	B
F42e	A325	1-1/8	1/16	4	2	8	2	1,539	4,911	0.313	A514	B
F42g	A325	1-1/8	1/16	4	2	8	2	1,770	4,982	0.355	A514	B
J42a	A490	1	1/16	4	2	8	2	2,135	6,120	0.349	A514	B
J42b	A490	1	1/16	4	2	8	2	2,251	5,693	0.395	A514	B
J42c	A490	1	1/16	4	2	8	2	2,304	5,693	0.405	A514	B
J42d	A490	1	1/16	4	2	8	2	1,993	5,693	0.350	A514	B
J071	A490	7/8	1/16	7	1	7	2	1,201	4,440	0.270	A514	B
J072	A490	7/8	1/16	7	1	7	2	1,619	4,340	0.373	A514	B
J131	A490	7/8	1/16	13	1	13	2	2,758	8,153	0.338	A514	B
J132	A490	1-1/8	1/16	13	1	13	2	4,332	12,779	0.339	A514	B
J171	A490	7/8	1/16	17	1	17	2	3,247	10,072	0.322	A514	B
J172	A490	7/8	1/16	17	1	17	2	3,114	10,117	0.308	A514	B
J252	A490	7/8	1/16	25	1	25	2	4,172	16,013	0.261	A514	B
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Author(s) **Lee, J. H.; Fisher, J. W.**
Title **Bolted Joints with Rectangular or Circular Fillers**
Source **Report 318.6, Fritz Engineering Laboratory, Lehigh University**
Year **1968**
Ref. in Bolt Guide **5.10**

Faying Surface *All specimens blast cleaned (S6-60 steel shot)*

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
SCA1-1	A325	7/8	1/16	4	1	4	2	890	1,281	0.694	A36	B
SCA1-2	A325	7/8	1/16	4	1	4	2	1,001	1,281	0.781	A36	B
SCA1-3	A325	7/8	1/16	4	1	4	2	943	1,281	0.736	A36	B
SCA2-1	A325	7/8	1/16	4	1	4	2	645	1,281	0.503	A36	B
SCA2-2	A325	7/8	1/16	4	1	4	2	623	1,281	0.486	A36	B
SCA2-3	A325	7/8	1/16	4	1	4	2	689	1,281	0.538	A36	B
SCA3-1	A325	7/8	1/16	4	1	4	2	311	1,281	0.243	A36	B
SCA3-2	A325	7/8	1/16	4	1	4	2	378	1,281	0.295	A36	B
SCA3-3	A325	7/8	1/16	4	1	4	2	356	1,281	0.278	A36	B
SCA4-1	A325	7/8	1/16	4	1	4	2	378	1,281	0.295	A36	B
SCA4-2	A325	7/8	1/16	4	1	4	2	400	1,281	0.313	A36	B
SCA4-3	A325	7/8	1/16	4	1	4	2	445	1,281	0.347	A36	B
SCA5-1	A325	7/8	1/16	4	1	4	2	712	1,281	0.556	A36	B
SCA5-2	A325	7/8	1/16	4	1	4	2	689	1,281	0.538	A36	B
SCA5-3	A325	7/8	1/16	4	1	4	2	578	1,281	0.451	A36	B
SCA6-1	A325	7/8	1/16	4	1	4	2	600	1,281	0.469	A36	B
SCA6-2	A325	7/8	1/16	4	1	4	2	734	1,281	0.573	A36	B
SCA6-3	A325	7/8	1/16	4	1	4	2	712	1,281	0.556	A36	B
SCA7-1	A325	7/8	1/16	4	1	4	2	725	1,281	0.566	A36	B
SCA7-2	A325	7/8	1/16	4	1	4	2	654	1,281	0.510	A36	B
SCA7-3	A325	7/8	1/16	4	1	4	2	689	1,281	0.538	A36	B
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Note: SCA1 no filler; SCA3 and SCA4 ϕ3-1/2" washers 1/2" thick (SCA4 tack welded); SCA2 and SCA5 5-1/4" x 21" x 1/2" filler plates (SCA5 tack welded); SCA6 5-1/4" x 21" x 1/16" and SCA7 5-1/4" x 21" x 1" filler plates
Slip load definition retained for this analysis: load at 0.02" slip, since no sudden slip occurred and it is believed that the 0.02" slip corresponds to the bolts coming into bearing

Author(s) **Munse, W. H.**
Title **Static and Fatigue Tests of Bolted Connections, Coated with Dimetcote 5 and 6**
Source **Corrosion Control Reporter, Vol. 19, No. 2**
Year **1968**
Ref. in Bolt Guide **---**

Faying Surface *Coated with Dimetcote 5 and 6 (inorganic zinc coatings)*

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
D5-1	A325	7/8	1/16	2	2	4	2	667	1,459	0.457	*	Unclassified
D5-2	A325	7/8	1/16	2	2	4	2	731	1,459	0.501	*	"
D5-3	A325	7/8	1/16	2	2	4	2	689	1,459	0.473	*	"
D6-4	A325	7/8	1/16	2	2	4	2	745	1,459	0.510	*	"
D6-5	A325	7/8	1/16	2	2	4	2	756	1,452	0.521	*	"
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Note: * A structural steel similar to A7, but with higher yield and tensile strengths was used.
Specimens D5-1, D5-2, and D6-4 were tested after fatigue loading (> 1,700,000 cycles).
For specimens D5-1, D5-2, and D6-4 no pretension is given, but can be assumed as to be approx. 41 kips per bolt.

Author(s) **Birkemoe, P. C.; Meinheit, D. F.; Munse W. H.**
Title **Fatigue of A514 Steel in Bolted Connections**
Source **Journal of the Structural Division, Vol. 95, pp. 2011 - 2030**
Year **1969**
Ref. in Bolt Guide **—**

Faying Surface *Mill Scale (cleaned and degreased)*

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
Q3A-1	A325	3/4	1/16	1.5	2	3	2	—	1166	0.220	A514	A
Q3A-2	A325	3/4	1/16	1.5	2	3	2	—	1166	0.200	A514	A
Q3A-3	A325	3/4	1/16	1.5	2	3	2	—	1169	0.220	A514	A
Q3B-1	A325	3/4	1/16	2	3	6	2	—	2317	0.200	A514	A
Q3B-2	A325	3/4	1/16	2	3	6	2	—	2333	0.170	A514	A
Q4B-5	A490	3/4	1/16	2	2	4	2	—	1929	0.210	A514	A
Q4B-6	A490	3/4	1/16	2	2	4	2	—	1932	0.230	A514	A
Q4B-13	A490	3/4	1/16	2	2	4	2	—	1936	0.240	A514	A
Q4B-14	A490	3/4	1/16	2	2	4	2	—	1925	0.270	A514	A
Q4B-15	A490	3/4	1/16	2	2	4	2	—	1936	0.300	A514	A
Q4G-1	A490	3/4	1/16	2	3	6	2	—	2898	0.200	A514	A
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Note: Fatigue tests; the slip behaviour is not reported, therefore it is not clear what definition for slip was used. Bolt tension determined with extensometer.

Author(s) **Lee, J. H.; O'Connor, C.; Fisher, J. W.**
Title **Effect of Surface Coating and Exposure on Slip**
Source **Journal of the Structural Division, ASCE, Vol. 95, ST 11, pp. 2371 - 2383**
Year **1969**
Ref. in Bolt Guide **5.11**

Faying Surface *Specimens SOH1*
vynil wash (on blast cleaned, not exposed surface)
Specimens SOH2
corroded (blast cleaned exposed for 12, 2, and 6 months)
Specimens SOH3
linseed oil (on blast cleaned and exposed (2 months) surface)
Specimens SOH4 and SOH5
vinyl wash (on blast cleaned and exposed (2 months) surface)
Specimens SSH1
blast cleaned (not exposed)

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
SOH1-1	A325	1	1/16	2	4	8	2	1,290	4,119	0.313	A36	Unclassified
SOH1-2	A325	1	1/16	2	4	8	2	890	3,203	0.278	A36	"
SOH1-3	A325	1	1/16	2	4	8	2	1,201	4,350	0.276	A36	"
SOH2-1	A325	1	1/4	2	4	8	2	1,308	3,372	0.388	A36	"
SOH2-2	A325	1	1/4	2	4	8	2	1,379	3,203	0.431	A36	"
SOH2-3	A325	1	1/4	2	4	8	2	1,512	3,203	0.472	A36	"
SOH3-1	A325	1	1/4	2	4	8	2	934	3,630	0.257	A36	"
SOH3-2	A325	1	1/4	2	4	8	2	943	3,505	0.269	A36	"
SOH3-3	A325	1	1/4	2	4	8	2	979	3,745	0.261	A36	"
SOH4-1	A325	1	5/16	2	4	8	2	912	4,083	0.223	A36	"
SOH4-2	A325	1	5/16	2	4	8	2	956	3,443	0.278	A36	"
SOH4-3	A325	1	5/16	2	4	8	2	1,223	3,941	0.310	A36	"
SOH5-1	A325	1	1/4	2	4	8	2	1,156	4,573	0.253	A36	"
SOH5-2	A325	1	1/4	2	4	8	2	1,156	4,270	0.271	A36	"
SOH5-3	A325	1	1/4	2	4	8	2	1,068	4,332	0.246	A36	"
SSH1-1	A325	1	SH_{par}	2	4	8	2	1,535	3,203	0.479	A36	B
SSH1-2	A325	1	SH_{par}	2	4	8	2	1,601	3,203	0.500	A36	B
SSH1-3	A325	1	SH_{par}	2	4	8	2	1,597	3,203	0.499	A36	B
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Note: Hole Clearance: SH_{par} = slotted hole parallel to line of load (only in enclosed plates)

Author(s)	**Munse, W. H.**
Title	**Structural Behaviour of Hot Galvanized Bolted Connections**
Source	**Proceedings, 8th International Conference on Hot Dip Galvanizing, London June 1967, Industrial Newspapers Limited, London, pp. 223 – 239**
Year	**1969**
Ref. in Bolt Guide	**4.19**

Faying Surface *all plates galvanized*

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
A-1	A325	3/4	1/16	2	2	4	2	198	1,267	0.157	A36	C
A-2	A325	3/4	1/16	2	2	4	2	202	1,142	0.177	A36	C
B-1	A325	3/4	1/16	2	2	4	2	207	1,132	0.183	A36	C
B-2	A325	3/4	1/16	2	2	4	2	276	1,309	0.211	A36	C
B-3	A325	3/4	1/16	2	2	4	2	247	1,245	0.198	A36	C
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Note: Series B: fatigue tests where the first cycle slip (if occurred) was measured

Author(s)	**Birkemoe, P. C.; Srinivasan, R.**
Title	**Fatigue of Bolted High Strength Structural Steel**
Source	**Journal of the Structural Division, Vol. 97, pp. 935 - 950**
Year	**1971**
Ref. in Bolt Guide	**—**

Faying Surface *Mill Scale (cleaned and degreased)*

Specimen	Bolt	ϕ_B	HC	n_L	n_R	n	m	F_s	P	μ	Plate	Surface
	Type	[in]	[in]	[—]	[—]	[—]	[—]	[kN]	[kN]	[—]	Grade	Class
L3B-2	A325	3/4	1/16	2	2	4	2	—	1,562	0.16	A440	A
L3B-3	A325	3/4	1/16	2	2	4	2	—	1,559	0.17	A440	A
L3B-4	A325	3/4	1/16	2	2	4	2	—	1,562	0.16	A440	A
L3B-6	A325	3/4	1/16	2	2	4	2	—	1544	0.16	A440	A
L3B-8	A325	3/4	1/16	2	2	4	2	—	1555	0.19	A440	A
L3B-9	A325	3/4	1/16	2	2	4	2	—	1555	0.17	A440	A
L3B-10	A325	3/4	1/16	2	2	4	2	—	1544	0.18	A440	A
L3B-11	A325	3/4	1/16	2	2	4	2	—	1559	0.18	A440	A
L3B-12	A325	3/4	1/16	2	2	4	2	—	1559	0.16	A440	A
L4B-1	A490	3/4	1/16	1.5	2	3	2	—	1449	0.20	A440	A
L4B-2	A490	3/4	1/16	1.5	2	3	2	—	1436	0.22	A440	A
L4B-3	A490	3/4	1/16	1.5	2	3	2	—	1446	0.19	A440	A
L4B-4	A490	3/4	1/16	1.5	2	3	2	—	1409	0.20	A440	A
L4B-5	A490	3/4	1/16	1.5	2	3	2	—	1441	0.18	A440	A
L4BX-6	A490	3/4	1/16	1.5	2	3	2	—	1446	0.16	A440	A
L4BX-7	A490	3/4	1/16	1.5	2	3	2	—	1441	0.16	A440	A
L4BX-10	A490	3/4	1/16	1.5	2	3	2	—	1449	0.16	A440	A
L4BX-11	A490	3/4	1/16	1.5	2	3	2	—	1449	0.18	A440	A
L4BX-12	A490	3/4	1/16	1.5	2	3	2	—	1449	0.19	A440	A
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Note: Fatigue tests; the slip behaviour is not reported, therefore it is not clear what definition for slip was used.

