

Variables Affecting The Assembly Bolt Stress Developed During Manual Tightening



Jim Payne, Consultant, JPAC Inc.,
Long Valley, New Jersey, USA

A. Fitzgerald (Jerry) Waterland, III, VSP Technologies, Inc.,
Prince George, Virginia, USA

Purpose and Goals

- Explore the effect of different variables on the bolt stress developed during manual bolt tightening of small diameter bolts.
- Compare the range of bolt load scatter found to the commonly accepted $\pm 50\%$ of the average load for manual assembly.
- Compare the average bolt load achieved during manual bolt tightening of small diameter bolts to the load predicted by the so called “Petrie” formula for probable bolt stress.

Original Research by E. C. Petrie

In 1936 Mr. E. C. Petrie reported on a project where the elongation of bolts in manually assembled joints was measured.

Previously assembled joints having various bolt sizes were disassembled after carefully measuring the assembled length of the bolts.

The unloaded bolts were again measured to determine the elongation, or “stretch” of these bolts and hence the inferred assembled load in each bolt.

Original Research by E. C. Petrie

Evaluation of the data led to the experimentally determined so called "Petrie" bolt stress formula of:

$$\begin{aligned}\text{Petrie Stress} &= 45,000 /(\text{bolt diameter-in.})^{0.5} \text{ psi} \\ &= 1564 /(\text{bolt diameter-mm})^{0.5} \text{ Mpa}\end{aligned}$$

This represents the probable average stress achieved by a typical mechanic who is considered an experienced bolted joint assembler.

This relationship is currently presented in Appendix S of the ASME Code, Section VIII as the “probable bolt stress developed manually, when using standard wrenches”

Probable Bolt Stress vs Diameter

Petrie's Equation

$$\text{Stress} = (45,000 \text{ psi}) / (\text{bolt dia.})^{.5}$$

ASME B&PV Section VIII,
(Appendix S)

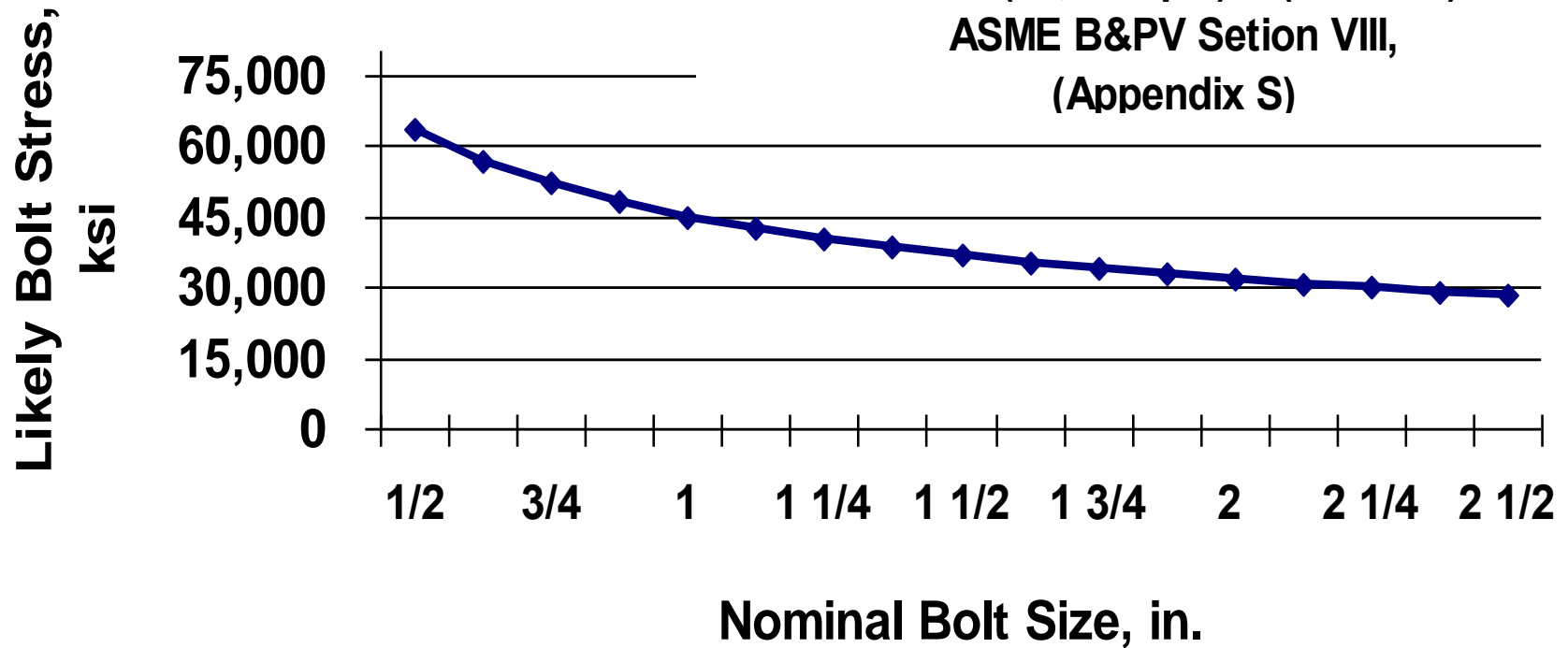
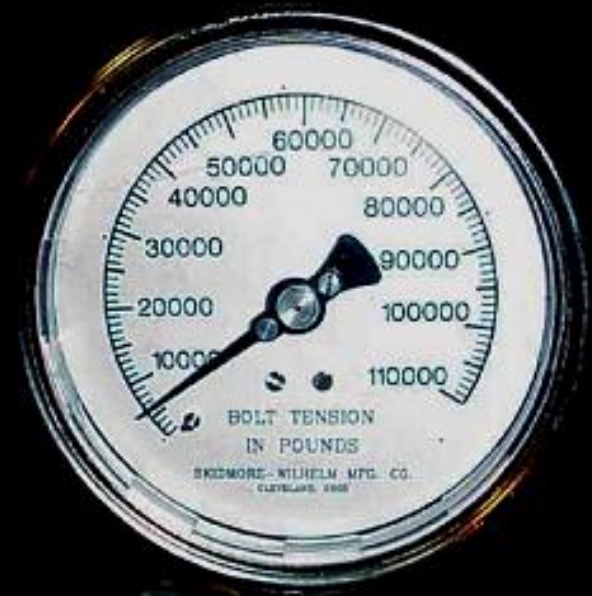


