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16. Abstract

The primary objective of this research was to test in the field a new method for installing break-away slip-base connections. The new method was developed in the laboratory in a previous phase of the research, and it is based on the utilization of Belleville spring washers. Stacks of spring washers, which come pre-wrapped, are installed on the bolts just as any ordinary washers. The bolts are torqued, and a block of filler gages measures the deflection of the stack of spring washers which is proportional to the tension in the bolt.
Seven signs were selected along Central and South Florida highways. At each sign, one of the posts was equipped with bolts with spring washers, while the other post remained connected with bolts with conventional flat washers. At each sign one of the bolt with spring washers and one of the bolts with flat washers were instrumented with strain gages. The variations of tension in these bolts were monitored over a period of one year by measuring the tension of the different bolts once a week.
The measurements showed that, at the time of installation, the new method was significantly more effective in ensuring the proper tension in the bolts. Similarly, over the long term, the bolts installed with spring washers maintained more effectively the tension in the bolt, without any loosening of the bolt. On the contrary, several bolts installed with flat washers exhibited a downward trend in the bolt tension.
The effectiveness of the break-away connection with spring washers was also demonstrated during a car accident. A car hit a sign post equipped with spring washers, near the Sebastian Inlet. The break-away functioned perfectly and the post separated from the base.

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# EXECUTIVE SUMMARY

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The measurements showed that, at the time of installation, the new method was significantly more effective in ensuring the proper tension in the bolts. Similarly, over the long term, the bolts installed with spring washers maintained more effectively the tension in the bolt, without any loosening of the bolt. On the contrary, several bolts installed with flat washers exhibited a downward trend in the bolt tension.

The effectiveness of the break-away connection with spring washers was also demonstrated during a car accident. A car hit a sign post equipped with spring washers, near the Sebastian Inlet. The break-away functioned perfectly and the post separated from the base.

The opinions, findings and conclusions expressed in this publication are those of the authors and not necessarily those of the U.S. Department of Transportation.

This report was prepared in cooperation with the State of Florida Department of Transportation and the U.S. Department of Transportation.

# TABLE OF CONTENTS

# LIST OF FIGURES

* Note: there is no Figure 25

# LIST OF TABLES

# INTRODUCTION

For the efficient control of traffic on highways it is necessary to provide large directional signs. These signs require massive fixed supports which, when located near the roadway, constitute a hazard to the occupants of an errant vehicle. To reduce the hazard, if the signs cannot be located behind a guardrail, the sign supports must be provided with a break-away device.

According to a detailed, mid-60's study of break-away signs performed by Edwards, Hirsch, and Olson at the Texas Transportation Institute, the *bolt tension is the single most critical factor for the safe operation of the break-away sign support.* In fact, the bolts in the slip-base connection must be tightened to a specific tension, in order to satisfy two conflicting requirements: 1) to ensure that the connection will successfully withstand the service loads due mainly to wind, traffic, and temperature effects; and 2) to ensure that the connection will break upon impact from an errant vehicle, thus ensuring the safety of the vehicle's passengers. Consequently, there is a need to accurately and directly measure the tension in the bolts, when the break-away system is installed.

Equally important, is a need to ensure that the tension in the bolts will remain within an acceptable range throughout the service life of the system. Even if the bolts were correctly installed with the proper tension, the bolts could still loosen over time. This arises from the fact that highway signs are subjected to a variety of dynamic loads including the vibrations induced by traffic, and the effect of wind induced vortex shedding. These vibrations are transmitted to the supporting structure and can result in a loosening of the base bolts. Temperature changes due to daily and seasonal changes can also cause non-uniform expansion and contraction of the break-away assembly introducing residual tension in the bolts. In the case of excessive bolt loosening, the base sign connection could fail during a wind event, result in a hazard and disruptions to highway traffic, and result in injury for the occupants of a vehicle, and costly liability for the responsible jurisdiction. In addition, the losses or damage to traffic signs are costly.

To solve the above problem, a two phase research program on break-away signs was carried on at Florida Tech, with funding from the Florida DOT. Phase I of the program addressed the first need listed above, by developing a new installation procedure for the bolts of the slip-base connections that will replace the calibrated wrench method currently being used. The new installation procedure determines the tension in the bolt by measuring the deflection of a stack of spring washers when installing the bolt.

Phase I of the research program also included laboratory tests on the effect of vibration and temperature variations on the loosening of the bolts in the break-away. It was shown in the laboratory that the spring washers substantially reduced the loosening of the bolts.

Phase II of the research program intended to verify, in the field, the results developed in the laboratory during Phase I. The objectives of Phase II were the following:

- To verify the long-term behavior of the Belleville spring washers, specifically their capacity to maintain the bolt tension within the acceptable range.
- To compare the behavior of the sign post break-away base installed with spring washers with the behavior of the sign post break-away base installed with regular flat washers.
- To determine the longevity of the galvanized and stainless steel spring washers in the open field Florida environment.

## FIELD TESTS SET-UP

### *Instrumentation of Bolts*

- Two bolts were used: 3/4" –A235 bolts with two different lengths of 3" and 3 1/2"; and 7/8" bolts also with lengths of 3" and 3 1/2". The 3" bolts were used with standard washer set-ups while the 3 1/2" bolts were used with the proposed Belleville washer set-ups.
- The bolts were instrumented with two strain gages each. The strain gages were mounted 180 degrees apart in the bolt shank in machined grooves in order to protect the strain gages from contact with the plates and the washers of the break-away connection. The strain gages were instrumented in this fashion so that the average of the two strain readings would cancel any bending effects, which may occur in the bolt shaft.
- • Two holes were drilled symmetrically in the bolt head above the two grooves to let electrical leads pass. Figure 1 shows an example of an instrumented bolt.
- The EA-06-240LZ-120 type of strain gages manufactured by Micro-Measurements Group Inc. was used. The gage resistance in ohms at 24 °C is 120.0 ± 0.3% and a gage factor at 24°C is 2.055± 0.5%.
- To take strain measurements, the gages were connected using a quarter bridge pattern to a P-3500 strain gage indicator which has an accuracy of ±0.1% for a gage factor greater than 1. The strain gage indicator was also manufactured by Micro-Measurements Group Inc.

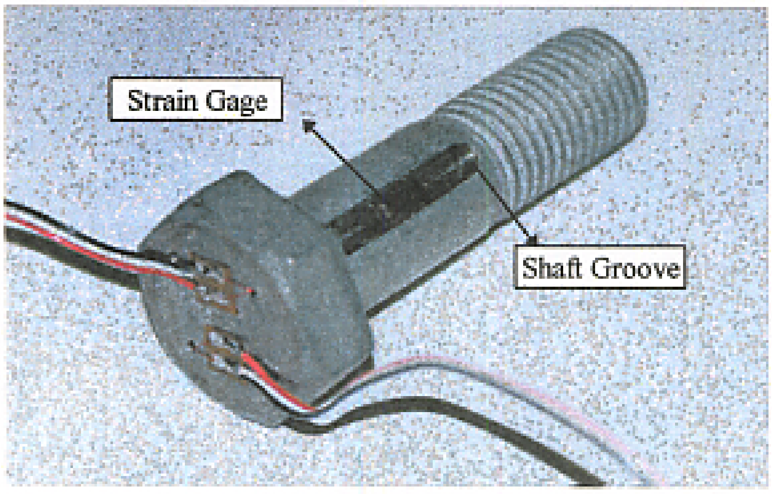
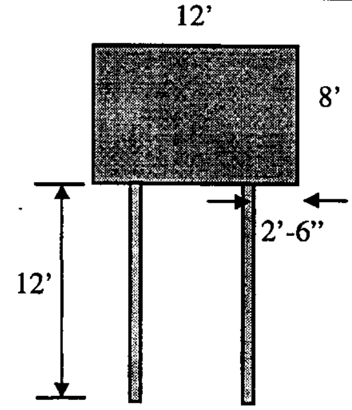