Author(s)	**Dusel, J. P.; Stoker, J. R.; Nordlin, E. F.**
Title	**The Effects of Coating Applied to Contact Surfaces of High-Strength Bolted Joints on Slip Behavior and Strength of Joints**
Source	**Report FHWA-CA-TL-6610-77-34, California DOT, Sacramento**
Year	**1977**
Ref. in Bolt Guide	**---**

Faying Surface

Specimens S
sand-blasted
Specimens M
mill scale (as received)
Specimens Z
zinc (hot-dip galvanized)
Specimens V
vinyl wash primer
Specimens O
organic zinc-rich primer

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
S-6	A325	7/8	1/8	1	2	2	2	453	961	0.471	A36	B
S-7	A325	7/8	1/8	1	2	2	2	473	961	0.493	A36	B
S-8	A325	7/8	1/8	1	2	2	2	482	961	0.502	A36	B
S-9	A325	7/8	1/8	1	2	2	2	450	961	0.469	A36	B
S-1DS	A325	7/8	1/8	1	2	2	2	469	961	0.488	A36	B
S-S1	A325	7/8	1/8	1	2	2	2	457	694	0.659	A36	B
S-S2	A325	7/8	1/8	1	2	2	2	445	694	0.641	A36	B
M-2DS	A325	7/8	1/8	1	2	2	2	269	961	0.280	A36	A
Z-GA	A325	7/8	1/8	1	2	2	2	338	694	0.487	A36	C
Z-GB	A325	7/8	1/8	1	2	2	2	294	694	0.424	A36	C
Z-GG	A325	7/8	1/8	1	2	2	2	379	961	0.395	A36	C
Z-GH	A325	7/8	1/8	1	2	2	2	389	961	0.405	A36	C
V-5DS	A325	7/8	1/8	1	2	2	2	187	961	0.194	A36	Unclassified
O-7A	A325	7/8	1/8	1	2	2	2	258	694	0.372	A36	"
O-7B	A325	7/8	1/8	1	2	2	2	262	694	0.378	A36	"
O-2G	A325	7/8	1/8	1	2	2	2	321	961	0.334	A36	"
O-2H	A325	7/8	1/8	1	2	2	2	336	961	0.350	A36	"
O-3DS	A325	7/8	1/8	1	2	2	2	368	961	0.383	A36	"
O-20	A325	7/8	1/8	1	2	2	2	321	694	0.463	A36	"
O-21	A325	7/8	1/8	1	2	2	2	259	694	0.373	A36	"
O-22	A325	7/8	1/8	1	2	2	2	282	694	0.406	A36	"
O-13	A325	7/8	1/8	1	2	2	2	318	961	0.331	A36	"
O-14	A325	7/8	1/8	1	2	2	2	320	961	0.333	A36	"
O-15	A325	7/8	1/8	1	2	2	2	305	961	0.318	A36	"
O-11A	A325	7/8	1/8	1	2	2	2	238	694	0.344	A36	"
O-12A	A325	7/8	1/8	1	2	2	2	219	694	0.316	A36	"
O-4DS	A325	7/8	1/8	1	2	2	2	262	961	0.273	A36	"
O-13A	A325	7/8	1/8	1	2	2	2	292	961	0.304	A36	"
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Author(s)	**Fouad, F. H.**
Title	**Slip Behavior of Bolted Friction-Type Joints with Coated Contact Surfaces**
Source	**M.Sc. Thesis, University of Texas at Austin**
Year	**1978**
Ref. in Bolt Guide	**12.14**

Faying Surface *all specimens blast-cleaned (sand-blasting)*

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
1AL6	A325	7/8	1/16	1	1	1	2	171	347	0.494	A36	B
2AL7	A325	7/8	1/16	1	1	1	2	192	347	0.554	A36	B
3CL8	A325	7/8	1/16	1	1	1	2	177	347	0.512	A514	B
4CL9	A325	7/8	1/16	1	1	1	2	166	347	0.478	A514	B
3AL8	A325	7/8	1/16	1	1	1	2	130	347	0.374	A36	B
3AL9	A325	7/8	1/16	1	1	1	2	157	347	0.451	A36	B
2CL7	A325	7/8	1/16	1	1	1	2	197	347	0.567	A514	B
5CL10	A325	7/8	1/16	1	1	1	2	222	347	0.641	A514	B
1BL9	A325	7/8	1/16	1	1	1	2	166	347	0.479	A572	B
2BL10	A325	7/8	1/16	1	1	1	2	236	347	0.679	A572	B
2BL12	A325	7/8	1/16	1	1	1	2	132	347	0.379	A572	B
1BL11	A325	7/8	1/16	1	1	1	2	149	347	0.429	A572	B
4BL13	A325	7/8	1/16	1	1	1	2	214	347	0.615	A572	B
5BL14	A325	7/8	1/16	1	1	1	2	178	347	0.514	A572	B
1AL20	A325	7/8	1/16	1	1	1	2	168	347	0.485	A36	B
2AL21	A325	7/8	1/16	1	1	1	2	123	347	0.355	A36	B
4AL15	A325	7/8	1/16	1	1	1	2	163	347	0.471	A36	B
4AL16	A325	7/8	1/16	1	1	1	2	184	347	0.531	A36	B
7BL19	A325	7/8	1/16	1	1	1	2	158	347	0.455	A572	B
8BL20	A325	7/8	1/16	1	1	1	2	155	347	0.446	A572	B
1AL1	A325	7/8	1/16	1	1	1	2	157	347	0.454	A36	B
2AL2	A325	7/8	1/16	1	1	1	2	149	347	0.429	A36	B
2AL3	A325	7/8	1/16	1	1	1	2	164	347	0.473	A36	B
7BL21	A325	7/8	1/16	1	1	1	2	195	347	0.563	A572	B
7BL23	A325	7/8	1/16	1	1	1	2	215	347	0.621	A572	B
1CL6	A325	7/8	1/16	1	1	1	2	158	347	0.455	A514	B
5CL5	A325	7/8	1/16	1	1	1	2	180	347	0.519	A514	B
7BL27	A325	7/8	1/16	1	1	1	2	179	347	0.517	A572	B
8BL28	A325	7/8	1/16	1	1	1	2	191	347	0.550	A572	B
12BL39	A325	7/8	1/16	1	1	1	2	197	347	0.569	A572	B
13BL40	A325	7/8	1/16	1	1	1	2	189	347	0.545	A572	B
6BL15	A325	7/8	1/16	1	1	1	2	215	347	0.621	A572	B
4BL16	A325	7/8	1/16	1	1	1	2	228	347	0.658	A572	B
1CL19	A325	7/8	1/16	1	1	1	2	136	347	0.391	A514	B
7CL20	A325	7/8	1/16	1	1	1	2	136	347	0.392	A514	B
4BLD84	A325	7/8	1/8	1	1	1	2	160	347	0.460	A572	B
2BLD86	A325	7/8	1/8	1	1	1	2	139	347	0.400	A572	B
7BLD811	A325	7/8	1/8	1	1	1	2	157	347	0.454	A572	B
8BLD812	A325	7/8	1/8	1	1	1	2	165	347	0.474	A572	B
5BLD83	A325	7/8	1/8	1	1	1	2	220	347	0.635	A572	B
6BLD84	A325	7/8	1/8	1	1	1	2	184	347	0.529	A572	B

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
10BLD911	A325	7/8	1/4	1	1	1	2	205	347	0.590	A572	B
11BLD912	A325	7/8	1/4	1	1	1	2	221	347	0.637	A572	B
11BLD831	A325	7/8	1/8	1	1	1	2	234	347	0.674	A572	B
10BLD832	A325	7/8	1/8	1	1	1	2	230	347	0.663	A572	B
1BLD93	A325	7/8	1/4	1	1	1	2	211	347	0.608	A572	B
6BLD98	A325	7/8	1/4	1	1	1	2	221	347	0.637	A572	B
2BLD94	A325	7/8	1/4	1	1	1	2	239	347	0.688	A572	B
7BLD97	A325	7/8	1/4	1	1	1	2	231	347	0.667	A572	B
3AH4	A490	7/8	1/16	1	1	1	2	251	436	0.576	A36	B
4AH5	A490	7/8	1/16	1	1	1	2	257	436	0.589	A36	B
2CH2	A490	7/8	1/16	1	1	1	2	217	436	0.497	A514	B
1CH1	A490	7/8	1/16	1	1	1	2	177	436	0.406	A514	B
4AH12	A490	7/8	1/16	1	1	1	2	175	436	0.402	A36	B
4AH11	A490	7/8	1/16	1	1	1	2	193	436	0.442	A36	B
3CH3	A490	7/8	1/16	1	1	1	2	304	436	0.698	A514	B
4CH4	A490	7/8	1/16	1	1	1	2	215	436	0.494	A514	B
1BH1	A490	7/8	1/16	1	1	1	2	271	436	0.622	A572	B
2BH2	A490	7/8	1/16	1	1	1	2	234	436	0.537	A572	B
1BH3	A490	7/8	1/16	1	1	1	2	206	436	0.472	A572	B
2BH4	A490	7/8	1/16	1	1	1	2	234	436	0.537	A572	B
4BH5	A490	7/8	1/16	1	1	1	2	183	436	0.420	A572	B
5BH6	A490	7/8	1/16	1	1	1	2	222	436	0.508	A572	B
1AH18	A490	7/8	1/16	1	1	1	2	222	436	0.508	A36	B
2AH19	A490	7/8	1/16	1	1	1	2	193	436	0.443	A36	B
4AH13	A490	7/8	1/16	1	1	1	2	187	436	0.429	A36	B
4AH14	A490	7/8	1/16	1	1	1	2	210	436	0.481	A36	B
7BH17	A490	7/8	1/16	1	1	1	2	193	436	0.443	A572	B
8BH18	A490	7/8	1/16	1	1	1	2	213	436	0.489	A572	B
8BH22	A490	7/8	1/16	1	1	1	2	271	436	0.622	A572	B
8BH24	A490	7/8	1/16	1	1	1	2	224	436	0.514	A572	B
2CH21	A490	7/8	1/16	1	1	1	2	200	436	0.458	A514	B
7CH22	A490	7/8	1/16	1	1	1	2	185	436	0.424	A514	B
4BH8	A490	7/8	1/16	1	1	1	2	216	436	0.495	A572	B
6BH7	A490	7/8	1/16	1	1	1	2	258	436	0.593	A572	B
2CH23	A490	7/8	1/16	1	1	1	2	203	436	0.465	A514	B
7CH24	A490	7/8	1/16	1	1	1	2	210	436	0.482	A514	B
12BH1	A490	7/8	1/16	1	1	1	2	237	436	0.544	A572	B
10BH2	A490	7/8	1/16	1	1	1	2	257	436	0.590	A572	B
1CH17	A490	7/8	1/16	1	1	1	2	212	436	0.486	A514	B
7CH18	A490	7/8	1/16	1	1	1	2	213	436	0.489	A514	B
12BH37	A490	7/8	1/16	1	1	1	2	242	436	0.555	A572	B
13BH38	A490	7/8	1/16	1	1	1	2	244	436	0.559	A572	B
8BH26	A490	7/8	1/16	1	1	1	2	262	436	0.600	A572	B
7BH25	A490	7/8	1/16	1	1	1	2	310	436	0.710	A572	B
6CH37	A490	7/8	1/16	1	1	1	2	225	436	0.516	A514	B
6CH38	A490	7/8	1/16	1	1	1	2	202	436	0.463	A514	B
11BH33	A490	7/8	1/16	1	1	1	2	218	436	0.499	A572	B
12BH34	A490	7/8	1/16	1	1	1	2	239	436	0.549	A572	B
4CH29	A490	7/8	1/16	1	1	1	2	202	436	0.464	A514	B
3CH25	A490	7/8	1/16	1	1	1	2	211	436	0.485	A514	B
2BHD81	A490	7/8	1/8	1	1	1	2	185	436	0.424	A572	B
4BHD82	A490	7/8	1/8	1	1	1	2	187	436	0.429	A572	B
7BHD89	A490	7/8	1/8	1	1	1	2	187	436	0.429	A572	B
8BHD810	A490	7/8	1/8	1	1	1	2	178	436	0.408	A572	B
5BHD81	A490	7/8	1/8	1	1	1	2	182	436	0.417	A572	B

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
6BHD82	A490	7/8	1/8	1	1	1	2	224	436	0.513	A572	B
10BHD99	A490	7/8	1/4	1	1	1	2	213	436	0.488	A572	B
11BHD910	A490	7/8	1/4	1	1	1	2	272	436	0.624	A572	B
2BHD92	A490	7/8	1/4	1	1	1	2	284	436	0.651	A572	B
6BHD96	A490	7/8	1/4	1	1	1	2	281	436	0.645	A572	B
1BHD91	A490	7/8	1/4	1	1	1	2	269	436	0.616	A572	B
7BHD95	A490	7/8	1/4	1	1	1	2	308	436	0.706	A572	B
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Author(s)	**Fouad, F. H.**
Title	**Slip Behavior of Bolted Friction-Type Joints with Coated Contact Surfaces**
Source	**M.Sc. Thesis, University of Texas at Austin**
Year	**1978**
Ref. in Bolt Guide	**12.14**