FIGURE 1 PROBABLE BOLT STRESS VS DIAMETER

Diverse Group of Volunteer Mechanics Enhance Significance of Findings

- Testing was conducted over a period of several months during VSP flanged joint assembly training classes at:
 - 10 different plant sites from
 - 6 different companies from
 - 4 different industries
- Training attendees were typically:
 - multi-skilled maintenance craftsmen,
 - pipefitters, welders,
 - maintenance foremen and maintenance planners.
- The 63 Participants were not selected, they volunteered!

Skidmore - Wilhelm Load-Tension Tester



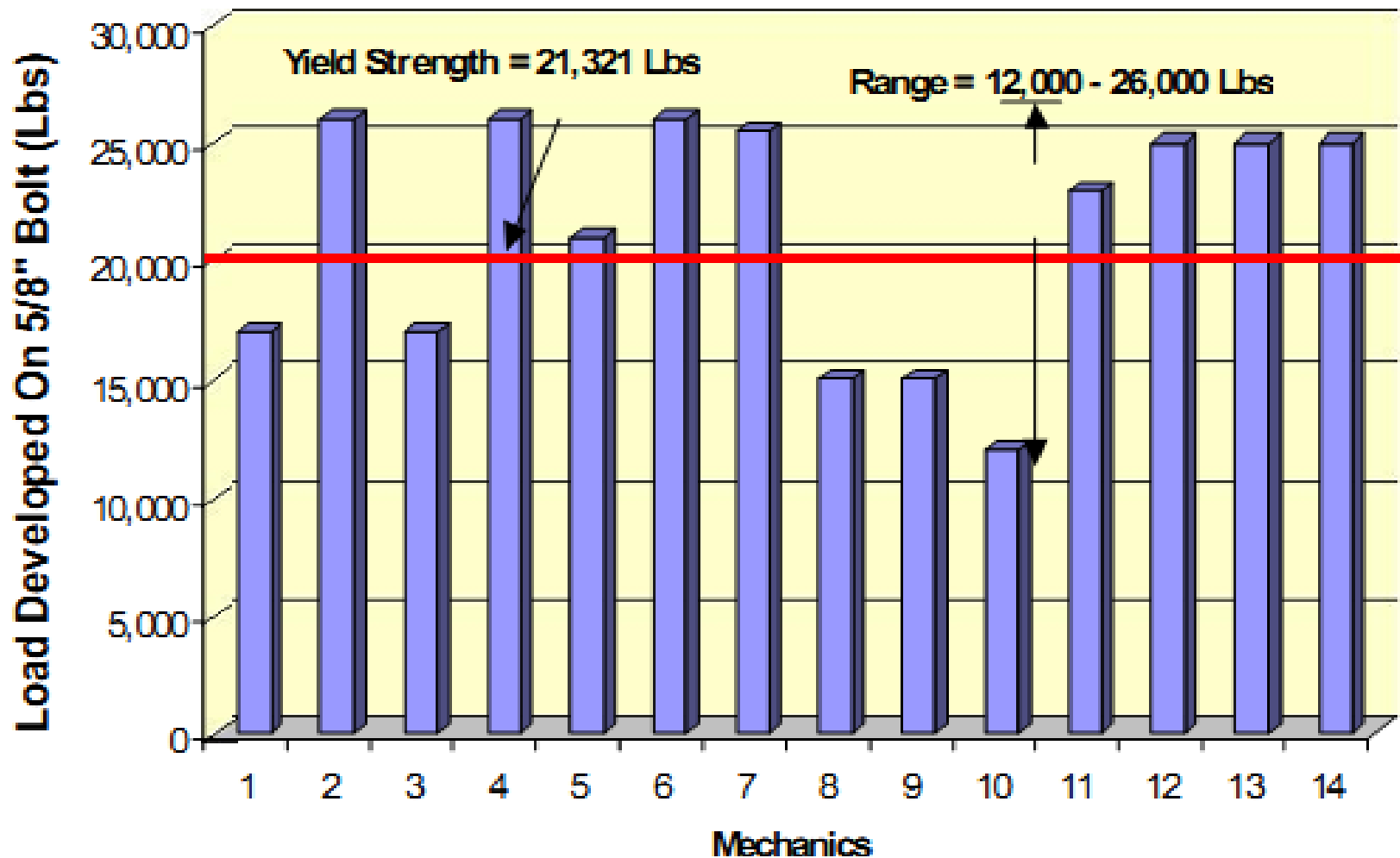
Experimental Procedure and Methods



- Mechanics were asked to tighten the bolt as they would in the field to the level that they consider “tight”.
- Bolt placed in the tester and tightened.
- Load gauge was covered so mechanic did not see applied load.
- Tester mounted to a table/bench at waist height, with full access to the tester and full range of movement for the mechanic.
- The assembly conditions, flange location and ergonomics were considered “ideal” (best possible) for the mechanic.