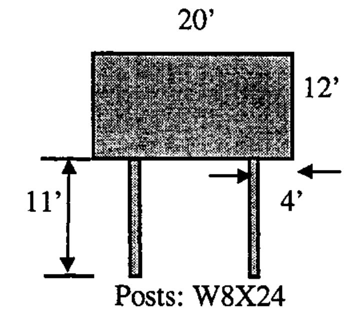
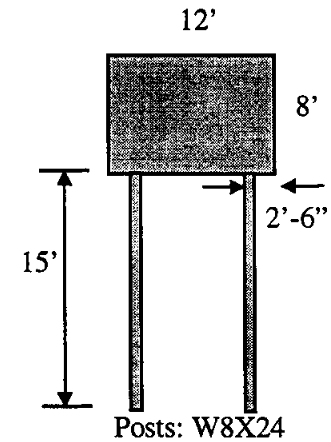
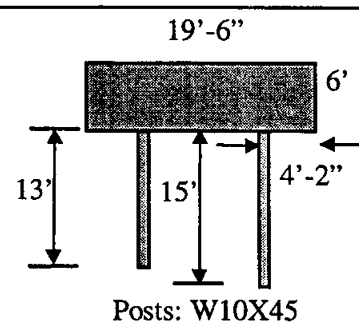
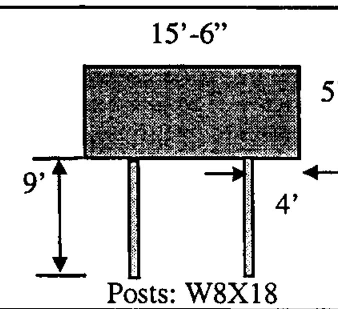
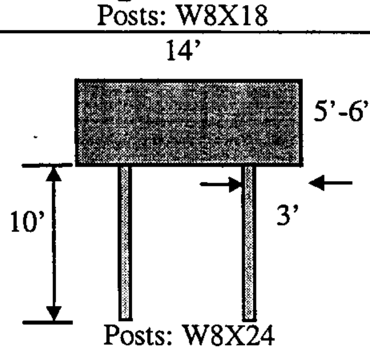

Figure 1 - 3/4" Diameter Instrumented Bolt

*Location and Details of Selected Signs*

The first step taken was to select suitable sites throughout Central Florida considering different conditions of wind, traffic and temperature. Seven appropriate sites were identified along I-95, I-4, I-75 and A1A, which are typical of different climate and traffic conditions in central and south Florida. At each site, representative break-away signs were selected for monitoring in coordination with the Florida DOT. Figure 2 and Table 1 show the location and details of the selected sites.

Figure 2 Location of Selected Signs


| | *Photograph* | *Dimensions (not to scale)* |
|---|---|---|
| **1. Tampa**<br><br>I-75 northbound just south of the I-75 / I-4 junction. Connected by ¾" bolts. Measurements taken since May 1998. |  | <br>Posts: W8X24 |

| | | |
|---|---|---|
| **2. Orlando**<br><br>I-4 westbound just north of the Highway 528 / I-4 junction. Connected by ¾" bolts. Measurements taken since May 1998. |  |  |
| **3. Brevard County (2)**<br><br>I-95 northbound second sign north of Exit 74. Connected by ¾" bolts. Measurements taken since May 1998. |  |  |
| **4. Brevard County (1)**<br><br>I-95 northbound first sign north of Exit 74. Connected by 7/8" bolts. Measurements taken since July 1998. |  |  |
| **5. Sebastian Inlet**<br><br>A1A northbound just south of Sebastian Inlet. Connected by ¾" bolts. Measurements taken since May 1998. |  |  |
| **6. Indian River County**<br><br>I-95 southbound just south of mile marker 146. Connected by ¾" bolts. Measurements taken since May 1998. |  |  |

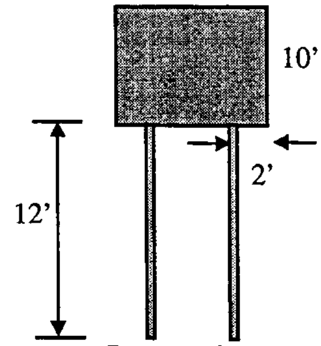
| | | |
|---|---|---|
| **7. Martin County**<br><br>I-95 northbound just north of mile marker 109. Connected by ¾" bolts. Measurements taken since May 1998. | <br> | <br> |

Table 1: Location and Details of Selected Signs

*Installation of Bolts*

After the break-away signs were selected, the instrumented bolts were installed. Each sign had two posts, each with four 3/4" bolts except for Brevard (1) which has 7/8" bolts. The bolts on one post were installed using the procedure defined in Phase I [1] with the proposed Belleville spring washer set-up, using the 3.5 in long bolts. The Belleville spring washer set-up used included four washers (# AI-1575107), two in series and two in parallel. This set-up requires a deflection of 0.026" to reach FDOT recommended bolt tension. Deflections were measured using filler gages. All material (washers, bolts, and nuts) was provided by FDOT with the exception of the spring washers, which was purchased by the research team. The actual installation was done by the research team with assistance from FDOT crew.

The bolts on the other post were installed following the conventional torquing method and washer set-up, using the 3 in. bolts. The bolts installed using this method were torqued to either 35 ft-lb or 43 ft-lb according to individual FDOT specifications. It can be seen that not all sites use the same torque values. Table 2 shows the specific torques for each of the signs.

Table 2: Recommended Torque Values

| *Sign* | *Recommended Torque (ft-lb)* |
|---|---|
| Tampa | 43 |
| Orlando | 35 |
| Brevard County | 43 |
| Sebastian Inlet | 43 |
| Indian River County | 43 |
| Martin County | 43 |

Each post was equipped with one instrumented bolt so a comparison could be made between the conventional set-up and the proposed set-up. Figures 3 and 4 compare the traditional set-up using conventional flat washer and the proposed set-up using spring washers. The requirement was for the washers to maintain the tension within 2400 lb. to 3600 lb.

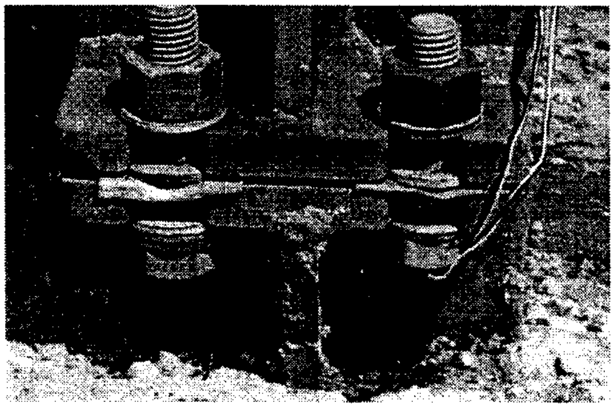


Figure 3 - Traditional Bolt Set-Up with Flat Washers

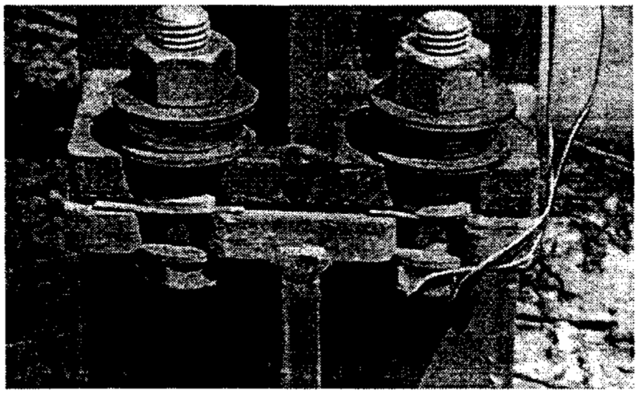


Figure 4 - Proposed Set-Up with Spring Washers

***Strain Reading Procedure***

1. The signs were checked once a week on average. The Indian River, Martin and Sebastian signs are checked one day while the two Brevard signs along with the Orlando and Tampa signs are checked another week day. Sometimes, the checking could not be carried out because of the weather or because the bolts are not accessible due to flooding.

2. The procedure was as follows:

- Measured the temperature using a BAT-10 Thermometer made by Physitemp, Inc.
- Checked for rusting on the spring washers.

- Checked if the strain gages were working (each gage should register a resistance of 120 Ω).
- Checked the offset readings and adjust the strain indicator accordingly. The offset readings were determined by setting the strain indicator readings to zero when the bolt is in zero tension.
- Measured the strains on the left and right strain gages.
- Replaced the wires in a sealed plastic bag and the bag is taped onto the signpost.

3. The measurements were placed in a spreadsheet. The spreadsheet calculated the tension and the eccentricity on each bolt.

4. If some of the instrumented bolts were damaged, the bolt was removed and replaced with an appropriate regular bolt. The instrumented bolt was brought back, repaired, re-tested in the lab, and re-installed in the field the following week.

### *Calculation of Tension and Eccentricity*

The monitoring of the bolt tensions began as soon as the bolts were installed. The results show how the tensions in the bolts changed since they were installed. Table 3 is an example of spreadsheet results.

| Operator | Date | Time | Temp | Strain Reading (με) | | | Bolt tension | | Eccent. |
|---|---|---|---|---|---|---|---|---|---|
| | | | °C | Left | Right | Average | lb. | kN | (in) |
| | | | Balance Offset >> | *392* | *59* | | | | |
| S.ON. | 7/16/98 | 9:00 | 30 | 284 | 55 | 170 | 2956 | 13.1 | 0.074 |
| S.ON. | 7/23/98 | 9:45 | 32 | 338 | 60 | 199 | 3470 | 15.4 | 0.076 |
| N | 8/11/98 | 1:00 | 36 | 237 | 57 | 147 | 2563 | 11.4 | 0.067 |
| N | 8/26/98 | 10:30 | 35 | 265 | 92 | 179 | 3113 | 13.8 | 0.053 |

Table 3: Brevard (1) Sign, Bolt with Spring Washer (Sample)

The averages of the strain measurements were used to calculate the tensions on each bolt. The eccentricity measures the distance between the bolt tension force and the centroid of the bolt.