Faying Surface *organic zinc primer*

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
1ALZ6	A325	7/8	1/16	1	1	1	2	191	347	0.551	A36	Unclassified
1ALZ7	A325	7/8	1/16	1	1	1	2	201	347	0.579	A36	"
2ALZ8	A325	7/8	1/16	1	1	1	2	189	347	0.546	A36	"
3ALZ9	A325	7/8	1/16	1	1	1	2	178	347	0.514	A36	"
3ALZ10	A325	7/8	1/16	1	1	1	2	194	347	0.560	A36	"
1AHZ1	A490	7/8	1/16	1	1	1	2	225	436	0.516	A36	"
1AHZ2	A490	7/8	1/16	1	1	1	2	234	436	0.536	A36	"
2AHZ3	A490	7/8	1/16	1	1	1	2	234	436	0.537	A36	"
3AHZ4	A490	7/8	1/16	1	1	1	2	255	436	0.586	A36	"
2AHZ5	A490	7/8	1/16	1	1	1	2	244	436	0.560	A36	"
4ALZ10	A325	7/8	1/16	1	1	1	2	198	347	0.571	A36	"
2ALZ7	A325	7/8	1/16	1	1	1	2	203	347	0.585	A36	"
3AHZ4	A490	7/8	1/16	1	1	1	2	256	436	0.587	A36	"
4AHZ17	A490	7/8	1/16	1	1	1	2	238	436	0.546	A36	"
1BLZN6	A325	7/8	1/16	1	1	1	2	154	347	0.444	A572	"
1BLZN7	A325	7/8	1/16	1	1	1	2	160	347	0.460	A572	"
1BLZN8	A325	7/8	1/16	1	1	1	2	152	347	0.438	A572	"
2BLZN9	A325	7/8	1/16	1	1	1	2	140	347	0.404	A572	"
2BLZN10	A325	7/8	1/16	1	1	1	2	159	347	0.459	A572	"
1BHZN1	A490	7/8	1/16	1	1	1	2	186	436	0.428	A572	"
1BHZN2	A490	7/8	1/16	1	1	1	2	171	436	0.393	A572	"
1BHZN3	A490	7/8	1/16	1	1	1	2	177	436	0.407	A572	"
1BHZN4	A490	7/8	1/16	1	1	1	2	169	436	0.388	A572	"
2BHZN5	A490	7/8	1/16	1	1	1	2	177	436	0.407	A572	"
1CLZN6	A325	7/8	1/16	1	1	1	2	147	347	0.423	A514	"
2CLZN7	A325	7/8	1/16	1	1	1	2	120	347	0.346	A514	"
3CLZN8	A325	7/8	1/16	1	1	1	2	120	347	0.346	A514	"
4CLZN9	A325	7/8	1/16	1	1	1	2	108	347	0.312	A514	"
5CLZN10	A325	7/8	1/16	1	1	1	2	114	347	0.329	A514	"
1CHZN1	A490	7/8	1/16	1	1	1	2	158	436	0.362	A514	"
2CHZN2	A490	7/8	1/16	1	1	1	2	160	436	0.366	A514	"
4CHZN4	A490	7/8	1/16	1	1	1	2	156	436	0.358	A514	"
3BLZ6	A325	7/8	1/16	1	1	1	2	159	347	0.459	A572	"
3BLZ7	A325	7/8	1/16	1	1	1	2	170	347	0.490	A572	"
4BLZ8	A325	7/8	1/16	1	1	1	2	173	347	0.497	A572	"
5BLZ9	A325	7/8	1/16	1	1	1	2	157	347	0.453	A572	"
6BLZ10	A325	7/8	1/16	1	1	1	2	145	347	0.417	A572	"
3BHZ1	A490	7/8	1/16	1	1	1	2	191	436	0.438	A572	"
3BHZ2	A490	7/8	1/16	1	1	1	2	193	436	0.444	A572	"

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
4BHZ3	A490	7/8	1/16	1	1	1	2	196	436	0.450	A572	Unclassified
5BHZ4	A490	7/8	1/16	1	1	1	2	183	436	0.419	A572	"
6BHZ5	A490	7/8	1/16	1	1	1	2	204	436	0.467	A572	"
3BLD83	A325	7/8	1/8	1	1	1	2	151	347	0.436	A572	"
3BLD87	A325	7/8	1/8	1	1	1	2	160	347	0.462	A572	"
3BLD88	A325	7/8	1/8	1	1	1	2	163	347	0.471	A572	"
3BLD89	A325	7/8	1/8	1	1	1	2	152	347	0.437	A572	"
3BLD810	A325	7/8	1/8	1	1	1	2	164	347	0.473	A572	"
3BHD81	A490	7/8	1/8	1	1	1	2	184	436	0.422	A572	"
3BHD82	A490	7/8	1/8	1	1	1	2	176	436	0.403	A572	"
3BHD83	A490	7/8	1/8	1	1	1	2	187	436	0.430	A572	"
3BHD84	A490	7/8	1/8	1	1	1	2	179	436	0.411	A572	"
3BHD85	A490	7/8	1/8	1	1	1	2	193	436	0.442	A572	"
10BLZK9	A325	7/8	1/16	1	1	1	2	202	347	0.582	A572	"
10BLZK10	A325	7/8	1/16	1	1	1	2	195	347	0.563	A572	"
9BHZK4	A490	7/8	1/16	1	1	1	2	225	436	0.516	A572	"
10BHZK5	A490	7/8	1/16	1	1	1	2	219	436	0.503	A572	"
4CLZK9	A325	7/8	1/16	1	1	1	2	202	347	0.582	A514	"
5CHZK10	A490	7/8	1/16	1	1	1	2	214	436	0.490	A514	"
4CHZK4	A490	7/8	1/16	1	1	1	2	244	436	0.560	A514	"
5CHZK5	A490	7/8	1/16	1	1	1	2	222	436	0.508	A514	"
6BLZ1	A325	7/8	1/16	1	1	1	2	194	347	0.560	A572	"
7BLZ2	A325	7/8	1/16	1	1	1	2	201	347	0.578	A572	"
6BHZ3	A490	7/8	1/16	1	1	1	2	250	436	0.573	A572	"
7BHZ4	A490	7/8	1/16	1	1	1	2	231	436	0.530	A572	"
8BLZN5	A325	7/8	1/16	1	1	1	2	187	347	0.540	A572	"
6BLZN6	A325	7/8	1/16	1	1	1	2	177	347	0.510	A572	"
6BHZN7	A490	7/8	1/16	1	1	1	2	204	436	0.468	A572	"
6BHZN8	A490	7/8	1/16	1	1	1	2	222	436	0.509	A572	"
1CLZK6	A325	7/8	1/16	1	1	1	2	134	347	0.387	A514	"
1CLZK7	A325	7/8	1/16	1	1	1	2	158	347	0.455	A514	"
3CLZK8	A325	7/8	1/16	1	1	1	2	176	347	0.506	A514	"
1CHZK1	A490	7/8	1/16	1	1	1	2	189	436	0.434	A514	"
2CHZK2	A490	7/8	1/16	1	1	1	2	158	436	0.362	A514	"
3CHZK3	A490	7/8	1/16	1	1	1	2	180	436	0.412	A514	"
7BLZK6	A325	7/8	1/16	1	1	1	2	175	347	0.504	A572	"
8BLZK7	A325	7/8	1/16	1	1	1	2	156	347	0.450	A572	"
9BLZK8	A325	7/8	1/16	1	1	1	2	173	347	0.500	A572	"
7BHZK1	A490	7/8	1/16	1	1	1	2	191	436	0.439	A572	"
8BHZK2	A490	7/8	1/16	1	1	1	2	193	436	0.442	A572	"
9BHZK3	A490	7/8	1/16	1	1	1	2	190	436	0.436	A572	"
2ALZK21	A325	7/8	1/16	1	1	1	2	173	347	0.500	A36	"
1ALZK20	A325	7/8	1/16	1	1	1	2	177	347	0.512	A36	"
2AHZK19	A490	7/8	1/16	1	1	1	2	196	436	0.449	A36	"
2AHKZ2	A490	7/8	1/16	1	1	1	2	190	436	0.436	A36	"
1CLZ6	A325	7/8	1/16	1	1	1	2	143	347	0.413	A514	"
2CLZ7	A325	7/8	1/16	1	1	1	2	141	347	0.405	A514	"
1CHZ1	A490	7/8	1/16	1	1	1	2	178	436	0.408	A514	"
2CHZ2	A490	7/8	1/16	1	1	1	2	173	436	0.396	A514	"
4CLZ9	A325	7/8	1/16	1	1	1	2	185	347	0.532	A514	"
5CLZ10	A325	7/8	1/16	1	1	1	2	179	347	0.517	A514	"
4CLZ10	A325	7/8	1/16	1	1	1	2	180	347	0.519	A514	"
3CHZ3	A490	7/8	1/16	1	1	1	2	245	436	0.561	A514	"

Specimen	Bolt	ϕ_B	HC	n_L	n_R	n	m	F_s	P	μ	Plate	Surface
	Type	[in]	[in]	[—]	[—]	[—]	[—]	[kN]	[kN]	[—]	Grade	Class
4CHZ4	A490	7/8	1/16	1	1	1	2	229	436	0.524	A514	Unclassified
5CHZ5	A490	7/8	1/16	1	1	1	2	229	436	0.524	A514	"
1BLZD96	A325	7/8	1/4	1	1	1	2	146	347	0.422	A572	"
2BLZD97	A325	7/8	1/4	1	1	1	2	133	347	0.382	A572	"
3BLZD98	A325	7/8	1/4	1	1	1	2	133	347	0.383	A572	"
4BLZD99	A325	7/8	1/4	1	1	1	2	138	347	0.399	A572	"
5BLZD910	A325	7/8	1/4	1	1	1	2	136	347	0.392	A572	"
1BHZD91	A490	7/8	1/4	1	1	1	2	173	436	0.396	A572	"
2BHZD92	A490	7/8	1/4	1	1	1	2	158	436	0.363	A572	"
3BHZD93	A490	7/8	1/4	1	1	1	2	173	436	0.397	A572	"
4BHZD94	A490	7/8	1/4	1	1	1	2	149	436	0.341	A572	"
5BHZD95	A490	7/8	1/4	1	1	1	2	151	436	0.347	A572	"

bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient

Author(s)	**Fouad, F. H.**
Title	**Slip Behavior of Bolted Friction-Type Joints with Coated Contact Surfaces**
Source	**M.Sc. Thesis, University of Texas at Austin**
Year	**1978**
Ref. in Bolt Guide	**12.14**

Faying Surface *organic zinc primer with epoxy top coat*

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
3ALE7	A325	7/8	1/16	1	1	1	2	113	347	0.326	A36	Unclassified
4ALE8	A325	7/8	1/16	1	1	1	2	106	347	0.306	A36	"
1AHE1	A490	7/8	1/16	1	1	1	2	117	436	0.269	A36	"
3AHE3	A490	7/8	1/16	1	1	1	2	116	436	0.265	A36	"
4BLE6	A325	7/8	1/16	1	1	1	2	100	347	0.288	A572	"
4CLE7	A325	7/8	1/16	1	1	1	2	104	347	0.300	A514	"
3BHE1	A490	7/8	1/16	1	1	1	2	109	436	0.249	A572	"
4BHE2	A490	7/8	1/16	1	1	1	2	118	436	0.270	A572	"
2CLE7	A325	7/8	1/16	1	1	1	2	104	347	0.299	A514	"
3CLE8	A325	7/8	1/16	1	1	1	2	100	347	0.287	A514	"
3CHE3	A490	7/8	1/16	1	1	1	2	145	436	0.333	A514	"
8CHE5	A490	7/8	1/16	1	1	1	2	119	436	0.273	A514	"
5BLE8	A325	7/8	1/16	1	1	1	2	92	347	0.265	A572	"
5BLE9	A325	7/8	1/16	1	1	1	2	101	347	0.290	A572	"
6BLE10	A325	7/8	1/16	1	1	1	2	97	347	0.281	A572	"
4BHE3	A490	7/8	1/16	1	1	1	2	123	436	0.282	A572	"
5BHE4	A490	7/8	1/16	1	1	1	2	116	436	0.265	A572	"
6BHE5	A490	7/8	1/16	1	1	1	2	96	436	0.219	A572	"
1CLE6	A325	7/8	1/16	1	1	1	2	86	347	0.247	A514	"
4CLE9	A325	7/8	1/16	1	1	1	2	92	347	0.265	A514	"
5CLE10	A325	7/8	1/16	1	1	1	2	98	347	0.282	A514	"
1CHE1	A490	7/8	1/16	1	1	1	2	95	436	0.218	A514	"
2CHE2	A490	7/8	1/16	1	1	1	2	119	436	0.273	A514	"
4CHE4	A490	7/8	1/16	1	1	1	2	119	436	0.273	A514	"
9BLEN6	A325	7/8	1/16	1	1	1	2	106	347	0.306	A572	"
9BLEN7	A325	7/8	1/16	1	1	1	2	105	347	0.301	A572	"
10BLEN8	A325	7/8	1/16	1	1	1	2	108	347	0.310	A572	"
9BHEN1	A490	7/8	1/16	1	1	1	2	130	436	0.298	A572	"
9BHEN2	A490	7/8	1/16	1	1	1	2	129	436	0.295	A572	"
10BHEN3	A490	7/8	1/16	1	1	1	2	108	436	0.248	A572	"
6CLEN6	A325	7/8	1/16	1	1	1	2	103	347	0.296	A514	"
6CLEN7	A325	7/8	1/16	1	1	1	2	99	347	0.286	A514	"
6CLEN8	A325	7/8	1/16	1	1	1	2	107	347	0.308	A514	"
6CHEN1	A490	7/8	1/16	1	1	1	2	129	436	0.297	A514	"
6CHEN2	A490	7/8	1/16	1	1	1	2	121	436	0.277	A514	"
6CHEN3	A490	7/8	1/16	1	1	1	2	114	436	0.261	A514	"
11BLEK6	A325	7/8	1/16	1	1	1	2	96	347	0.277	A572	"
12BLEK7	A325	7/8	1/16	1	1	1	2	110	347	0.317	A572	"
13BHEK8	A490	7/8	1/16	1	1	1	2	95	436	0.218	A572	"
11BHEL1	A490	7/8	1/16	1	1	1	2	124	436	0.284	A572	"