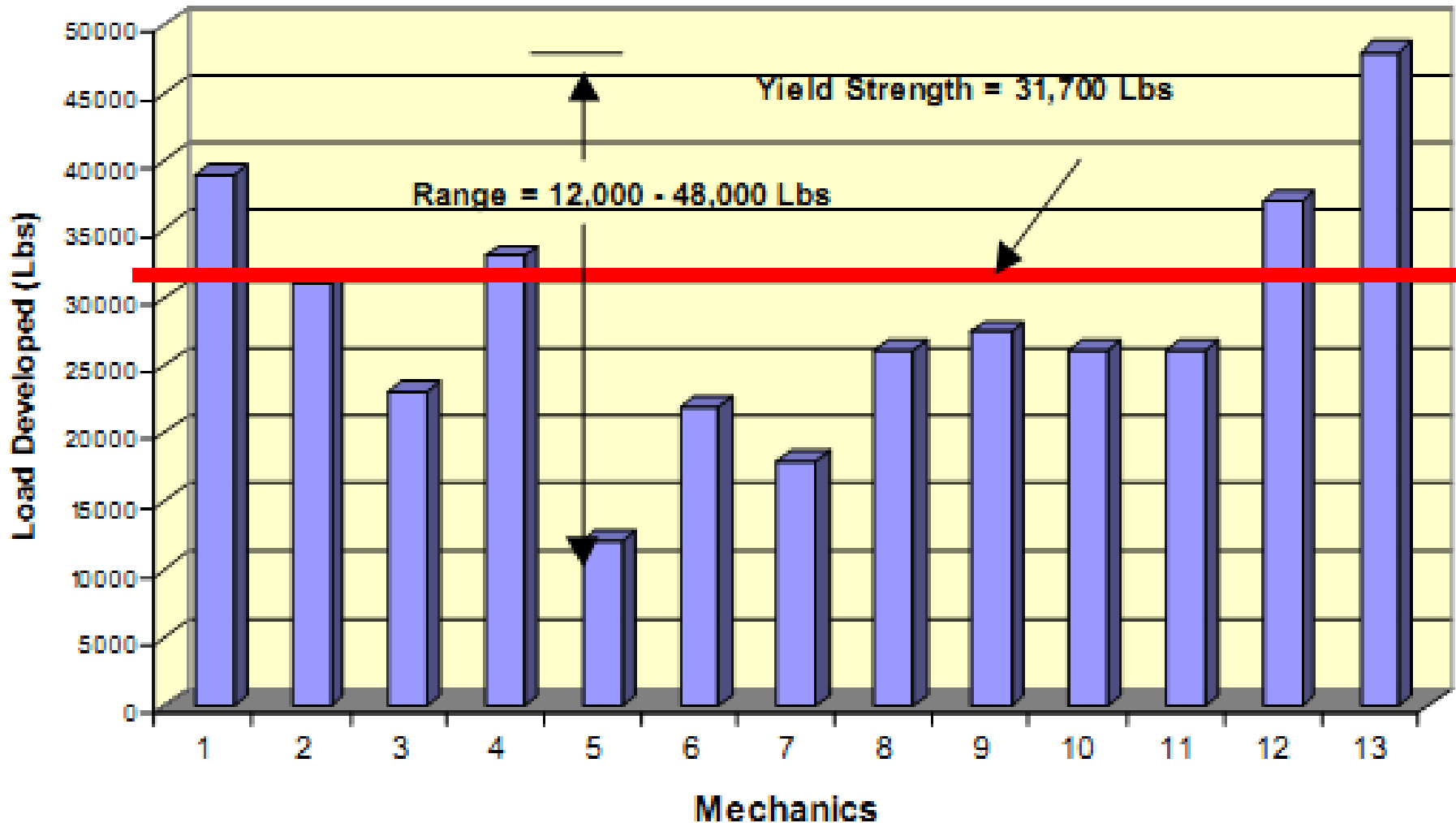
Typical Classroom Result

Bolt Load Developed With Hand Wrenches
5/8 in A193-B7 Lubricated Studs



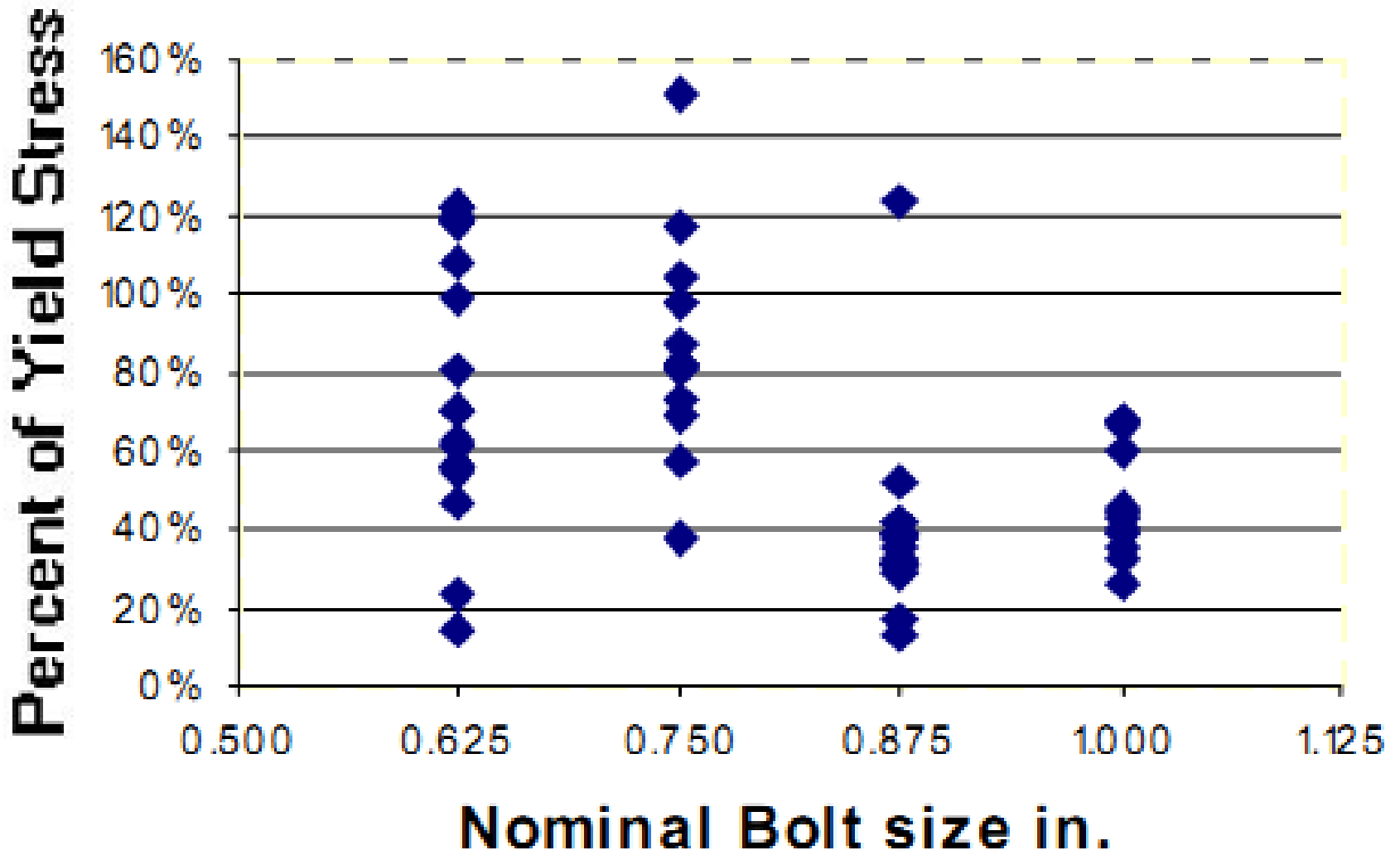
Typical Classroom Result

**Bolt Load Developed With Hand Wrenches
3/4 in A193-B7 Lubricated Studs**



Extensive Scatter and Excessive Bolt Loads Immediately Evident