The equations used are:

$$Tension = T = E\,\varepsilon_{ave}\,A$$

Where:

E = Young's modulus measured in the lab. On average, it is equal to $2.9 \times 10^7$ psi

A = area of the bolt

$$= \pi\left(\frac{0.75}{2}\right)^2 \qquad for\ the\ \tfrac{3}{4}''\ bolt$$

$$= \pi\left(\frac{0.875}{2}\right)^2 \qquad for\ the\ \tfrac{7}{8}''\ bolt$$

$$Eccentricity = \frac{d}{8}\frac{\varepsilon_L - \varepsilon_R}{\varepsilon_L + \varepsilon_R}$$

Where:

d = diameter of the bolt

Figure 5 illustrates the relationship between tension, strain and eccentricity.

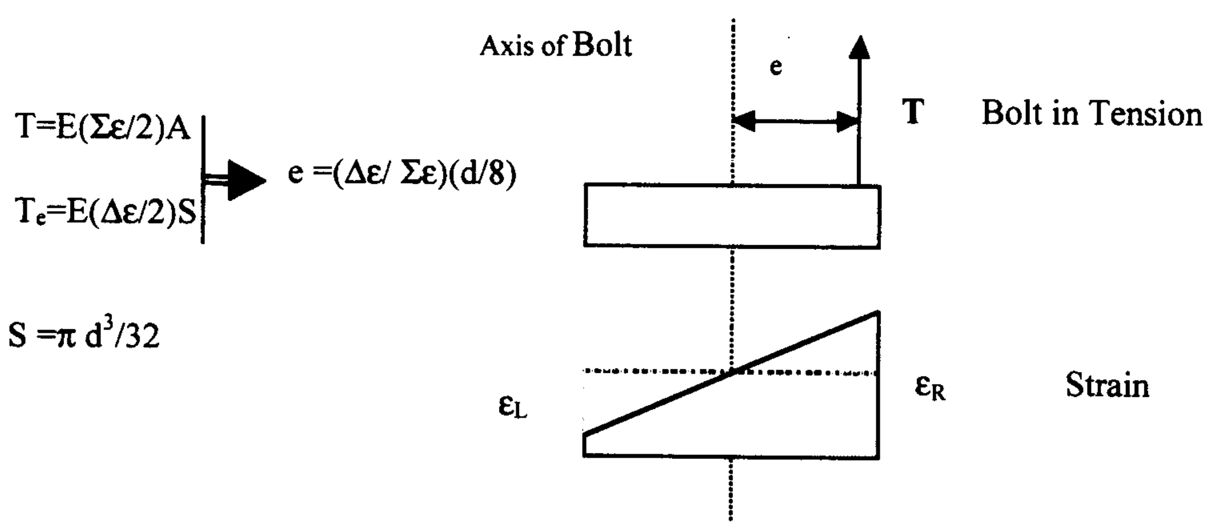



Figure 5 - Bolt Tension Eccentricity

# TENSILE TESTS

Prior to installation of the instrumented bolts in the field, tensile tests were performed in the lab, to ensure that the strain gages had been properly installed. The tests were performed following the technique described in the Phase 1 report [1]. In each case, the goal was to verify that the measured modulus of elasticity was close to the theoretical value of 29,000 ksi. Every time a bolt was brought back to the lab for re-instrumenting, a new tensile test was performed prior to re-installing.

Below are the results of the tests for each instrumented bolt. The stress-strain curves are plotted for each bolt. In each figure, the readings from each strain gage are plotted with triangular dots for the left gage and square dots for the right gage. The average values are represented with a solid line. The slope of this line or measured modulus of elasticity is indicated in each plot.

***Tampa***

Figure 6 shows the result of the tensile test of May 18, 1998 for the short bolt (to be installed with flat washers).

Figure 7 shows the results of the tensile test of May 18, 1998 and the tensile test for the long bolt (to be installed with spring washers) of December 8, 1998.

***Orlando***

Figures 8 and 9 show the results of the tensile tests of May 16, 1998 and December 1, 1998 for the short bolt.

***Brevard (2)***

Figures 10, 11, and 12 show the results of the tensile tests of May 16, 1998, November 10, 1998 and January 22, 1999 for the short bolt.

***Brevard (1)***

Figures 13 and 14 show the results of the tensile test of July 14, 1998 for both bolts and Figure 15 shows the tensile test for the long bolt of November 19, 1998.

*Sebastian Inlet*

Figures 16 shows the results of the tensile test of December 8, 1998 for the long bolt and Figure 17 shows the results of the tensile test of December 3, 1998 for the short bolt.

*Indian River*

Figures 18 and 19 show the results of the tensile tests of May 15, 1998 and February 3, 1999 for the long bolt.

Figures 20, 21, and 22 show the results of the tensile test of May 15, 1998, December 8, 1998 and February 2, 1999 for the short bolt.

*Martin County*

Figure 23 shows the results of the tensile test of December 3, 1998 for the long bolt and Figure 24 shows the results of the tensile test of December 3, 1998 for the short bolt.