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
12BHEK2	A490	7/8	1/16	1	1	1	2	114	436	0.261	A572	Unclassified
13BHEK3	A490	7/8	1/16	1	1	1	2	116	436	0.266	A572	"
1CLEK6	A325	7/8	1/16	1	1	1	2	91	347	0.262	A514	"
2CLEK7	A325	7/8	1/16	1	1	1	2	111	347	0.319	A514	"
3CLEK8	A325	7/8	1/16	1	1	1	2	88	347	0.253	A514	"
6CHEK1	A490	7/8	1/16	1	1	1	2	102	436	0.234	A514	"
6CHEK2	A490	7/8	1/16	1	1	1	2	134	436	0.308	A514	"
7CHEK3	A490	7/8	1/16	1	1	1	2	126	436	0.290	A514	"
2ALE6	A325	7/8	1/16	1	1	1	2	89	347	0.256	A36	"
4ALE9	A325	7/8	1/16	1	1	1	2	121	347	0.350	A36	"
4ALE10	A325	7/8	1/16	1	1	1	2	120	347	0.346	A36	"
3AHE2	A490	7/8	1/16	1	1	1	2	130	436	0.298	A36	"
4AHE5	A490	7/8	1/16	1	1	1	2	132	436	0.303	A36	"
4AHE13	A490	7/8	1/16	1	1	1	2	143	436	0.329	A36	"
10BLEN9	A325	7/8	1/16	1	1	1	2	94	347	0.272	A572	"
11BLEN10	A325	7/8	1/16	1	1	1	2	93	347	0.267	A572	"
10BHEN4	A490	7/8	1/16	1	1	1	2	109	436	0.251	A572	"
11BHEN5	A490	7/8	1/16	1	1	1	2	123	436	0.283	A572	"
8CLEN9	A325	7/8	1/16	1	1	1	2	107	347	0.309	A514	"
8CLEN10	A325	7/8	1/16	1	1	1	2	84	347	0.242	A514	"
8CHEN4	A490	7/8	1/16	1	1	1	2	82	436	0.188	A514	"
8CHEN5	A490	7/8	1/16	1	1	1	2	137	436	0.315	A514	"
13BLEK9	A325	7/8	1/16	1	1	1	2	100	347	0.287	A572	"
13BLEK10	A325	7/8	1/16	1	1	1	2	106	347	0.306	A572	"
13BHEK4	A490	7/8	1/16	1	1	1	2	127	436	0.292	A572	"
13BHEK5	A490	7/8	1/16	1	1	1	2	103	436	0.236	A572	"
4CLEK9	A325	7/8	1/16	1	1	1	2	100	347	0.287	A514	"
5CLEK10	A325	7/8	1/16	1	1	1	2	101	347	0.292	A514	"
8CHEK4	A490	7/8	1/16	1	1	1	2	102	436	0.235	A514	"
5CHEK5	A490	7/8	1/16	1	1	1	2	125	436	0.288	A514	"
12BLED86	A325	7/8	1/8	1	1	1	2	83	347	0.240	A572	"
12BLED87	A325	7/8	1/8	1	1	1	2	89	347	0.255	A572	"
11BLED88	A325	7/8	1/8	1	1	1	2	86	347	0.249	A572	"
11BLED89	A325	7/8	1/8	1	1	1	2	85	347	0.246	A572	"
9BLED810	A325	7/8	1/8	1	1	1	2	92	347	0.264	A572	"
11BHED81	A490	7/8	1/8	1	1	1	2	108	436	0.247	A572	"
12BHED82	A490	7/8	1/8	1	1	1	2	79	436	0.182	A572	"
11BHED83	A490	7/8	1/8	1	1	1	2	105	436	0.241	A572	"
12BHED84	A490	7/8	1/8	1	1	1	2	118	436	0.270	A572	"
13BHED85	A490	7/8	1/8	1	1	1	2	117	436	0.267	A572	"
3BLED96	A325	7/8	1/4	1	1	1	2	104	347	0.300	A572	"
4BLED97	A325	7/8	1/4	1	1	1	2	94	347	0.272	A572	"
5BLED98	A325	7/8	1/4	1	1	1	2	92	347	0.264	A572	"
6BLED99	A325	7/8	1/4	1	1	1	2	86	347	0.247	A572	"
7BLED910	A325	7/8	1/4	1	1	1	2	78	347	0.224	A572	"
3BHED91	A490	7/8	1/4	1	1	1	2	118	436	0.271	A572	"
4BHED92	A490	7/8	1/4	1	1	1	2	113	436	0.260	A572	"
5BHED93	A490	7/8	1/4	1	1	1	2	95	436	0.218	A572	"
6BHED94	A490	7/8	1/4	1	1	1	2	120	436	0.274	A572	"
7BHED95	A490	7/8	1/4	1	1	1	2	109	436	0.250	A572	"
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Author(s)	**Fouad, F. H.**
Title	**Slip Behavior of Bolted Friction-Type Joints with Coated Contact Surfaces**
Source	**M.Sc. Thesis, University of Texas at Austin**
Year	**1978**
Ref. in Bolt Guide	**12.14**

Faying Surface *inorganic zinc primer with vinyl top coat*

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
6BLV6	A325	7/8	1/16	1	1	1	2	188	347	0.542	A572	Unclassified
6BLV7	A325	7/8	1/16	1	1	1	2	167	347	0.481	A572	"
6BLV8	A325	7/8	1/16	1	1	1	2	168	347	0.485	A572	"
7BLV9	A325	7/8	1/16	1	1	1	2	173	347	0.500	A572	"
8BLV10	A325	7/8	1/16	1	1	1	2	167	347	0.481	A572	"
6BHV1	A490	7/8	1/16	1	1	1	2	205	436	0.470	A572	"
6BHV2	A490	7/8	1/16	1	1	1	2	220	436	0.505	A572	"
6BHV3	A490	7/8	1/16	1	1	1	2	226	436	0.519	A572	"
7BHV4	A490	7/8	1/16	1	1	1	2	212	436	0.486	A572	"
8BHV5	A490	7/8	1/16	1	1	1	2	199	436	0.457	A572	"
1ALV6	A325	7/8	1/16	1	1	1	2	133	347	0.383	A36	"
1ALV7	A325	7/8	1/16	1	1	1	2	136	347	0.391	A36	"
1ALV1	A325	7/8	1/16	1	1	1	2	158	347	0.456	A36	"
3ALV5	A325	7/8	1/16	1	1	1	2	154	347	0.444	A36	"
6CLV6	A325	7/8	1/16	1	1	1	2	154	347	0.444	A514	"
6CLV7	A325	7/8	1/16	1	1	1	2	151	347	0.436	A514	"
6CHV2	A490	7/8	1/16	1	1	1	2	141	436	0.324	A514	"
7CHV4	A490	7/8	1/16	1	1	1	2	206	436	0.472	A514	"
1CLVN6	A325	7/8	1/16	1	1	1	2	138	347	0.397	A514	"
2CLVN7	A325	7/8	1/16	1	1	1	2	148	347	0.426	A514	"
1CHVN1	A490	7/8	1/16	1	1	1	2	149	436	0.342	A514	"
2CHVN2	A490	7/8	1/16	1	1	1	2	177	436	0.407	A514	"
6CLVK6	A325	7/8	1/16	1	1	1	2	155	347	0.446	A514	"
6CLVK7	A325	7/8	1/16	1	1	1	2	141	347	0.405	A514	"
6CHVK1	A490	7/8	1/16	1	1	1	2	212	436	0.487	A514	"
6CHVK2	A490	7/8	1/16	1	1	1	2	182	436	0.418	A514	"
7BLVN6	A325	7/8	1/16	1	1	1	2	153	347	0.442	A572	"
8BLVN7	A325	7/8	1/16	1	1	1	2	158	347	0.455	A572	"
7BHVN1	A490	7/8	1/16	1	1	1	2	176	436	0.403	A572	"
8BHVN2	A490	7/8	1/16	1	1	1	2	161	436	0.370	A572	"
3CLVN8	A325	7/8	1/16	1	1	1	2	167	347	0.481	A514	"
4CLVN9	A325	7/8	1/16	1	1	1	2	182	347	0.524	A514	"
5CLVN10	A325	7/8	1/16	1	1	1	2	175	347	0.504	A514	"
3CHVN3	A490	7/8	1/16	1	1	1	2	195	436	0.448	A514	"
4CHVN4	A490	7/8	1/16	1	1	1	2	189	436	0.434	A514	"
5CHVN5	A490	7/8	1/16	1	1	1	2	212	436	0.487	A514	"
7CLV8	A325	7/8	1/16	1	1	1	2	190	347	0.549	A514	"
7CLV9	A325	7/8	1/16	1	1	1	2	199	347	0.573	A514	"

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
8CLV10	A325	7/8	1/16	1	1	1	2	190	347	0.547	A514	Unclassified
6CHV1	A490	7/8	1/16	1	1	1	2	225	436	0.515	A514	"
7CHV3	A490	7/8	1/16	1	1	1	2	229	436	0.526	A514	"
8CHV5	A490	7/8	1/16	1	1	1	2	218	436	0.501	A514	"
7CLVK8	A325	7/8	1/16	1	1	1	2	200	347	0.576	A514	"
7CLVK9	A325	7/8	1/16	1	1	1	2	200	347	0.577	A514	"
8CLVK10	A325	7/8	1/16	1	1	1	2	206	347	0.595	A514	"
7CHVK3	A490	7/8	1/16	1	1	1	2	246	436	0.564	A514	"
7CHVK4	A490	7/8	1/16	1	1	1	2	234	436	0.537	A514	"
8CHVK5	A490	7/8	1/16	1	1	1	2	239	436	0.548	A514	"
2ALV8	A325	7/8	1/16	1	1	1	2	181	347	0.523	A36	"
3ALV9	A325	7/8	1/16	1	1	1	2	205	347	0.592	A36	"
3ALV10	A325	7/8	1/16	1	1	1	2	196	347	0.565	A36	"
1AHV2	A490	7/8	1/16	1	1	1	2	237	436	0.544	A36	"
2AHV3	A490	7/8	1/16	1	1	1	2	238	436	0.547	A36	"
3AHV4	A490	7/8	1/16	1	1	1	2	234	436	0.538	A36	"
9BLVN8	A325	7/8	1/16	1	1	1	2	178	347	0.514	A572	"
10BLVN9	A325	7/8	1/16	1	1	1	2	183	347	0.528	A572	"
10BLVN10	A325	7/8	1/16	1	1	1	2	176	347	0.508	A572	"
9BHVN3	A490	7/8	1/16	1	1	1	2	215	436	0.494	A572	"
9BHVN4	A490	7/8	1/16	1	1	1	2	210	436	0.481	A572	"
10BHVN5	A490	7/8	1/16	1	1	1	2	211	436	0.485	A572	"
11BLVK6	A325	7/8	1/16	1	1	1	2	195	347	0.563	A572	"
12BLVK7	A325	7/8	1/16	1	1	1	2	196	347	0.564	A572	"
12BLVK8	A325	7/8	1/16	1	1	1	2	192	347	0.553	A572	"
12BLVK9	A325	7/8	1/16	1	1	1	2	191	347	0.550	A572	"
13BLVK10	A325	7/8	1/16	1	1	1	2	185	347	0.532	A572	"
11BHVK1	A490	7/8	1/16	1	1	1	2	246	436	0.563	A572	"
11BHVK2	A490	7/8	1/16	1	1	1	2	251	436	0.577	A572	"
12BHVK3	A490	7/8	1/16	1	1	1	2	227	436	0.520	A572	"
12BHVK4	A490	7/8	1/16	1	1	1	2	227	436	0.520	A572	"
13BHVK5	A490	7/8	1/16	1	1	1	2	235	436	0.540	A572	"
5BLED86	A325	7/8	1/8	1	1	1	2	196	347	0.564	A572	"
4BLED87	A325	7/8	1/8	1	1	1	2	195	347	0.563	A572	"
4BLED88	A325	7/8	1/8	1	1	1	2	197	347	0.569	A572	"
5BLED89	A325	7/8	1/8	1	1	1	2	196	347	0.564	A572	"
5BLED810	A325	7/8	1/8	1	1	1	2	193	347	0.556	A572	"
5BHED81	A490	7/8	1/8	1	1	1	2	228	436	0.522	A572	"
4BHED82	A490	7/8	1/8	1	1	1	2	247	436	0.567	A572	"
6BHED83	A490	7/8	1/8	1	1	1	2	240	436	0.551	A572	"
5BHED84	A490	7/8	1/8	1	1	1	2	232	436	0.533	A572	"
5BHED85	A490	7/8	1/8	1	1	1	2	243	436	0.558	A572	"
8BLVD96	A325	7/8	1/4	1	1	1	2	206	347	0.594	A572	"
8BLVD97	A325	7/8	1/4	1	1	1	2	180	347	0.518	A572	"
8BLVD98	A325	7/8	1/4	1	1	1	2	196	347	0.565	A572	"
9BLVD99	A325	7/8	1/4	1	1	1	2	196	347	0.564	A572	"
10BLVD910	A325	7/8	1/4	1	1	1	2	203	347	0.586	A572	"
8BHVD91	A490	7/8	1/4	1	1	1	2	217	436	0.497	A572	"
8BHVD92	A490	7/8	1/4	1	1	1	2	237	436	0.543	A572	"
9BHVD93	A490	7/8	1/4	1	1	1	2	226	436	0.518	A572	"
9BHVD94	A490	7/8	1/4	1	1	1	2	239	436	0.549	A572	"
10BHVD95	A490	7/8	1/4	1	1	1	2	238	436	0.547	A572	"
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Author(s)	**Fouad, F. H.**
Title	**Slip Behavior of Bolted Friction-Type Joints with Coated Contact Surfaces**
Source	**M.Sc. Thesis, University of Texas at Austin**
Year	**1978**
Ref. in Bolt Guide	**12.14**

Faying Surface *vinyl primer*

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
3AHX4	A490	7/8	1/16	1	1	1	2	94	436	0.216	A36	Unclassified
3AHX5	A490	7/8	1/16	1	1	1	2	81	436	0.186	A36	"
1AHX6	A490	7/8	1/16	1	1	1	2	98	436	0.224	A36	"
2AHX8	A490	7/8	1/16	1	1	1	2	87	436	0.200	A36	"
1AHX10	A490	7/8	1/16	1	1	1	2	90	436	0.206	A36	"
11BHX1	A490	7/8	1/16	1	1	1	2	85	436	0.196	A572	"
12BHX2	A490	7/8	1/16	1	1	1	2	84	436	0.192	A572	"
13BHX3	A490	7/8	1/16	1	1	1	2	86	436	0.197	A572	"
13BHX4	A490	7/8	1/16	1	1	1	2	77	436	0.177	A572	"
13BHX5	A490	7/8	1/16	1	1	1	2	74	436	0.170	A572	"
1CHX1	A490	7/8	1/16	1	1	1	2	77	436	0.178	A514	"
2CHX2	A490	7/8	1/16	1	1	1	2	76	436	0.174	A514	"
3CHX3	A490	7/8	1/16	1	1	1	2	77	436	0.178	A514	"
4CHX4	A490	7/8	1/16	1	1	1	2	89	436	0.205	A514	"
3CHX7	A490	7/8	1/16	1	1	1	2	86	436	0.198	A514	"
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Author(s) **Fouad, F. H.**
Title **Slip Behavior of Bolted Friction-Type Joints with Coated Contact Surfaces**
Source **M.Sc. Thesis, University of Texas at Austin**
Year **1978**
Ref. in Bolt Guide **12.14**