- When the mechanics were asked to tighten the bolt to the level that they consider “tight”, they had already seen demonstrations of:
 - increased bolt load results from a lubricated bolts versus an unlubricated bolt.
 - yield strength differences between different bolt grades and metallurgy’s.
 - demonstrations of bolts being tightened up into the plastic region.
- Nevertheless, there were a number of instances of the minimum specified yield strength of the bolt being exceeded!



Excessive Bolt Loads More Evident for 5/8in and 3/4in bolts

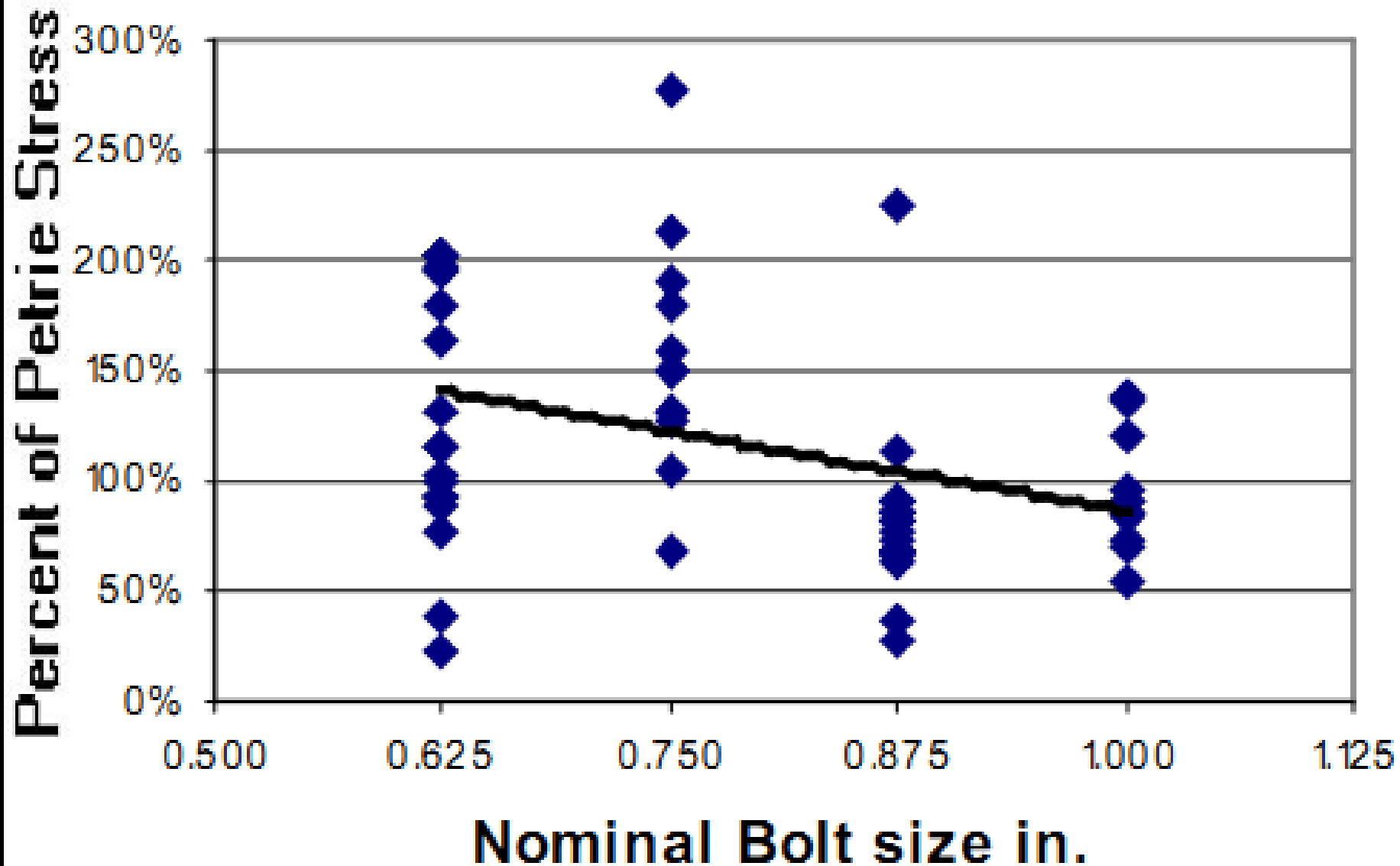
- Nine 5/8 in. bolts were between 99 and 123% of minimum specified yield strength.
- Three 3/4 in. bolts were between 104 and 123% of minimum specified yield strength and one was at 151% (by an inexperienced and untrained mechanic).