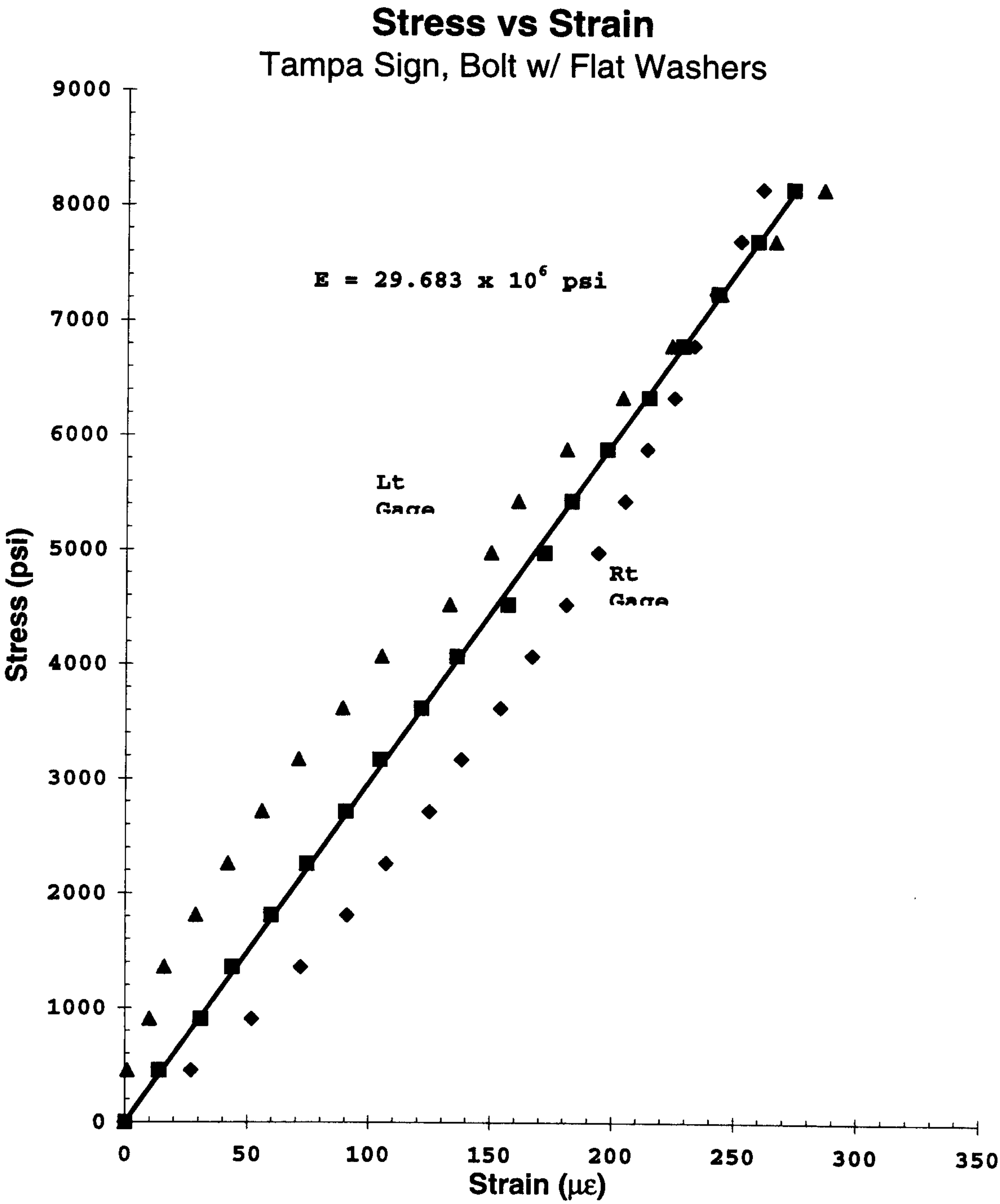



Figure 6 Stress vs Strain, Tampa Sign, Bolt with Flat Washers, May 18, 1998

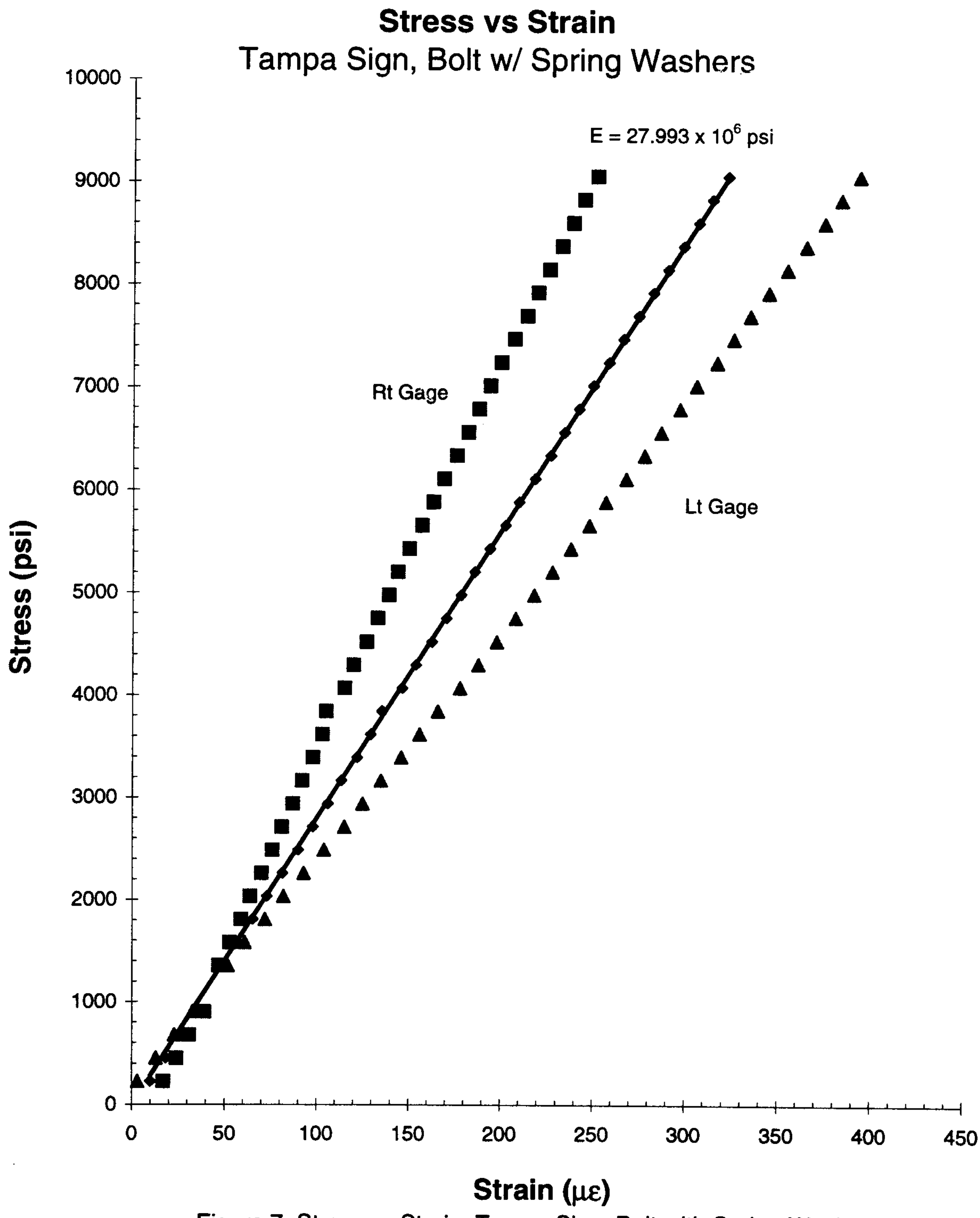



Figure 7 Stress vs Strain, Tampa Sign, Bolt with Spring Washers, December 8, 1998