Faying Surface *all vinyl (primer + top coat)*

Specimen	Bolt	ϕ_B	HC	n_L	n_R	n	m	F_s	P	μ	Plate	Surface
	Type	[in]	[in]	[—]	[—]	[—]	[—]	[kN]	[kN]	[—]	Grade	Class
1CHA6	A490	7/8	1/16	1	1	1	2	83	436	0.190	A514	Unclassified
2CHA7	A490	7/8	1/16	1	1	1	2	93	436	0.212	A514	"
3CHA8	A490	7/8	1/16	1	1	1	2	89	436	0.203	A514	"
4CHA9	A490	7/8	1/16	1	1	1	2	76	436	0.174	A514	"
5CHA10	A490	7/8	1/16	1	1	1	2	86	436	0.197	A514	"
4CHA99	A490	7/8	1/16	1	1	1	2	85	436	0.196	A514	"
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Author(s)	**Fouad, F. H.**
Title	**Slip Behavior of Bolted Friction-Type Joints with Coated Contact Surfaces**
Source	**M.Sc. Thesis, University of Texas at Austin**
Year	**1978**
Ref. in Bolt Guide	**12.14**

Faying Surface *powder epoxy*

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
1ALP6	A325	7/8	1/16	1	1	1	2	25	347	0.072	A36	Unclassified
2ALP7	A325	7/8	1/16	1	1	1	2	28	347	0.082	A36	"
2ALP8	A325	7/8	1/16	1	1	1	2	20	347	0.058	A36	"
3ALP9	A325	7/8	1/16	1	1	1	2	24	347	0.071	A36	"
4ALP10	A325	7/8	1/16	1	1	1	2	29	347	0.085	A36	"
1AHP1	A490	7/8	1/16	1	1	1	2	42	436	0.096	A36	"
2AHP2	A490	7/8	1/16	1	1	1	2	40	436	0.092	A36	"
2AHP3	A490	7/8	1/16	1	1	1	2	32	436	0.072	A36	"
3AHP4	A490	7/8	1/16	1	1	1	2	33	436	0.076	A36	"
4AHP5	A490	7/8	1/16	1	1	1	2	36	436	0.082	A36	"
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Author(s)	**Fouad, F. H.**
Title	**Slip Behavior of Bolted Friction-Type Joints with Coated Contact Surfaces**
Source	**M.Sc. Thesis, University of Texas at Austin**
Year	**1978**
Ref. in Bolt Guide	**12.14**

Faying Surface *inorganic zinc-rich primer (80% zinc)*

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
1BLI6	A325	7/8	1/16	1	1	1	2	217	347	0.626	A572	Unclassified
1BLI7	A325	7/8	1/16	1	1	1	2	229	347	0.659	A572	"
2BLI8	A325	7/8	1/16	1	1	1	2	226	347	0.650	A572	"
2BLI9	A325	7/8	1/16	1	1	1	2	214	347	0.617	A572	"
2BLI10	A325	7/8	1/16	1	1	1	2	189	347	0.546	A572	"
1BHI1	A490	7/8	1/16	1	1	1	2	269	436	0.616	A572	"
1BHI2	A490	7/8	1/16	1	1	1	2	264	436	0.606	A572	"
2BHI3	A490	7/8	1/16	1	1	1	2	252	436	0.578	A572	"
2BHI4	A490	7/8	1/16	1	1	1	2	253	436	0.581	A572	"
2BHI5	A490	7/8	1/16	1	1	1	2	259	436	0.594	A572	"
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Author(s) **Fouad, F. H.**
Title **Slip Behavior of Bolted Friction-Type Joints with Coated Contact Surfaces**
Source **M.Sc. Thesis, University of Texas at Austin**
Year **1978**
Ref. in Bolt Guide **12.14**

Faying Surface *inorganic zinc-rich primer (75% zinc)*

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
12BHI1	A490	7/8	1/16	1	1	1	2	214	436	0.492	A572	Unclassified
13BHI2	A490	7/8	1/16	1	1	1	2	219	436	0.503	A572	"
11BHI3	A490	7/8	1/16	1	1	1	2	223	436	0.511	A572	"
13BHI4	A490	7/8	1/16	1	1	1	2	222	436	0.510	A572	"
13BHI5	A490	7/8	1/16	1	1	1	2	226	436	0.518	A572	"
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Author(s)	**Fouad, F. H.**
Title	**Slip Behavior of Bolted Friction-Type Joints with Coated Contact Surfaces**
Source	**M.Sc. Thesis, University of Texas at Austin**
Year	**1978**
Ref. in Bolt Guide	**12.14**

Faying Surface *inorganic zinc-rich primer (0% zinc)*

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
12BHS6	A490	7/8	1/16	1	1	1	2	120	436	0.274	A572	Unclassified
11BHS7	A490	7/8	1/16	1	1	1	2	121	436	0.279	A572	"
8BHS8	A490	7/8	1/16	1	1	1	2	121	436	0.278	A572	"
9BHS9	A490	7/8	1/16	1	1	1	2	120	436	0.276	A572	"
9BHS10	A490	7/8	1/16	1	1	1	2	118	436	0.271	A572	"
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Author(s) **Moss, D. S.**
Title **High Strength Friction Grip Bolted Joints - Effects after One Year of Weathering under Load**
Source **Transport and Road Research Laboratory, Supplementary Report 499, Crowthorne, U.K.**
Year **1979**
Ref. in Bolt Guide **---**

Faying Surface *different surface conditions (see individual tests)*

Specimen	Bolt Type	ϕ_B [mm]	HC [mm]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class	Surface Condition
—	10.9?	16	3	2	1	2	2	—	—	0.453	Grade 50	B	grit blasted, unweathered
—	10.9?	16	3	2	1	2	2	—	—	0.421	Grade 50	B	grit blasted, unweathered
—	10.9?	16	3	2	1	2	2	—	—	0.391	Grade 50	B	grit blasted, unweathered
—	10.9?	16	3	2	1	2	2	—	—	0.378	Weathering	B	grit blasted, unweathered
—	10.9?	16	3	2	1	2	2	—	—	0.377	Weathering	B	grit blasted, unweathered
—	10.9?	16	3	2	1	2	2	—	—	0.345	Weathering	B	grit blasted, unweathered
25	10.9?	16	3	2	1	2	2	—	—	0.476	Grade 50	Unclassified	zinc silicate primer on grit blasted, unweathered
26	10.9?	16	3	2	1	2	2	—	—	0.446	Grade 50	"	zinc silicate primer on grit blasted, unweathered
27	10.9?	16	3	2	1	2	2	—	—	0.432	Grade 50	"	zinc silicate primer on grit blasted, unweathered
47	10.9?	16	3	2	1	2	2	—	—	0.764	Grade 50	"	zinc metal spray on grit blasted, unweathered
48	10.9?	16	3	2	1	2	2	—	—	0.716	Grade 50	"	zinc metal spray on grit blasted, unweathered
50	10.9?	16	3	2	1	2	2	—	—	0.691	Grade 50	"	zinc metal spray on grit blasted, unweathered
69	10.9?	16	3	2	1	2	2	—	—	0.766	Grade 50	"	aluminium metal spray on grit blasted, unweathered
70	10.9?	16	3	2	1	2	2	—	—	0.700	Grade 50	"	aluminium metal spray on grit blasted, unweathered
70A	10.9?	16	3	2	1	2	2	—	—	0.612	Grade 50	"	aluminium metal spray on grit blasted, unweathered
—	10.9?	16	3	2	1	2	2	—	—	0.567	Grade 50	B	grit blasted, weathered (10 weeks industrial, loose rust removed)
—	10.9?	16	3	2	1	2	2	—	—	0.504	Grade 50	B	grit blasted, weathered (10 weeks industrial, loose rust removed)
—	10.9?	16	3	2	1	2	2	—	—	0.398	Grade 50	B	grit blasted, weathered (10 weeks industrial, loose rust removed)
—	10.9?	16	3	2	1	2	2	—	—	0.561	Grade 50	B	grit blasted, weathered (10 weeks marine, loose rust removed)
—	10.9?	16	3	2	1	2	2	—	—	0.543	Grade 50	B	grit blasted, weathered (10 weeks marine, loose rust removed)
—	10.9?	16	3	2	1	2	2	—	—	0.530	Grade 50	B	grit blasted, weathered (10 weeks marine, loose rust removed)
—	10.9?	16	3	2	1	2	2	—	—	0.483	Weathering	B	grit blasted, weathered (10 weeks industrial, loose rust removed)
—	10.9?	16	3	2	1	2	2	—	—	0.462	Weathering	B	grit blasted, weathered (10 weeks industrial, loose rust removed)
—	10.9?	16	3	2	1	2	2	—	—	0.510	Weathering	B	grit blasted, weathered (10 weeks marine, loose rust removed)
—	10.9?	16	3	2	1	2	2	—	—	0.501	Weathering	B	grit blasted, weathered (10 weeks marine, loose rust removed)
3	10.9?	16	3	2	1	2	2	—	—	0.453	Grade 50	Unclassified	zinc silicate primer on grit blasted, weathered (10 weeks industrial)
5	10.9?	16	3	2	1	2	2	—	—	0.433	Grade 50	"	zinc silicate primer on grit blasted, weathered (10 weeks industrial)
8	10.9?	16	3	2	1	2	2	—	—	0.410	Grade 50	"	zinc silicate primer on grit blasted, weathered (10 weeks industrial)
29	10.9?	16	3	2	1	2	2	—	—	0.431	Grade 50	"	zinc silicate primer on grit blasted, weathered (10 weeks marine)
30	10.9?	16	3	2	1	2	2	—	—	0.424	Grade 50	"	zinc silicate primer on grit blasted, weathered (10 weeks marine)
33	10.9?	16	3	2	1	2	2	—	—	0.421	Grade 50	"	zinc silicate primer on grit blasted, weathered (10 weeks marine)
52	10.9?	16	3	2	1	2	2	—	—	0.613	Grade 50	"	zinc metal spray on grit blasted, weathered (10 weeks industrial)
55	10.9?	16	3	2	1	2	2	—	—	0.613	Grade 50	"	zinc metal spray on grit blasted, weathered (10 weeks industrial)
58	10.9?	16	3	2	1	2	2	—	—	0.579	Grade 50	"	zinc metal spray on grit blasted, weathered (10 weeks industrial)
14	10.9?	16	3	2	1	2	2	—	—	0.724	Grade 50	"	zinc metal spray on grit blasted, weathered (10 weeks marine)
17	10.9?	16	3	2	1	2	2	—	—	0.664	Grade 50	"	zinc metal spray on grit blasted, weathered (10 weeks marine)

Specimen	Bolt Type	ϕ_B [mm]	HC [mm]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class	Surface Condition
24	10.9?	16	3	2	1	2	2	—	—	0.626	Grade 50	Unclassified	zinc metal spray on grit blasted, weathered (10 weeks marine)
37	10.9?	16	3	2	1	2	2	—	—	0.632	Grade 50	"	aluminium metal spray on grit blasted, weathered (10 weeks industrial)
39	10.9?	16	3	2	1	2	3	—	—	0.589	Grade 50	"	aluminium metal spray on grit blasted, weathered (10 weeks industrial)
43	10.9?	16	3	2	1	2	4	—	—	0.585	Grade 50	"	aluminium metal spray on grit blasted, weathered (10 weeks industrial)
60	10.9?	16	3	2	1	2	5	—	—	0.644	Grade 50	"	aluminium metal spray on grit blasted, weathered (10 weeks marine)
63	10.9?	16	3	2	1	2	6	—	—	0.643	Grade 50	"	aluminium metal spray on grit blasted, weathered (10 weeks marine)
67	10.9?	16	3	2	1	2	2	—	—	0.618	Grade 50	"	aluminium metal spray on grit blasted, weathered (10 weeks marine)
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient			

Note: Weathered means that the plates were exposed prior to assembly.

More test were carried out on specimens subjected to sustained loads before slip testing

Author(s) **Hansen, M. A.**
Title **Influence of Undeveloped Fillers on Shear Strength of Bolted Splice Joints**
Source **M.Sc. Thesis, University of Texas, Austin**
Year **1980**
Ref. in Bolt Guide **---**

Faying Surface *all plates clean mill scale*

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
0A	A325	1	1/16	2	1	2	2	276	792	0.348	A514	A
0B	A325	1	1/16	2	1	2	2	231	770	0.300	A514	A
25A	A325	1	1/16	2	1	2	2	196	777	0.252	A514/A36	A
25B	A325	1	1/16	2	1	2	2	222	774	0.287	A514/A36	A
75A	A325	1	1/16	2	1	2	2	182	950	0.192	A514/A36	A
75B	A325	1	1/16	2	1	2	2	142	921	0.155	A514/A36	A
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Note: Specimens 0 without filler plates, Specimens 25 with filler plates t=0.25in, Specimens 75 with filler plates t=3*0.25=0.75in
Main and splice plates A514, filler plates A36

Author(s)	**Frank, K. H.; Yura, J. A.**
Title	**An Experimental Study of Bolted Shear Connections**
Source	**Report No. FHWA/RD-81/148, FHWA, U.S. Dep of Transportation, Washington, D.C.**
Year	**1981**
Ref. in Bolt Guide	**5.53**

Faying Surface *Specimens 1 - 8*
Organic zinc (6 mils) on sandblasted surface
Specimens 9 - 16
Organic zinc (8 mils) plus Epoxy Topcoat (3 mils) on sandbl. surface
Specimens 17 - 22
Inorganic zinc (3 mils) on sandblasted surface
Specimens 23 - 32
Millscale
Specimens 33 - 42
Sandblasted