Same Data As a % of “Petrie” Stress



Plot of the same data shows a nearly straight polynomial trendline suggesting the possibility of an interim alternative equation for bolts in the range of 1/2 to 1in. diameter, which is:

$$\text{Stress} = 45,000/(\text{bolt diameter})$$



Variables Evaluated



The following data was recorded for each session:

- Age (< 30, 30 - 45, > 45) years
- Male - Female?
- Bolt diameter (5/8, 3/4, 7/8, 1.0) inch
- Lubricated bolts Y/N?
- Received Formal Assembly Training Y/N?
- Routinely Assemble Joints Y/N?

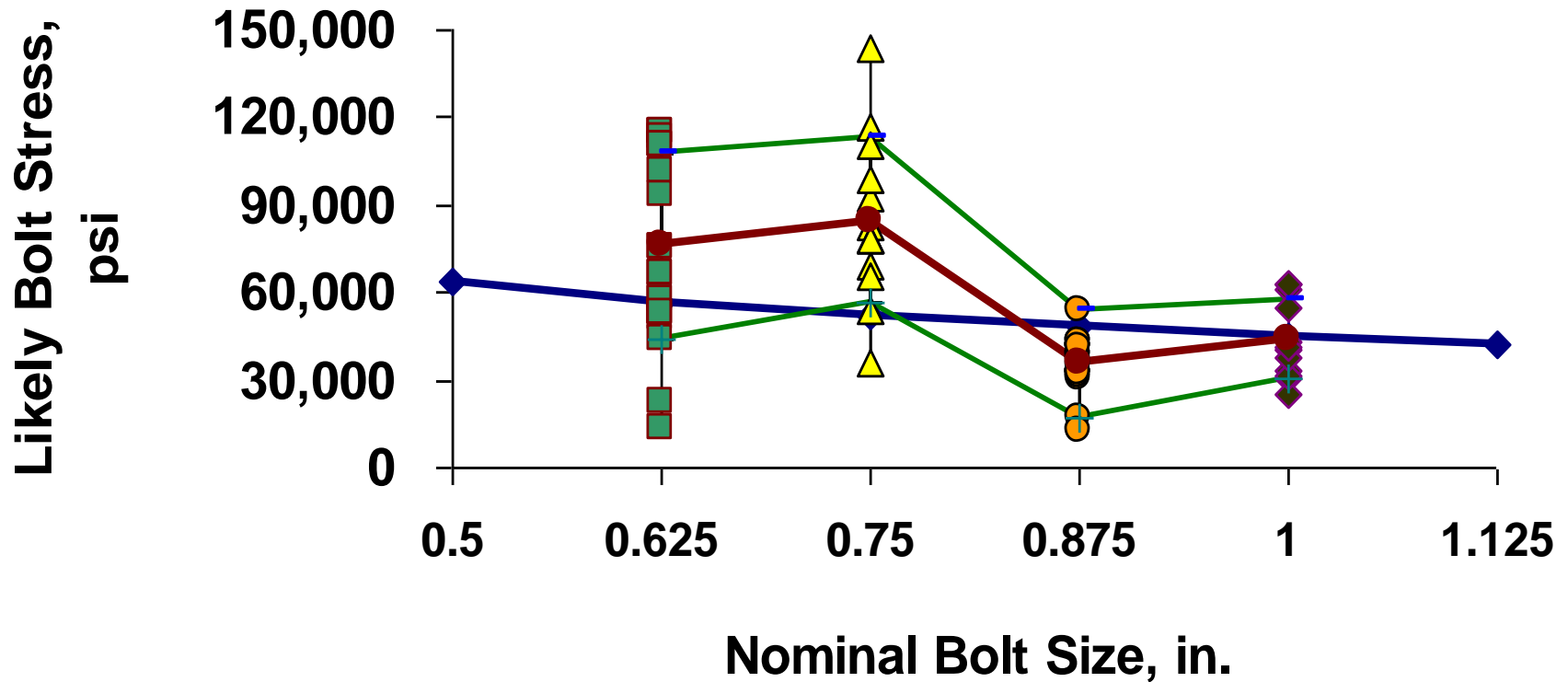
Statistical Treatment

A simple database covering all tests was established to consider the variables of Age, Gender, Bolt size, Experience and Training.