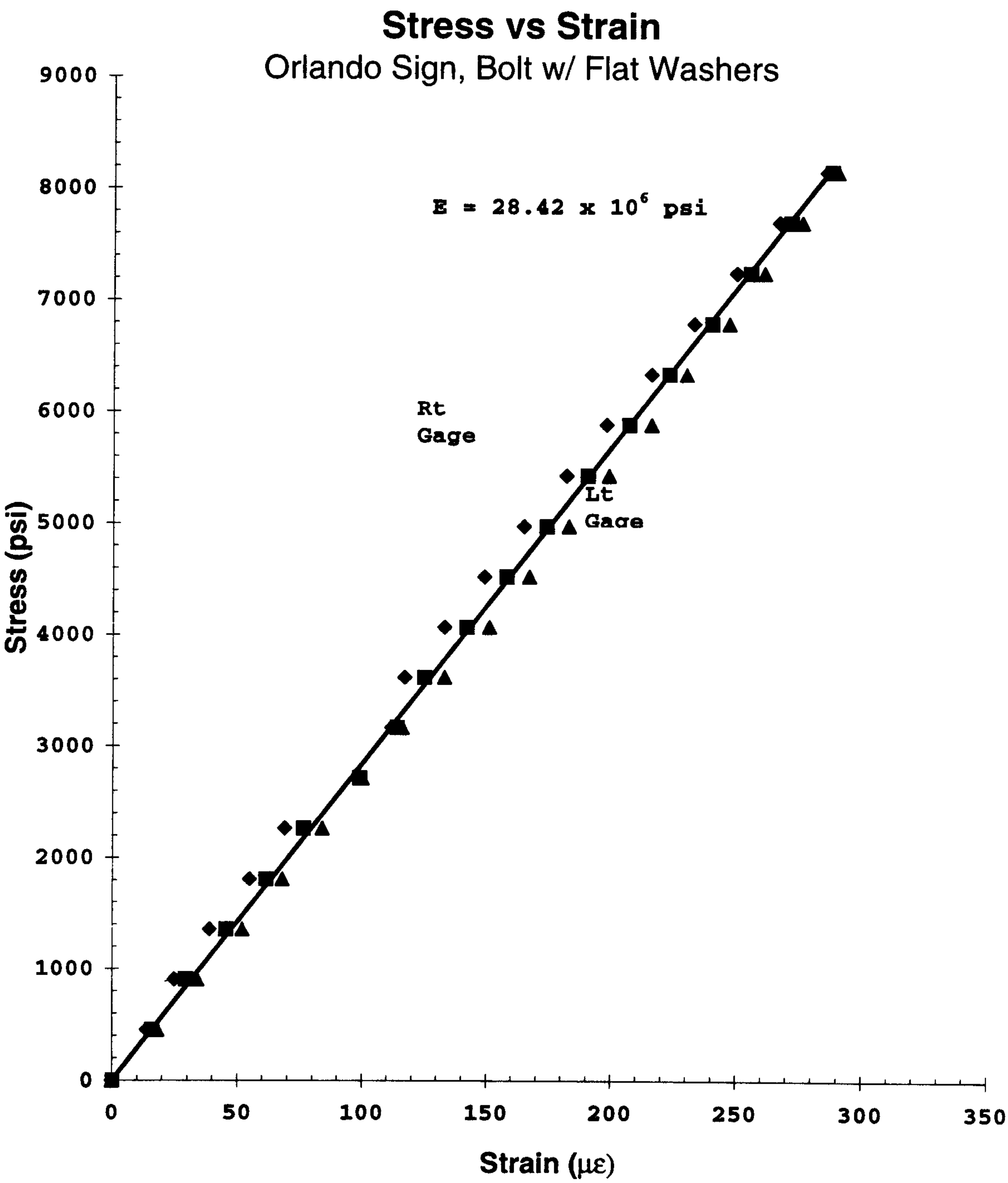



Figure 8 Stress vs Strain, Orlando Sign, Bolt with Flat Washers, May 16, 1998

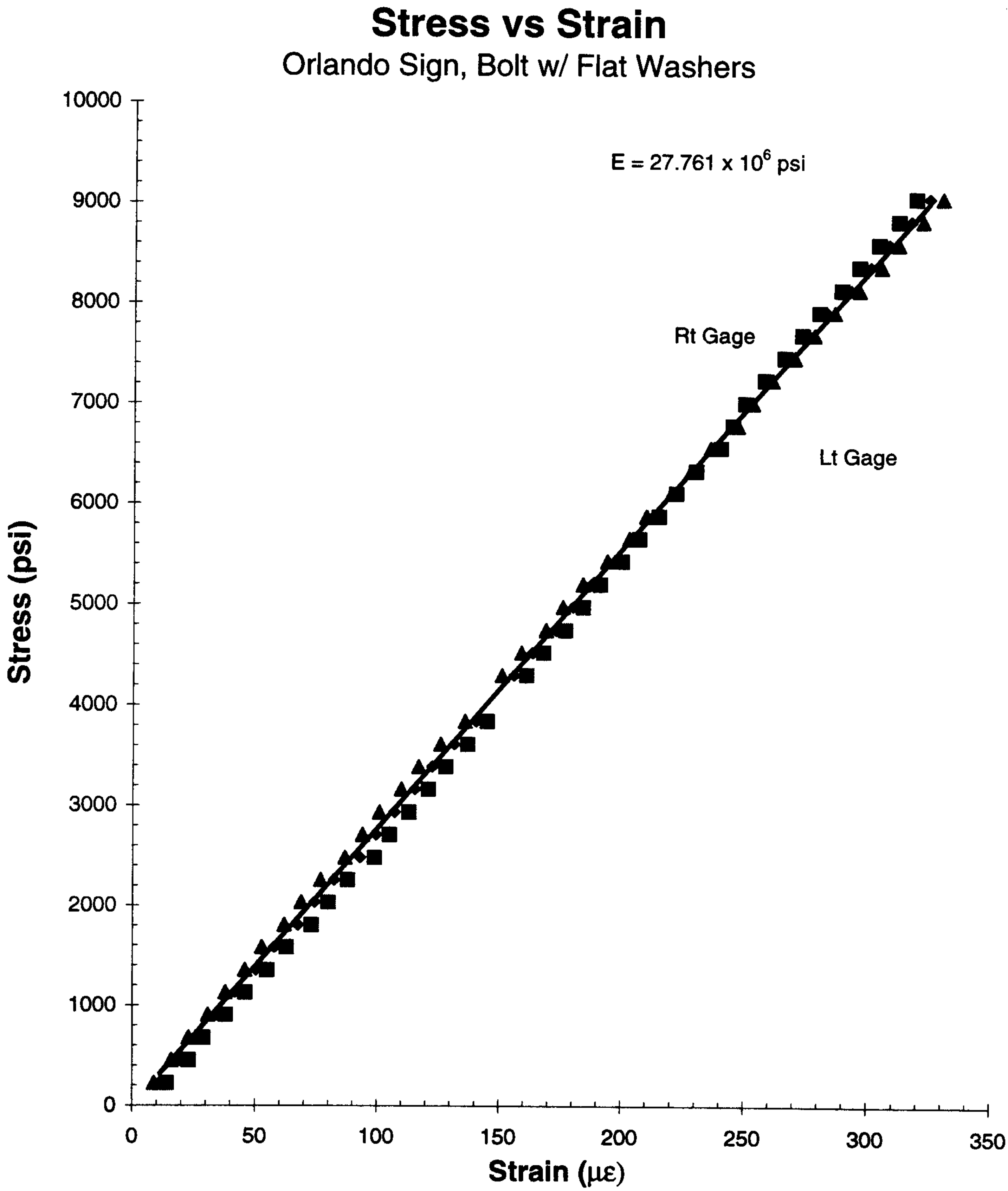



Figure 9 Stress vs Strain, Orlando Sign, Bolt with Flat Washers, December 1, 1998

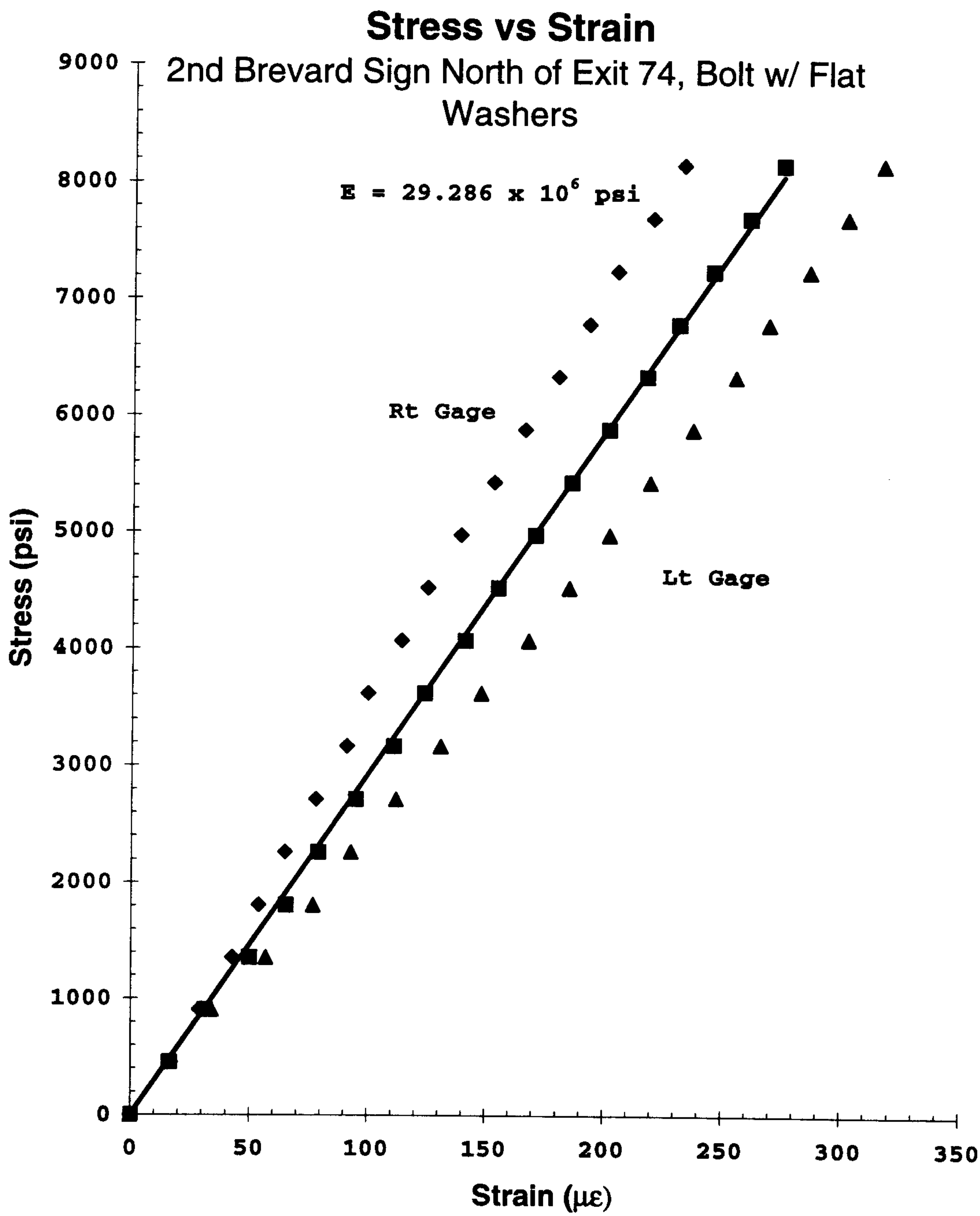



Figure 10 Stress vs Strain, Brevard (2) Sign, Bolt with Flat Washers, May 16, 1998