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
1	A325	7/8	1/16	1	1	1	2	---	---	0.480	A572	Unclassified
2	A325	7/8	1/16	1	1	1	2	---	---	0.520	A572	"
3	A325	7/8	1/8	1	1	1	2	---	---	0.400	A572	"
4	A325	7/8	1/8	1	1	1	2	---	---	0.480	A572	"
5	A325	7/8	1/8	1	1	1	2	---	---	0.430	A572	"
6	A325	7/8	1/8	1	1	1	2	---	---	0.470	A572	"
7	A325	7/8	1/4	1	1	1	2	---	---	0.480	A572	"
8	A325	7/8	1/4	1	1	1	2	---	---	0.410	A572	"
9	A325	7/8	1/16	1	1	1	2	---	---	0.340	A572	"
10	A325	7/8	1/16	1	1	1	2	---	---	0.380	A572	"
11	A325	7/8	1/8	1	1	1	2	---	---	0.310	A572	"
12	A325	7/8	1/8	1	1	1	2	---	---	0.330	A572	"
13	A325	7/8	1/8	1	1	1	2	---	---	0.240	A572	"
14	A325	7/8	1/8	1	1	1	2	---	---	0.330	A572	"
15	A325	7/8	1/4	1	1	1	2	---	---	0.320	A572	"
16	A325	7/8	1/4	1	1	1	2	---	---	0.340	A572	"
17	A325	7/8	1/16	1	1	1	2	---	---	0.520	A572	"
18	A325	7/8	1/16	1	1	1	2	---	---	0.540	A572	"
19	A325	7/8	1/8	1	1	1	2	---	---	0.490	A572	"
20	A325	7/8	1/8	1	1	1	2	---	---	0.480	A572	"
21	A325	7/8	1/8	1	1	1	2	---	---	0.410	A572	"
22	A325	7/8	1/8	1	1	1	2	---	---	0.420	A572	"
23	A325	7/8	1/8	1	1	1	2	---	---	0.290	A36	A
24	A325	7/8	1/8	1	1	1	2	---	---	0.410	A36	A
25	A325	7/8	1/16	1	1	1	2	---	---	0.200	A572	A
26	A325	7/8	1/16	1	1	1	2	---	---	0.210	A572	A
27	A325	7/8	1/8	1	1	1	2	---	---	0.230	A572	A
28	A325	7/8	1/8	1	1	1	2	---	---	0.210	A572	A
29	A325	7/8	1/4	1	1	1	2	---	---	0.240	A572	A
30	A325	7/8	1/4	1	1	1	2	---	---	0.210	A572	A
31	A325	7/8	1/8	1	1	1	2	---	---	0.300	A514	A
32	A325	7/8	1/8	1	1	1	2	---	---	0.300	A514	A
33	A325	7/8	1/8	1	1	1	2	---	---	0.700	A36	B
34	A325	7/8	1/8	1	1	1	2	---	---	0.750	A36	B
35	A325	7/8	1/16	1	1	1	2	---	---	0.700	A572	B

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
36	A325	7/8	1/16	1	1	1	2	---	---	0.610	A572	B
37	A325	7/8	1/8	1	1	1	2	---	---	0.750	A572	B
38	A325	7/8	1/8	1	1	1	2	---	---	0.770	A572	B
39	A325	7/8	1/4	1	1	1	2	---	---	0.630	A572	B
40	A325	7/8	1/4	1	1	1	2	---	---	0.760	A572	B
41	A325	7/8	1/8	1	1	1	2	---	---	0.610	A514	B
42	A325	7/8	1/8	1	1	1	2	---	---	0.620	A514	B
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Note: Only μ is given in ref. (no data on F_s and P)

Author(s)	**Frank, K. H.; Yura, J. A.**
Title	**An Experimental Study of Bolted Shear Connections**
Source	**Report No. FHWA/RD-81/148, FHWA, U.S. Dep of Transportation, Washington, D.C**
Year	**1981**
Ref. in Bolt Guide	**5.53**

Faying Surface *Specimens 1 - 3*
Inorganic zinc (3 - 4 mils) on sandblasted surface
Specimens 4 - 6
Organic zinc (4 mils) on sandbl. surface
Specimen 7
Organic zinc (4 mils) plus Epoxy Topcoat (2 mils) on sandblasted surface
Specimens 8 - 11
Sandblasted

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
1a	A325	7/8	1/16	2	5	10	2	2,073	4,573	0.453	A572	Unclassified
1b	A325	7/8	1/16	2	5	10	2	2,211	4,573	0.483	A572	"
2a	A325	7/8	1/16	2	5	10	2	1,984	4,581	0.433	A572	"
2b	A325	7/8	1/16	2	5	10	2	1,984	4,581	0.433	A572	"
3a	A325	7/8	3/16	2	5	10	2	1,930	4,626	0.417	A572	"
3b	A325	7/8	3/16	2	5	10	2	2,175	4,626	0.470	A572	"
4a	A325	7/8	1/16	2	5	10	2	1,979	4,608	0.430	A572	"
4b	A325	7/8	1/16	2	5	10	2	2,220	4,608	0.482	A572	"
5a	A325	7/8	1/16	2	5	10	2	1,948	4,590	0.424	A572	"
5b	A325	7/8	1/16	2	5	10	2	2,091	4,590	0.455	A572	"
6a	A325	7/8	3/16	2	5	10	2	1,748	4,670	0.374	A572	"
6b	A325	7/8	3/16	2	5	10	2	2,055	4,670	0.440	A572	"
7a	A325	7/8	1/16	2	5	10	2	1,019	4,581	0.222	A572	"
7b	A325	7/8	1/16	2	5	10	2	1,076	4,581	0.235	A572	"
8a	A325	7/8	1/16	2	5	9	2	2,371	4,107	0.577	A572	B
8b	A325	7/8	1/16	2	5	8.5	2	2,411	3,879	0.621	A572	B
9a	A325	7/8	1/16	2	5	10	2	2,019	4,110	0.491	A572	B
9b	A325	7/8	1/16	2	5	10	2	2,273	4,110	0.553	A572	B
10a	A325	7/8	1/16	2	5	10	2	1,281	3,354	0.382	A572	B
10b	A325	7/8	1/16	2	5	10	2	1,583	3,354	0.472	A572	B
11a	A325	7/8	1/16	2	5	10	2	1,837	3,799	0.484	A572	B
11b	A325	7/8	1/16	2	5	10	2	2,059	3,799	0.542	A514	B
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Note: Specimen 8 was assembled in Lab., Specimen 9 by Fabricator A, Specimen 10 by Fabricator B and Specimen 11 with Torque Control bolts (Lejeune) by manufacturer.

Specimen configuration was designed so that 2 tests per specimen could be obtained (except Specimen 1). There was either slip in the horizontal or the vertical configuration, sometimes even in a mixed mode. Therefore the number of bolts in a row and the number of bolt rows can be interchanged according to the slip mode.

Specimen 8a had only 18 bolts (2 removed) and Specimen 8b only 17 (3 removed), due to capacity restriction of testing machine.

Author(s)	**Yura, J. A.; Frank, K. H.; Cayes, L.**
Title	**Bolted Friction Connections with Weathering Steel**
Source	**Journal of the Structural Division, ASCE, Vol. 107, ST 11, pp. 2071 - 2087**
Year	**1981**
Ref. in Bolt Guide	**5.55**

No specific data is given; only average slip coefficients are presented.
The following reference does not contain more detailed data:

Yura, J. A.; Frank, K. H.; Cayes, L.
Friction-Type Bolted Shear Connections with A588 Weathering Steel
Report No. FHWA/RD-80, FHWA, U.S. Dep. of Transportation, Washington, D.C.
1980

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class	Number of Tests	Stand. Dev. [—]
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient				
Series "1"										0.20	A588	A	4	0.015
Series "2"										0.20	A588	A	2	0.015
Series "3"										0.20	A588	A	5	0.009
Series "4"										0.26	A588	A	5	0.016
Series "5"										0.28	A588	A	5	0.008
Series "6"										0.23	A588	A	5	0.019
Series "7"										0.23	A588	A	5	0.016
										0.232			***31***	***0.0325***
Series "11"										0.59	A588	B	5	0.083
Series "12"										0.38	A588	B	5	0.018
Series "13"										0.50	A588	B	5	0.078
Series "14"										0.60	A588	B	5	0.047
										0.518			***20***	***0.107***

Note: More tests were carried out with exposed faying surfaces (3 (20 tests), 6 (19) or 12 (31) months)
Class B surfaces of Series "11" to "14" were grit-blasted

Author(s)	**Hou, Z.; He, X.**
Title	**The Deformation Criteria of High-Strength Bolt Connections Subjected to Shearing Load**
Source	**Proceedings, 4th Pacific Structural Steel Conference, Singapore, Vol. 2, pp. 137 - 142**
Year	**1995**
Ref. in Bolt Guide	**---**

Faying Surface *Specimens A*
sand-blasted
Specimens C
"smoothing"

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
A1	—	—	—	1	1	1	2	—	102	0.451	Not reported	B
A2	—	—	—	1	1	1	2	—	90	0.430	"	B
A3	—	—	—	1	1	1	2	—	53	0.465	"	B
A4	—	—	—	1	1	1	2	—	100	0.430	"	B
A5	—	—	—	1	1	1	2	—	101	0.365	"	B
A6	—	—	—	1	1	1	2	—	99	0.445	"	B
A7	—	—	—	1	1	1	2	—	100	0.463	"	B
A8	—	—	—	1	1	1	2	—	101	0.513	"	B
A9	—	—	—	1	1	1	2	—	100	0.397	"	B
A10	—	—	—	1	1	1	2	—	90	0.422	"	B
C1	—	—	—	1	1	1	2	—	98	0.204	"	n/a
C2	—	—	—	1	1	1	2	—	106	0.204	"	n/a
C3	—	—	—	1	1	1	2	—	79	0.126	"	n/a
C4	—	—	—	1	1	1	2	—	97	0.207	"	n/a
C5	—	—	—	1	1	1	2	—	97	0.216	"	n/a
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		

Note: There is no mention of when the slip load was measured (first slip, major slip, etc?).

Author(s) **Stankevicius, Josi, Grondin and Kulak**
Title **Measurement of Slip Coefficient for Grade ASTM A588 Steel**
Source **Structural Engineering Report 268, Department of Civil and Environmental**
Year **2007**

Faying Surface

Specimens 4N
Degreased surfaces
Specimens 4S
As-received surfaces
Specimens 4T
Pretension of 90% of tensile stren
Specimens 4D
Oversized hole
Specimens 4P
Prunched holes

Specimens 5N
Degreased surfaces
Specimens 5S
As-received surfaces
Specimens 5T
Pretension of 90% of tensile strength
Specimens 5D
Oversized hole
Specimens 5P
Prunched holes

Notes: Unless otherwise indicated, all specimens prepared with bolts pretensioned to 70% of the bolt tensile strength and drilled holes.

Specimens from the 4 series were prepared with 1/2 in. plates. The specimens from the 5 series were prepared with 5/8 in. plates.

				no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying surfaces	slip load	total bolt preload	slip coefficient		
Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
4N1	A325	3/4	1/16	1	1	1	2	101	124	0.41	A588	A
4N2	A325	3/4	1/16	1	1	1	2	82	125	0.33	A588	A
4N3	A325	3/4	1/16	1	1	1	2	97	125	0.39	A588	A
4N4	A325	3/4	1/16	1	1	1	2	90	129	0.35	A588	A
4N5	A325	3/4	1/16	1	1	1	2	117	126	0.47	A588	A
4N6	A325	3/4	1/16	1	1	1	2	110	127	0.43	A588	A
4N7	A325	3/4	1/16	1	1	1	2	84	127	0.33	A588	A
4N8	A325	3/4	1/16	1	1	1	2	86	120	0.36	A588	A
4N9	A325	3/4	1/16	1	1	1	2	87	127	0.34	A588	A
4N10	A325	3/4	1/16	1	1	1	2	117	127	0.46	A588	A
4N11	A325	3/4	1/16	1	1	1	2	104	128	0.41	A588	A
4N12	A325	3/4	1/16	1	1	1	2	106	128	0.42	A588	A
4N14	A325	3/4	1/16	1	1	1	2	106	131	0.41	A588	A
4N15	A325	3/4	1/16	1	1	1	2	136	133	0.51	A588	A
4S1	A325	3/4	1/16	1	1	1	2	73	128	0.29	A588	A
4S2	A325	3/4	1/16	1	1	1	2	83	126	0.33	A588	A
4S3	A325	3/4	1/16	1	1	1	2	85	127	0.33	A588	A
4S4	A325	3/4	1/16	1	1	1	2	84	128	0.33	A588	A
4S5	A325	3/4	1/16	1	1	1	2	79	129	0.31	A588	A
4S6	A325	3/4	1/16	1	1	1	2	77	126	0.31	A588	A
4S7	A325	3/4	1/16	1	1	1	2	83	130	0.32	A588	A
4S8	A325	3/4	1/16	1	1	1	2	72	126	0.29	A588	A
4S9	A325	3/4	1/16	1	1	1	2	78	133	0.29	A588	A
4S10	A325	3/4	1/16	1	1	1	2	88	126	0.35	A588	A
4T1	A325	3/4	1/16	1	1	1	2	108	164	0.33	A588	A
4T2	A325	3/4	1/16	1	1	1	2	140	163	0.43	A588	A
4T3	A325	3/4	1/16	1	1	1	2	130	166	0.39	A588	A
4T4	A325	3/4	1/16	1	1	1	2	131	163	0.40	A588	A
4T5	A325	3/4	1/16	1	1	1	2	136	163	0.42	A588	A