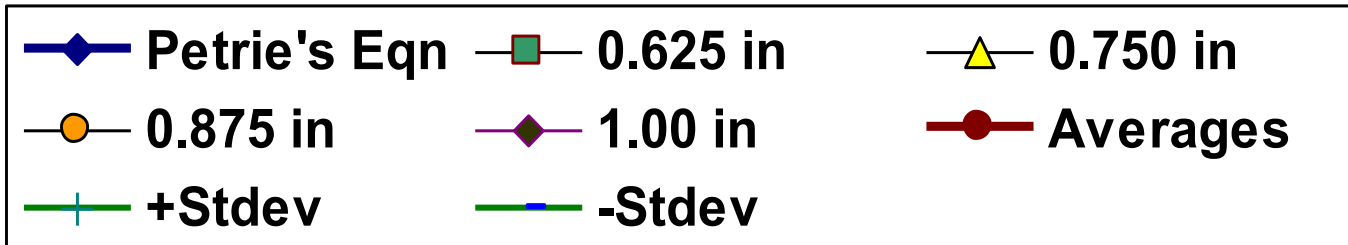
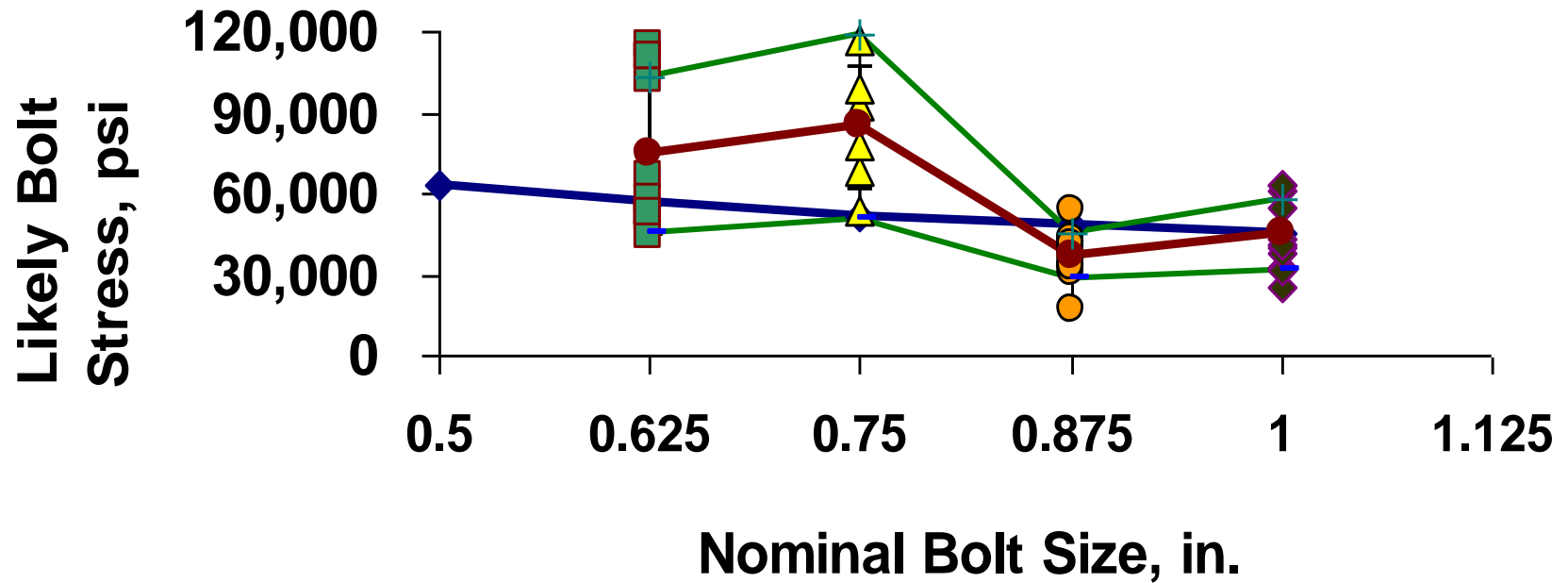
66 tests were performed by 63 Mechanics. Of these:

- 42 Routinely assemble joints (22 were formally trained)
- of the remaining mechanics 17 of the 33 were formally trained.
- The most significant variables appear to be bolt diameter and experience as seen in the following plots.
- Only 4 of the Mechanics were Female and since only one routinely assembled joints, there is no statistical conclusion about Gender.