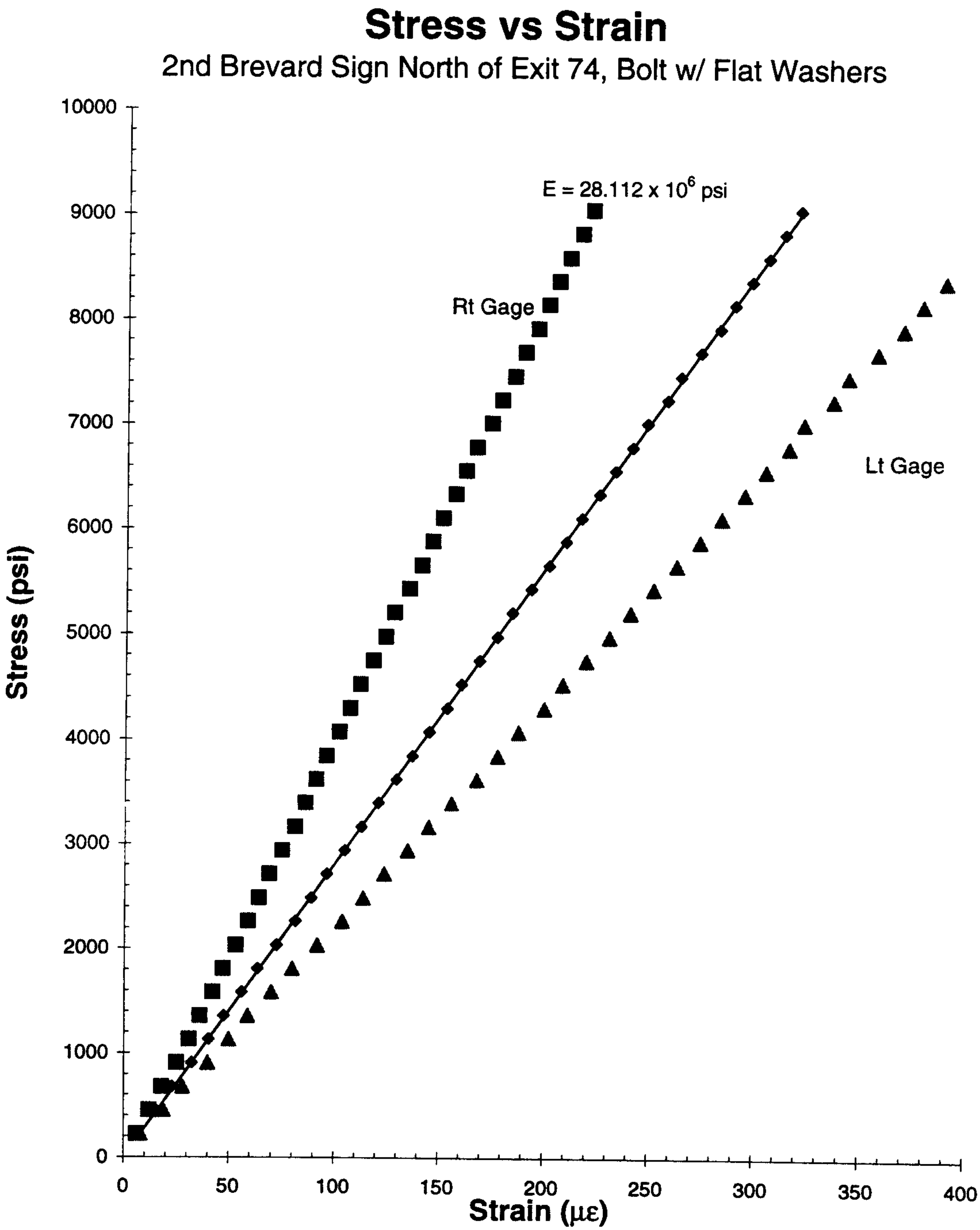



Figure 11 Stress vs Strain, Brevard (2) Sign, Bolt with Flat Washers, November 10, 1998

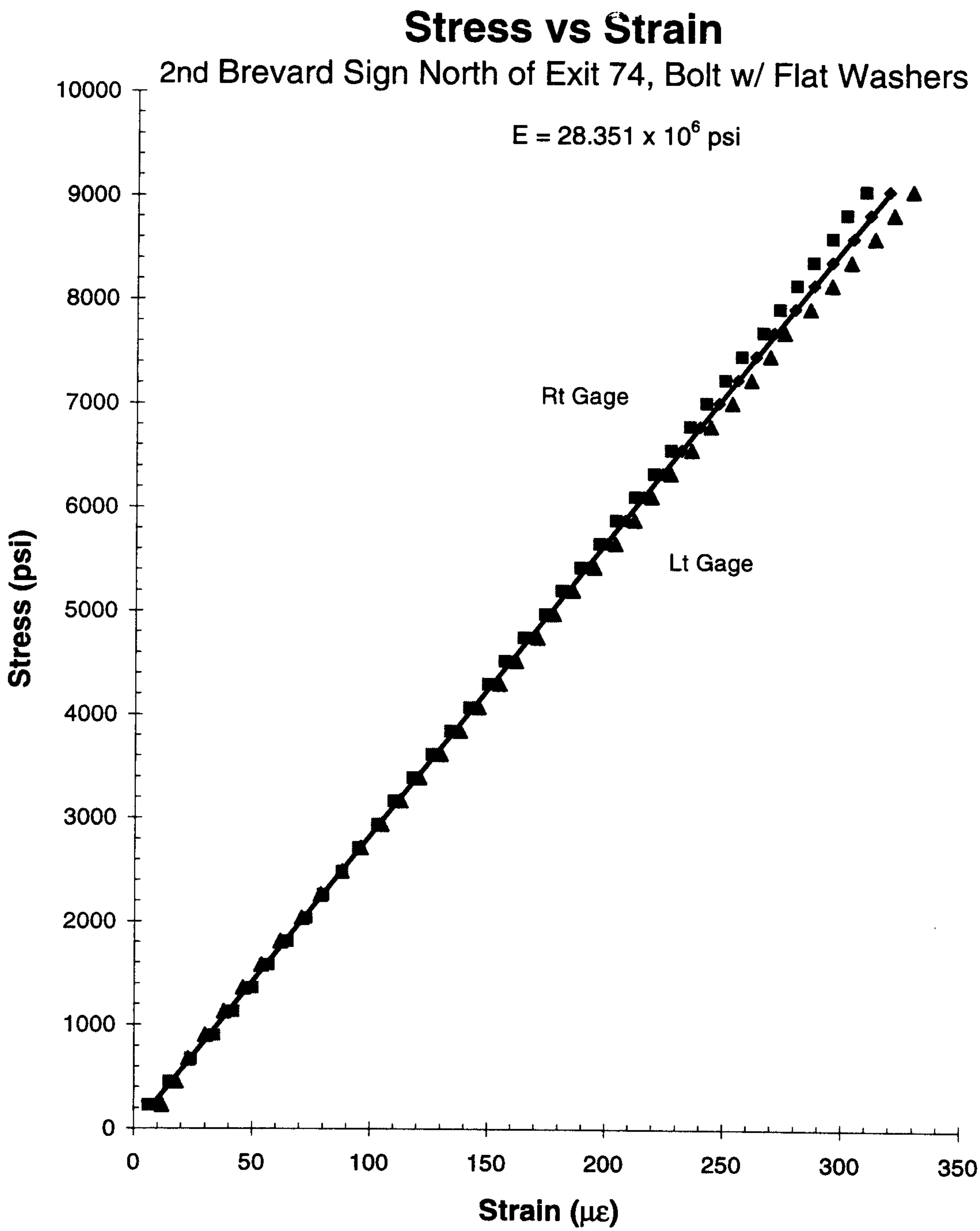



Figure 12 Stress vs Strain, Brevard (2) Sign, Bolt with Flat Washers, January 22, 1999