Specimen	Bolt	ϕ_B	HC	n_L	n_R	n	m	F_s	P	μ	Plate	Surface
	Type	[in]	[in]	[—]	[—]	[—]	[—]	[kN]	[kN]	[—]	Grade	Class
5N1	A325	3/4	1/16	1	1	1	2	83	127	0.33	A588	A
5N2	A325	3/4	1/16	1	1	1	2	91	127	0.36	A588	A
5N3	A325	3/4	1/16	1	1	1	2	94	130	0.36	A588	A
5N4	A325	3/4	1/16	1	1	1	2	110	129	0.43	A588	A
5N5	A325	3/4	1/16	1	1	1	2	115	128	0.45	A588	A
5N6	A325	3/4	1/16	1	1	1	2	104	127	0.41	A588	A
5N7	A325	3/4	1/16	1	1	1	2	99	128	0.39	A588	A
5N8	A325	3/4	1/16	1	1	1	2	85	128	0.33	A588	A
5N9	A325	3/4	1/16	1	1	1	2	120	127	0.47	A588	A
5N10	A325	3/4	1/16	1	1	1	2	107	130	0.41	A588	A
5S1	A325	3/4	1/16	1	1	1	2	106	133	0.40	A588	A
5S2	A325	3/4	1/16	1	1	1	2	94	129	0.37	A588	A
5S3	A325	3/4	1/16	1	1	1	2	92	124	0.37	A588	A
5S4	A325	3/4	1/16	1	1	1	2	107	128	0.42	A588	A
5S5	A325	3/4	1/16	1	1	1	2	80	127	0.31	A588	A
5S6	A325	3/4	1/16	1	1	1	2	76	130	0.29	A588	A
5S7	A325	3/4	1/16	1	1	1	2	71	126	0.28	A588	A
5S8	A325	3/4	1/16	1	1	1	2	105	126	0.42	A588	A
5S9	A325	3/4	1/16	1	1	1	2	95	129	0.37	A588	A
5S10	A325	3/4	1/16	1	1	1	2	108	126	0.43	A588	A
5T1	A325	3/4	1/16	1	1	1	2	155	162	0.48	A588	A
5T2	A325	3/4	1/16	1	1	1	2	156	164	0.48	A588	A
5T3	A325	3/4	1/16	1	1	1	2	139	162	0.43	A588	A
5T4	A325	3/4	1/16	1	1	1	2	105	161	0.33	A588	A
5T5	A325	3/4	1/16	1	1	1	2	155	160	0.48	A588	A
5T6	A325	3/4	1/16	1	1	1	2	155	163	0.48	A588	A
5T7	A325	3/4	1/16	1	1	1	2	115	161	0.36	A588	A
5T8	A325	3/4	1/16	1	1	1	2	145	161	0.45	A588	A
5T9	A325	3/4	1/16	1	1	1	2	145	162	0.45	A588	A
5T10	A325	3/4	1/16	1	1	1	2	170	162	0.52	A588	A
5D1	A325	3/4	3/16	1	1	1	2	120	129	0.47	A588	A
5D2	A325	3/4	3/16	1	1	1	2	100	130	0.39	A588	A
5D3	A325	3/4	3/16	1	1	1	2	100	129	0.39	A588	A
5D4	A325	3/4	3/16	1	1	1	2	105	127	0.41	A588	A
5D5	A325	3/4	3/16	1	1	1	2	115	131	0.44	A588	A
5D6	A325	3/4	3/16	1	1	1	2	93	127	0.37	A588	A
5D7	A325	3/4	3/16	1	1	1	2	120	128	0.47	A588	A
5D8	A325	3/4	3/16	1	1	1	2	135	127	0.53	A588	A
5D9	A325	3/4	3/16	1	1	1	2	115	128	0.45	A588	A
5D10	A325	3/4	3/16	1	1	1	2	98	130	0.38	A588	A
5P1	A325	3/4	1/16	1	1	1	2	108	127	0.43	A588	A
5P2	A325	3/4	1/16	1	1	1	2	100	127	0.40	A588	A
5P3	A325	3/4	1/16	1	1	1	2	90	126	0.36	A588	A
5P4	A325	3/4	1/16	1	1	1	2	107	129	0.42	A588	A
5P5	A325	3/4	1/16	1	1	1	2	100	129	0.39	A588	A
5P6	A325	3/4	1/16	1	1	1	2	90	131	0.34	A588	A
5P7	A325	3/4	1/16	1	1	1	2	96	129	0.37	A588	A
5P8	A325	3/4	1/16	1	1	1	2	100	127	0.39	A588	A
5P9	A325	3/4	1/16	1	1	1	2	114	129	0.44	A588	A
5P10	A325	3/4	1/16	1	1	1	2	115	127	0.45	A588	A
4D1	A325	3/4	3/16	1	1	1	2	84	126	0.34	A588	A
4D2	A325	3/4	3/16	1	1	1	2	103	126	0.41	A588	A
4D3	A325	3/4	3/16	1	1	1	2	72	124	0.29	A588	A

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
4D4	A325	3/4	3/16	1	1	1	2	77	126	0.31	A588	A
4D5	A325	3/4	3/16	1	1	1	2	124	126	0.49	A588	A
4D6	A325	3/4	3/16	1	1	1	2	82	127	0.32	A588	A
4D7	A325	3/4	3/16	1	1	1	2	80	129	0.31	A588	A
4D8	A325	3/4	3/16	1	1	1	2	92	128	0.36	A588	A
4D9	A325	3/4	3/16	1	1	1	2	89	129	0.35	A588	A
4D10	A325	3/4	3/16	1	1	1	2	95	131	0.36	A588	A
4P1	A325	3/4	1/16	1	1	1	2	94	131	0.36	A588	A
4P2	A325	3/4	1/16	1	1	1	2	88	128	0.34	A588	A
4P3	A325	3/4	1/16	1	1	1	2	85	122	0.35	A588	A
4P4	A325	3/4	1/16	1	1	1	2	93	130	0.36	A588	A
4P5	A325	3/4	1/16	1	1	1	2	88	130	0.34	A588	A
4P6	A325	3/4	1/16	1	1	1	2	94	127	0.37	A588	A
4P7	A325	3/4	1/16	1	1	1	2	88	131	0.34	A588	A
4P8	A325	3/4	1/16	1	1	1	2	92	129	0.36	A588	A
4P9	A325	3/4	1/16	1	1	1	2	96	129	0.37	A588	A
4P10	A325	3/4	1/16	1	1	1	2	84	131	0.32	A588	A
4N1-2	A325	3/4	1/16	2	1	2	2	170	268	0.32	A588	A
4N3-2	A325	3/4	1/16	2	1	2	2	190	270	0.35	A588	A
4N4-2	A325	3/4	1/16	2	1	2	2	185	264	0.35	A588	A
4N8-2	A325	3/4	1/16	2	1	2	2	173	263	0.33	A588	A
4N10-2	A325	3/4	1/16	2	1	2	2	169	250	0.34	A588	A
4N12-2	A325	3/4	1/16	2	1	2	2	193	257	0.38	A588	A
4N14-2	A325	3/4	1/16	2	1	2	2	173	256	0.34	A588	A
4N15-2	A325	3/4	1/16	2	1	2	2	181	253	0.36	A588	A
4S1-2	A325	3/4	1/16	2	1	2	2	141	257	0.27	A588	A
4S2-2	A325	3/4	1/16	2	1	2	2	130	253	0.26	A588	A
4S3-2	A325	3/4	1/16	2	1	2	2	126	253	0.25	A588	A
4S4-2	A325	3/4	1/16	2	1	2	2	148	251	0.29	A588	A
4S5-2	A325	3/4	1/16	2	1	2	2	132	256	0.26	A588	A
4S6-2	A325	3/4	1/16	2	1	2	2	158	256	0.31	A588	A
4S7-2	A325	3/4	1/16	2	1	2	2	150	253	0.30	A588	A
4S8-2	A325	3/4	1/16	2	1	2	2	143	254	0.28	A588	A
4S9-2	A325	3/4	1/16	2	1	2	2	174	255	0.34	A588	A
4S10-2	A325	3/4	1/16	2	1	2	2	153	251	0.30	A588	A
4T1-2	A325	3/4	1/16	2	1	2	2	228	322	0.35	A588	A
4T2-2	A325	3/4	1/16	2	1	2	2	185	322	0.29	A588	A
4T3-2	A325	3/4	1/16	2	1	2	2	188	322	0.29	A588	A
4T4-2	A325	3/4	1/16	2	1	2	2	183	323	0.28	A588	A
4T5-2	A325	3/4	1/16	2	1	2	2	214	323	0.33	A588	A
5N1-2	A325	3/4	1/16	2	1	2	2	222	252	0.44	A588	A
5N2-2	A325	3/4	1/16	2	1	2	2	288	253	0.57	A588	A
5N3-2	A325	3/4	1/16	2	1	2	2	182	252	0.36	A588	A
5N4-2	A325	3/4	1/16	2	1	2	2	235	253	0.46	A588	A
5N5-2	A325	3/4	1/16	2	1	2	2	252	252	0.50	A588	A
5N6-2	A325	3/4	1/16	2	1	2	2	259	253	0.51	A588	A
5N7-2	A325	3/4	1/16	2	1	2	2	250	253	0.49	A588	A
5N8-2	A325	3/4	1/16	2	1	2	2	250	252	0.50	A588	A
5N9-2	A325	3/4	1/16	2	1	2	2	210	252	0.42	A588	A
5S1-2	A325	3/4	1/16	2	1	2	2	170	253	0.34	A588	A
5S2-2	A325	3/4	1/16	2	1	2	2	176	252	0.35	A588	A
5S3-2	A325	3/4	1/16	2	1	2	2	181	256	0.35	A588	A
5S4-2	A325	3/4	1/16	2	1	2	2	159	253	0.31	A588	A

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
5S5-2	A325	3/4	1/16	2	1	2	2	186	252	0.37	A588	A
5S6-2	A325	3/4	1/16	2	1	2	2	196	251	0.39	A588	A
5S7-2	A325	3/4	1/16	2	1	2	2	206	250	0.41	A588	A
5S8-2	A325	3/4	1/16	2	1	2	2	213	253	0.42	A588	A
5S9-2	A325	3/4	1/16	2	1	2	2	171	251	0.34	A588	A
5S10-2	A325	3/4	1/16	2	1	2	2	182	252	0.36	A588	A
5T2-2	A325	3/4	1/16	2	1	2	2	250	325	0.38	A588	A
5T3-2	A325	3/4	1/16	2	1	2	2	300	322	0.47	A588	A
5T4-2	A325	3/4	1/16	2	1	2	2	320	324	0.49	A588	A
5T5-2	A325	3/4	1/16	2	1	2	2	280	319	0.44	A588	A
5T6-2	A325	3/4	1/16	2	1	2	2	275	323	0.43	A588	A
5T7-2	A325	3/4	1/16	2	1	2	2	300	323	0.46	A588	A
5T8-2	A325	3/4	1/16	2	1	2	2	325	324	0.50	A588	A
5T9-2	A325	3/4	1/16	2	1	2	2	320	326	0.49	A588	A
5T10-2	A325	3/4	3/16	2	1	2	2	275	324	0.42	A588	A
5D1-2	A325	3/4	3/16	2	1	2	2	245	258	0.47	A588	A
5D2-2	A325	3/4	3/16	2	1	2	2	267	254	0.53	A588	A
5D3-2	A325	3/4	3/16	2	1	2	2	261	253	0.52	A588	A
5D4-2	A325	3/4	3/16	2	1	2	2	165	251	0.33	A588	A
5D5-2	A325	3/4	3/16	2	1	2	2	245	250	0.49	A588	A
5D6-2	A325	3/4	3/16	2	1	2	2	260	258	0.50	A588	A
5D7-2	A325	3/4	3/16	2	1	2	2	246	249	0.49	A588	A
5D8-2	A325	3/4	3/16	2	1	2	2	225	254	0.44	A588	A
5D9-2	A325	3/4	3/16	2	1	2	2	220	251	0.44	A588	A
5D10-2	A325	3/4	1/16	2	1	2	2	262	254	0.52	A588	A
5P1-2	A325	3/4	1/16	2	1	2	2	260	257	0.51	A588	A
5P2-2	A325	3/4	1/16	2	1	2	2	240	257	0.47	A588	A
5P3-2	A325	3/4	1/16	2	1	2	2	277	250	0.55	A588	A
5P4-2	A325	3/4	1/16	2	1	2	2	260	255	0.51	A588	A
5P5-2	A325	3/4	1/16	2	1	2	2	270	250	0.54	A588	A
5P6-2	A325	3/4	1/16	2	1	2	2	226	252	0.45	A588	A
5P7-2	A325	3/4	1/16	2	1	2	2	230	249	0.46	A588	A
5P8-2	A325	3/4	1/16	2	1	2	2	220	252	0.44	A588	A
5P9-2	A325	3/4	1/16	2	1	2	2	214	254	0.42	A588	A
5P10-2	A325	3/4	3/16	2	1	2	2	167	255	0.33	A588	A
4D1-2	A325	3/4	3/16	2	1	2	2	165	249	0.33	A588	A
4D2-2	A325	3/4	3/16	2	1	2	2	131	250	0.26	A588	A
4D3-2	A325	3/4	3/16	2	1	2	2	161	255	0.32	A588	A
4D4-2	A325	3/4	3/16	2	1	2	2	135	251	0.27	A588	A
4D5-2	A325	3/4	3/16	2	1	2	2	180	254	0.35	A588	A
4D6-2	A325	3/4	3/16	2	1	2	2	170	255	0.33	A588	A
4D7-2	A325	3/4	3/16	2	1	2	2	165	251	0.33	A588	A
4D8-2	A325	3/4	3/16	2	1	2	2	158	259	0.31	A588	A
4D9-2	A325	3/4	3/16	2	1	2	2	156	260	0.30	A588	A
4D10-2	A325	3/4	1/16	2	1	2	2	147	255	0.29	A588	A
4P1-2	A325	3/4	1/16	2	1	2	2	175	258	0.34	A588	A
4P2-2	A325	3/4	1/16	2	1	2	2	204	249	0.41	A588	A
4P3-2	A325	3/4	1/16	2	1	2	2	205	251	0.41	A588	A
4P4-2	A325	3/4	1/16	2	1	2	2	207	256	0.40	A588	A
4P5-2	A325	3/4	1/16	2	1	2	2	170	254	0.33	A588	A
4P6-2	A325	3/4	1/16	2	1	2	2	195	255	0.38	A588	A
4P7-2	A325	3/4	1/16	2	1	2	2	164	257	0.32	A588	A
4P8-2	A325	3/4	1/16	2	1	2	2	219	251	0.44	A588	A

Specimen	Bolt Type	ϕ_B [in]	HC [in]	n_L [—]	n_R [—]	n [—]	m [—]	F_s [kN]	P [kN]	μ [—]	Plate Grade	Surface Class
4P9-2	A325	3/4	1/16	2	1	2	2	196	252	0.39	A588	A
4P10-2	A325	3/4	1/16	2	1	2	2	192	254	0.38	A588	A
		bolt diameter	hole clearance	no. of bolts in a row	no. of bolt rows	total no. of bolts	no. of faying	slip load	total bolt preload	slip coefficient		

Appendix B

Description of Truss Models

Description of truss models

Two truss models were built to investigate the effect of slip magnitude in joints of long span truss. The model truss used for developing the non-linear analysis procedure described in section 4.2 was obtained from Cives Steel Company. The truss consists of a single span 331.33 ft long subdivided into 17 panels. Figure B-1 identifies the truss geometry and node numbers used to generate the truss. The coordinates of the joints are presented in Table B-1. Figure B-2 shows the locations of the truss members connections to gusset plates. End elements were added to all points of discontinuities in the truss. A description of the member sizes and end connection details (length of end element and number of bolts in the joint in the slip critical joint) is provided in Table B-2.