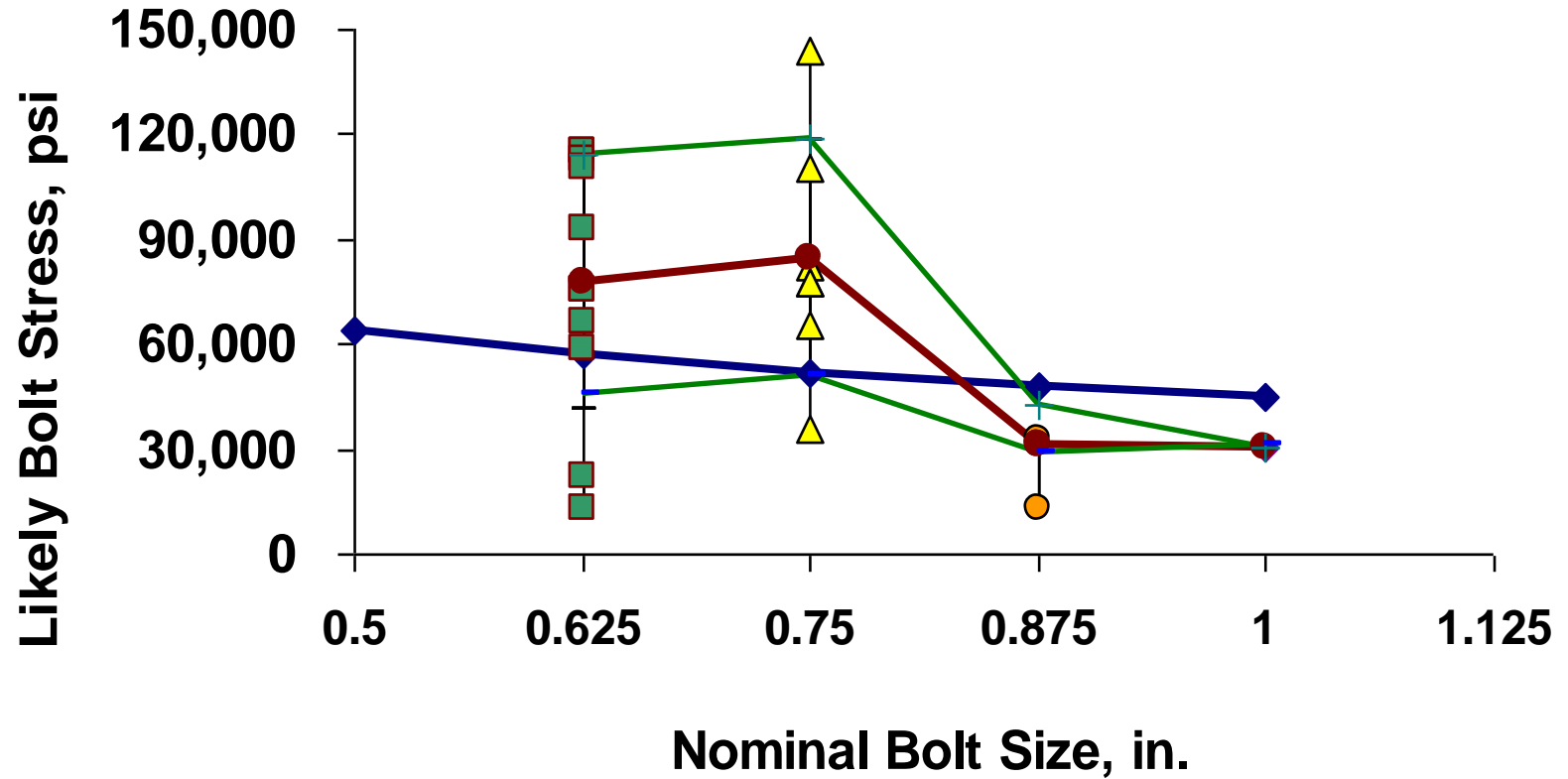
All Tests - Bolt Stress vs Diameter Compared to Petrie's Equation



Experienced Mechanics - Bolt Stress Compared to Petrie's Equation



Other Mechanics - Bolt Stress Data Compared to Petrie's Equation



Results & Observations

- An average of 21% scatter reduction is seen for the experienced mechanics.
- The largest reduction is 54 % for the 7/8 in. bolts.
- The average stress for the 1 in bolt measurements very close to the Petrie prediction, that is 99.5% !
- For all but the 1.0in diameter bolts the extreme limits of scatter well exceed 50% .
- If standard deviations are considered for experienced mechanics, then 50% scatter or slightly less is a reasonable assumption.

Conclusions

- The benefits of experience and supervision and training are clear.
- Manually assembled gasketed joints using 5/8 in. or 3/4 in. bolts may easily experience excessive bolt loads causing gasket or flange damage, or insufficient load and leakage.
- For critical service applications some form of controlled loading (Torque) should be used for 3/4 and 5/8 in. bolts.
- For bolts less than 1 in. diameter the average bolt stress achieved by an experienced mechanic exceeds the Petrie stress prediction. A better prediction is :

$$\text{Stress} = 45,000/(\text{bolt diameter})$$

Future Work

- Initially additional work was planned to further investigate other variables.
- The extensive scatter found to exist in the current investigation makes additional research pointless.
- No further research is planned!