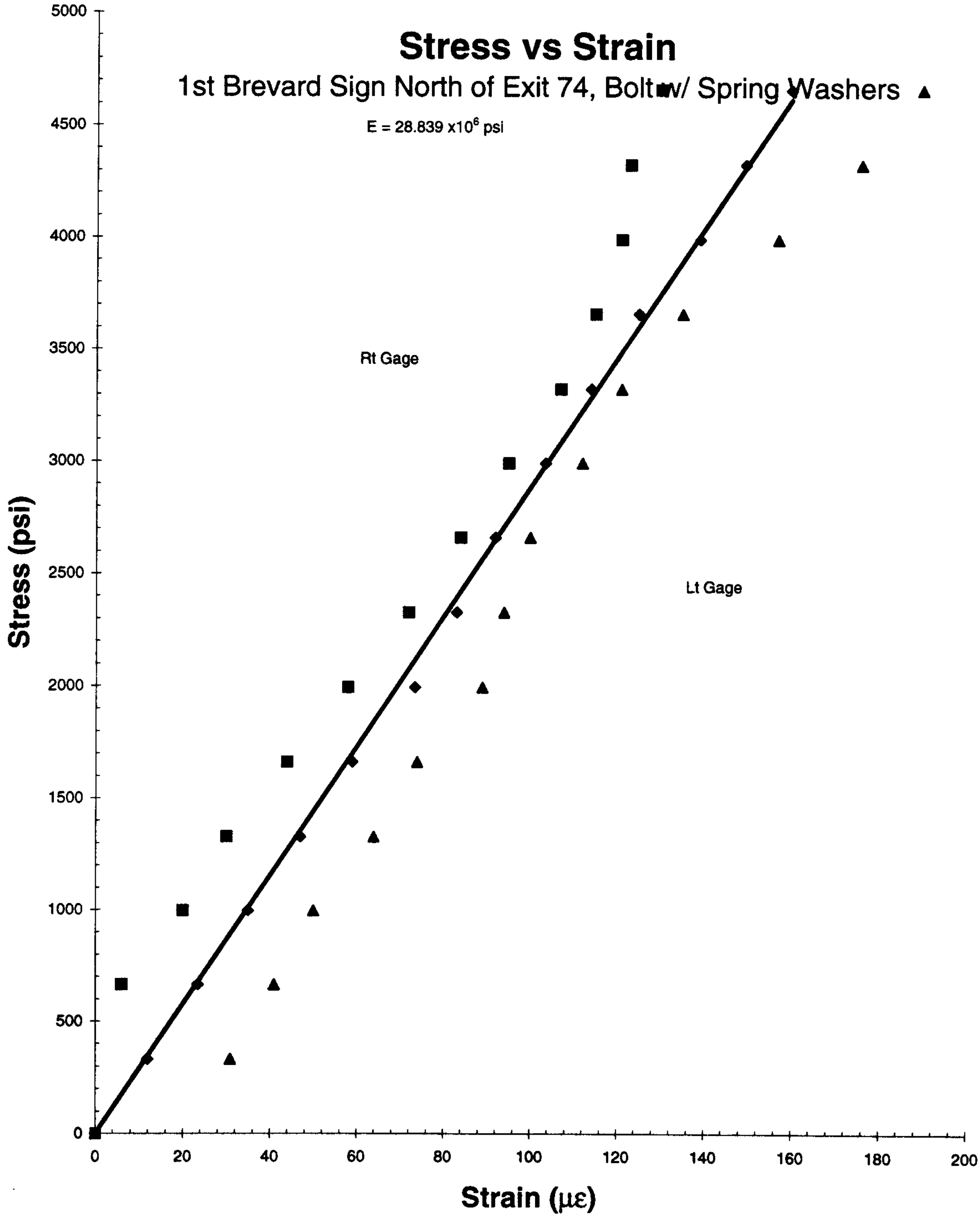



Figure 13 Stress vs Strain, Brevard (1) Sign, Bolt with Spring Washers, July 14, 1998

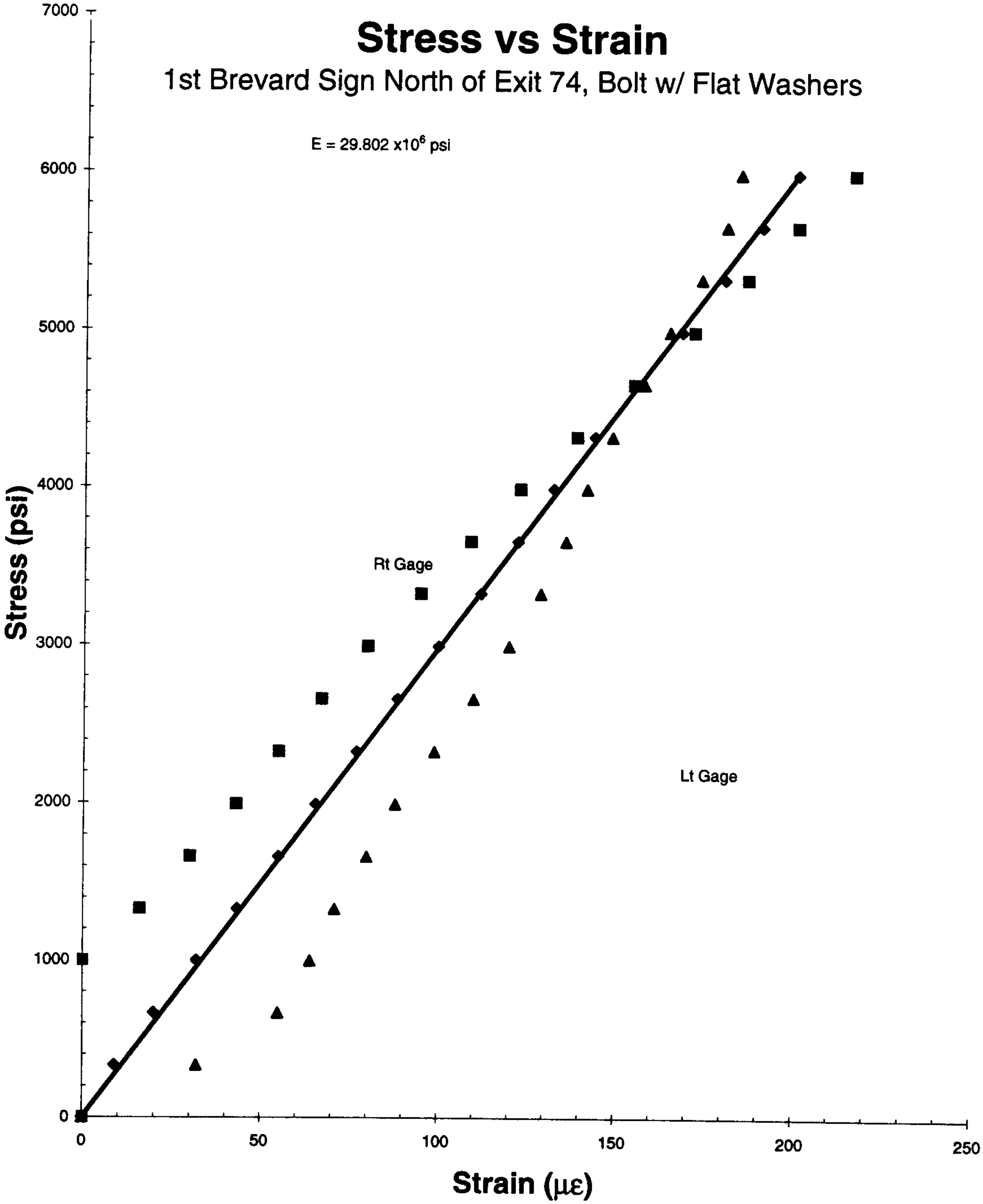



Figure 14 Stress vs Strain, Brevard (1) Sign, Bolt with Flat Washers, July 14, 1998

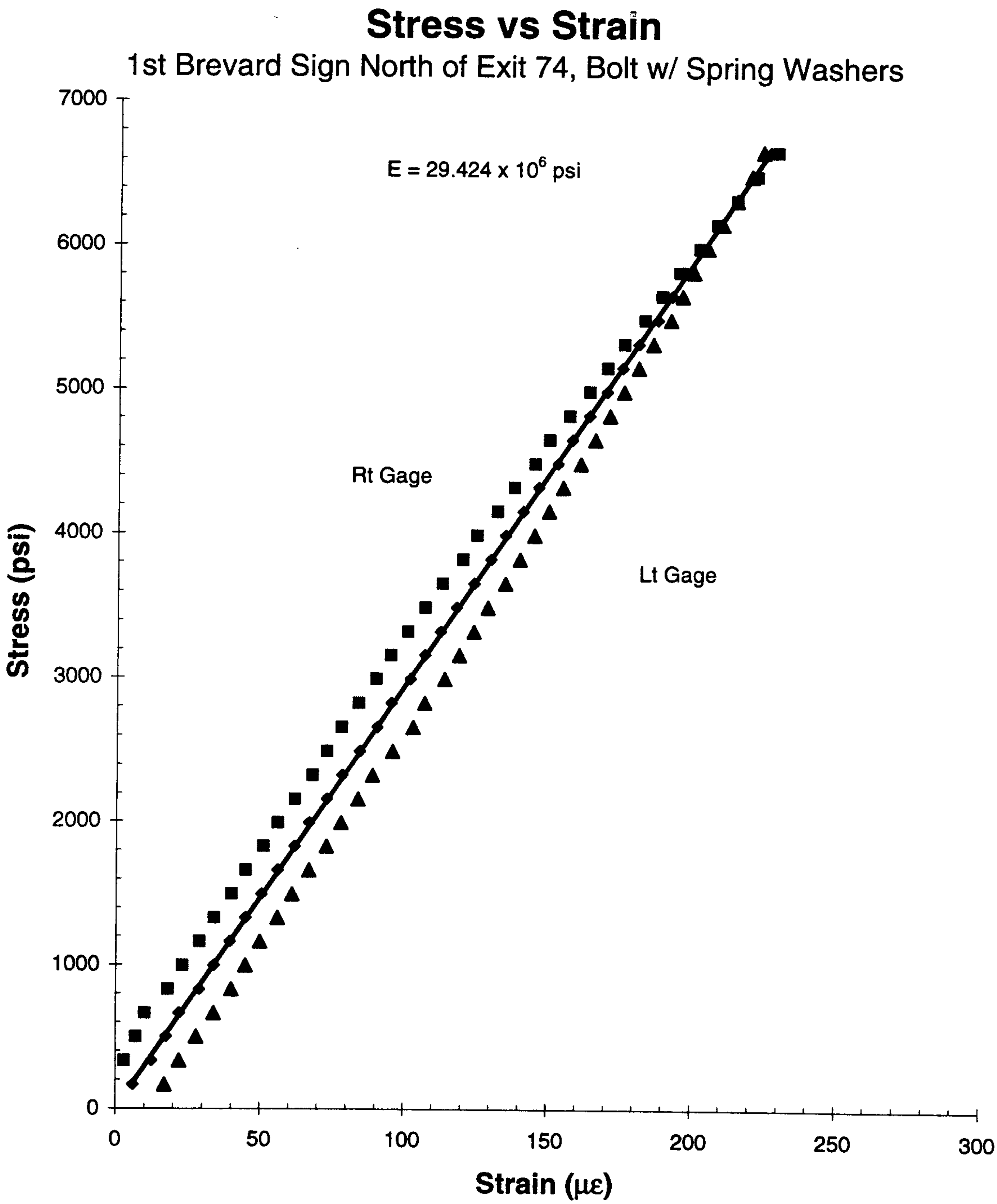



Figure 15 Stress vs Strain, Brevard (1) Sign, Bolt with Spring Washers, November 19, 1998