The geometry of the flat roof truss and node numbers at the intersection points between truss members are presented in Figure B-3. The joint coordinates are summarized in Table B-3. A description of the member sizes and end connection details for this truss configuration is presented in Table B-4.

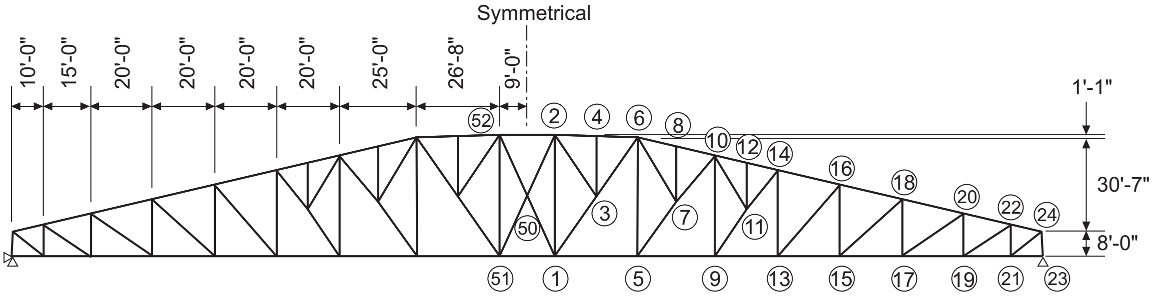

Figure B-1 – Joint numbers

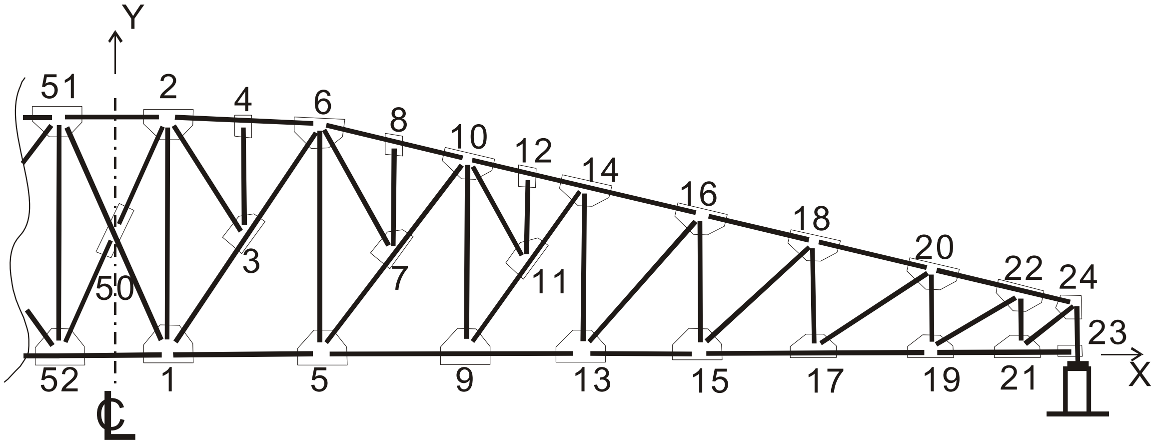

Figure B-2 – Configurations of end connections

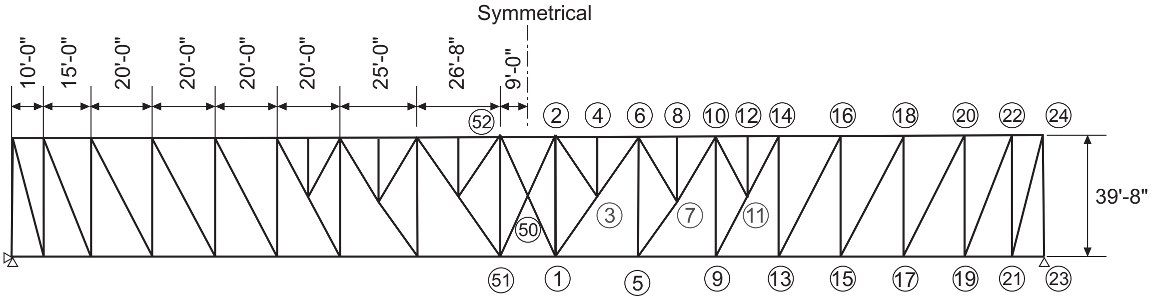

Figure B-3 – Flat roof truss configuration and joint numbers

Table B-1 – Nodal coordinates of the original (sloping roof) truss

Node Number	X (ft)	Y (ft)
1	9.000	0.000
2	9.000	39.667
3	22.333	19.562
4	22.333	39.125
5	35.667	0.000
6	35.667	38.583
7	48.167	17.821
8	48.167	35.643
9	60.667	0.000
10	60.667	32.702
11	70.667	15.175
12	70.667	30.349
13	80.667	0.000
14	80.667	27.997
15	100.667	0.000
16	100.667	23.292
17	120.667	0.000
18	120.667	18.587
19	140.667	0.000
20	140.667	13.881
21	155.667	0.000
22	155.667	10.353
23	165.667	0.000
24	165.667	8.000
50	0.000	19.833

Table B-2 – Configuration of the original truss

Node Number		Member			Connections			
					End1		End2	
@End1	@End2	Number	Length (ft)	Size	Length (ft)	Number of bolts	Length (ft)	Number of bolts
02	04	0204	13.333	W14x283	2.708	22	—	0
04	06	0406	13.333	W14x283	—	0	5.708	46
06	08	0608	12.500	W14x257	5.875	46	—	0
08	10	0810	12.500	W14x257	—	0	2.458	20
10	12	1012	10.000	W14x257	2.708	20	—	0
12	14	1214	10.000	W14x257	—	0	—	0
14	16	1416	20.000	W14x257	—	0	2.708	22
16	18	1618	20.000	W14x257	2.958	22	—	0
18	20	1820	20.000	W14x257	—	0	2.458	20
20	22	2022	15.000	W14x176	2.708	20	—	0
22	24	2224	10.000	W14x176	—	0	2.813	16
01	05	0105	26.667	W14x193	2.708	22	4.458	30
05	09	0509	25.000	W14x193	4.208	34	—	0
09	13	0913	20.000	W14x193	—	0	2.458	20
13	15	1315	20.000	W14x176	2.458	20	2.208	18
15	17	1517	20.000	W14x176	2.208	18	—	0
17	19	1719	20.000	W14x176	—	0	3.208	14
19	21	1921	15.000	W14x109	3.208	14	—	0
21	23	2123	10.000	W14x109	—	0	1.479	4
01	02	0102	39.667	W14x176	2.917	10	2.438	8
03	04	0304	19.833	W14x34	1.646	4	1.188	4
05	06	0506	39.667	W14x99	2.917	10	2.500	8
07	08	0708	19.833	W14x34	1.583	4	1.208	4
09	10	0910	39.667	W14x283	2.417	8	2.000	6
11	12	1112	19.833	W14x34	1.375	4	1.208	4
13	14	1314	39.667	W14x283	2.417	8	2.000	6
15	16	1516	39.667	W14x283	1.896	6	1.500	4
17	18	1718	39.667	W14x283	2.563	6	1.500	6
19	20	1920	39.667	W14x283	3.063	8	1.729	8
21	22	2122	39.667	W14x283	4.063	12	2.292	12
23	24	2324	39.667	W14x132	0.917	4	3.5	16
01	03	0103	23.898	W14x193	2.750	4	—	0
03	06	0306	23.898	W14x193	—	0	2.646	6
05	07	0507	23.444	W14x176	2.542	6	—	0
07	10	0710	23.444	W14x176	—	0	2.042	6
09	11	0911	22.212	W14x283	1.854	4	—	0
11	14	1114	22.212	W14x283	—	0	2.104	4
13	16	1316	44.423	W14x283	2.000	6	1.667	4
15	18	1518	44.423	W14x257	2.167	6	1.854	6
17	20	1720	44.423	W14x132	3.063	10	2.563	10

Table B-2 – Cont'd

Node Number		Member			Connections			
					End1		End2	
@End1	@End2	Number	Length (ft)	Size	Length (ft)	Number of bolts	Length (ft)	Number of bolts
19	22	1922	42.408	W14x99	3.500	14	3.042	14
21	24	2124	40.908	W14x99	4.292	20	3.833	20
02	03	0203	23.898	W14x34	2.021	4	1.063	4
06	07	0607	23.444	W14x68	2.688	6	1.083	4
10	11	1011	22.212	W14x68	2.708	22	—	0
02	52	0252	18.000	W14x283	2.708	22	2.708	22
01	51	0151	18.000	W14x193	2.708	22	2.708	22
01	50	0150	21.780	W14x283	2.146	6	—	0
50	52	5052	21.780	W14x283	—	0	2.542	6
02	50	0250	21.780	W14x283	2.542	4	0.417	4
50	51	5051	21.780	W14x283	0.417	4	2.146	4

Table B-3 – Nodal coordinates of the flat roof truss

Node Number	X (ft)	Y (ft)
1	9.000	0.000
2	9.000	39.667
3	22.333	19.833
4	22.333	39.667
5	35.667	0.000
6	35.667	39.667
7	48.167	19.833
8	48.167	39.667
9	60.667	0.000
10	60.667	39.667
11	70.667	19.833
12	70.667	39.667
13	80.667	0.000
14	80.667	39.667
15	100.667	0.000
16	100.667	39.667
17	120.667	0.000
18	120.667	39.667
19	140.667	0.000
20	140.667	39.667
21	155.667	0.000
22	155.667	39.667
23	165.667	0.000
24	165.667	39.667
50	0.000	19.833

Table B-4 – Configuration of flat roof truss

Node Number		Member			Connections			
					End1		End2	
@End1	@End2	Number	Length (ft)	Size	Length (ft)	Number of bolts	Length (ft)	Number of bolts
02	04	0204	13.333	W14x283	2.708	20	—	0
04	06	0406	13.333	W14x283	—	0	5.708	20
06	08	0608	12.500	W14x257	5.875	18	—	0
08	10	0810	12.500	W14x257	—	0	2.458	18
10	12	1012	10.000	W14x257	2.708	16	—	0
12	14	1214	10.000	W14x257	—	0	—	0
14	16	1416	20.000	W14x257	—	0	2.708	14
16	18	1618	20.000	W14x257	2.958	12	—	0
18	20	1820	20.000	W14x257	—	0	2.458	8
20	22	2022	15.000	W14x176	2.708	4	—	0
22	24	2224	10.000	W14x176	—	0	2.813	2
01	05	0105	26.667	W14x193	2.708	18	4.458	18
05	09	0509	25.000	W14x193	4.208	16	—	0
09	13	0913	20.000	W14x193	—	0	2.458	14
13	15	1315	20.000	W14x176	2.458	12	2.208	12
15	17	1517	20.000	W14x176	2.208	8	—	0
17	19	1719	20.000	W14x176	—	0	3.208	4
19	21	1921	15.000	W14x109	3.208	2	—	0
21	23	2123	10.000	W14x109	—	0	1.479	2
01	02	0102	39.667	W14x176	2.917	2	2.438	2
03	04	0304	19.833	W14x34	1.646	2	1.188	2
05	06	0506	39.667	W14x99	2.917	2	2.500	2
07	08	0708	19.833	W14x34	1.583	2	1.208	2
09	10	0910	39.667	W14x283	2.417	2	2	2
11	12	1112	19.833	W14x34	1.375	2	1.208	2
13	14	1314	39.667	W14x283	2.417	4	2.000	4
15	16	1516	39.667	W14x283	1.896	6	1.500	6
17	18	1718	39.667	W14x283	2.563	6	1.500	6
19	20	1920	39.667	W14x283	3.063	8	1.729	8
21	22	2122	39.667	W14x283	4.063	8	2.292	8
23	24	2324	39.667	W14x132	0.917	8	3.500	8
01	03	0103	23.898	W14x193	2.750	2	—	0
03	06	0306	23.898	W14x193	—	0	2.646	2
05	07	0507	23.444	W14x176	2.542	2	—	0
07	10	0710	23.444	W14x176	—	0	2.042	2
09	11	0911	22.212	W14x283	1.854	4	—	0
11	14	1114	22.212	W14x283	—	0	2.104	4
13	16	1316	44.423	W14x283	2.000	6	1.667	6
15	18	1518	44.423	W14x257	2.167	6	1.854	6

Table B-4 – Cont'd

Node Number		Member			Connections			
					End1		End2	
@End1	@End2	Number	Length (ft)	Size	Length (ft)	Number of bolts	Length (ft)	Number of bolts
17	20	1720	44.423	W14x132	3.063	8	2.563	8
19	22	1922	42.408	W14x99	3.500	8	3.042	8
21	24	2124	40.908	W14x99	4.292	8	3.833	8
02	03	0203	23.898	W14x34	2.021	2	1.063	2
06	07	0607	23.444	W14x68	2.688	2	1.083	2
10	11	1011	22.212	W14x68	2.708	2	—	2
02	52	0252	18.000	W14x283	2.708	18	2.708	18
01	51	0151	18.000	W14x193	2.708	20	2.708	20
01	50	0150	9.000	W14x283	2.146	2	—	0
50	52	5052	40.675	W14x283	—	0	2.542	2
02	50	0250	40.675	W14x283	2.542	2	0.417	2
50	51	5051	9.000	W14x283	0.417	2	2.146	2

Note: Member length is the distance between the nodes at two ends.