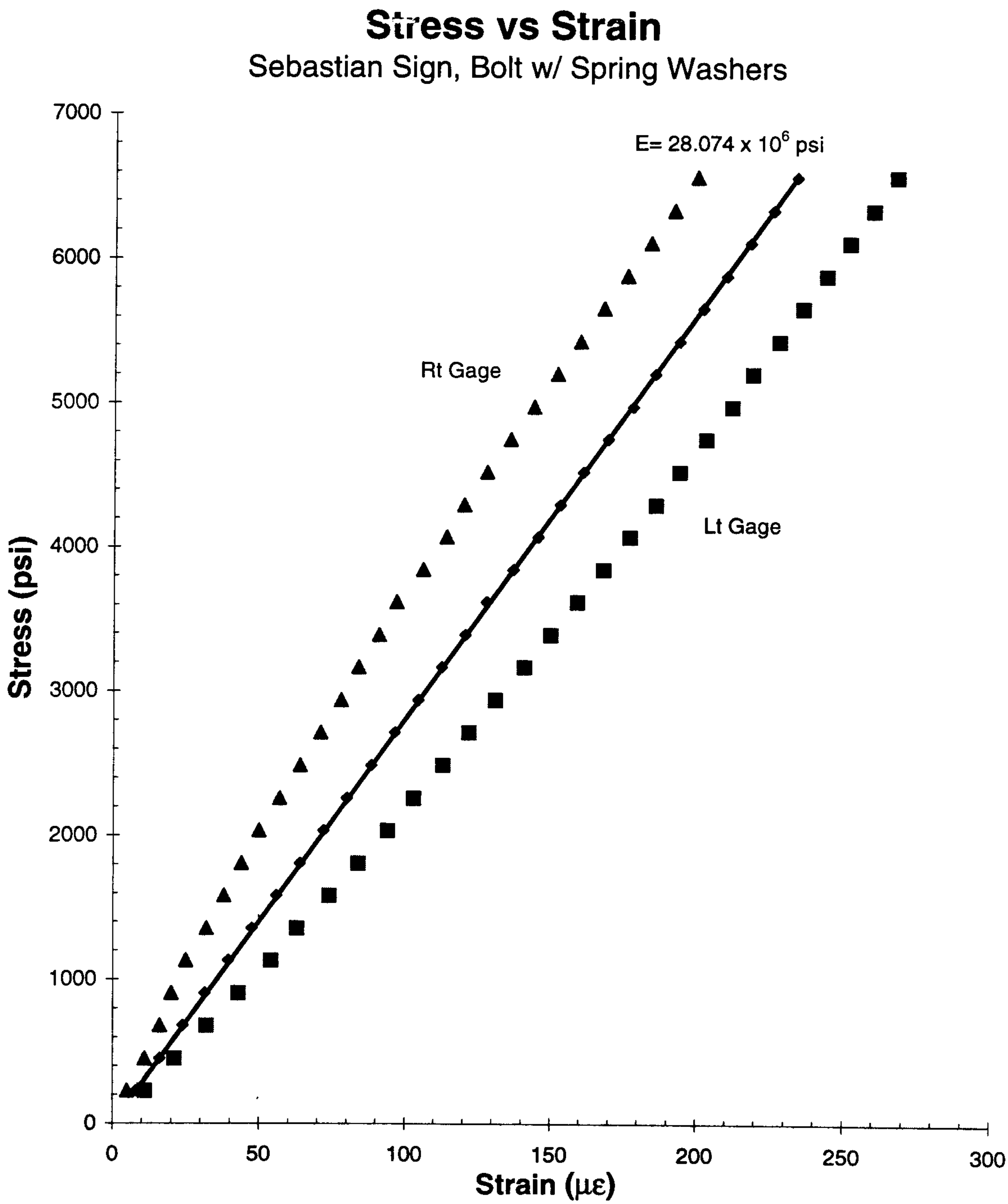



Figure 16 Stress vs Strain, Sebastian Inlet Sign, Bolt with Spring Washers, December 8, 1998

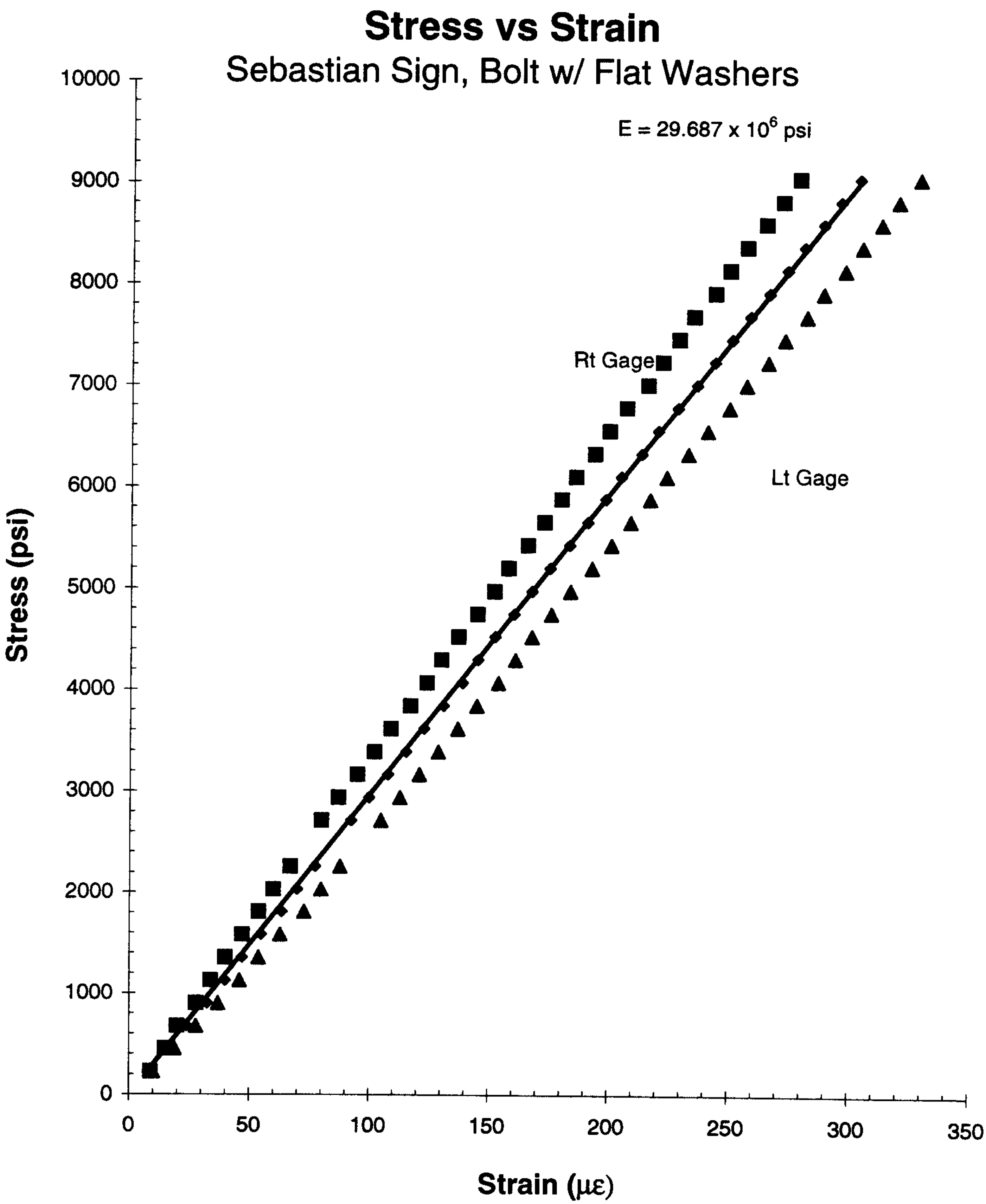



Figure 17 Stress vs Strain, Sebastian Inlet Sign, Bolt with Flat Washers, December 3, 1998

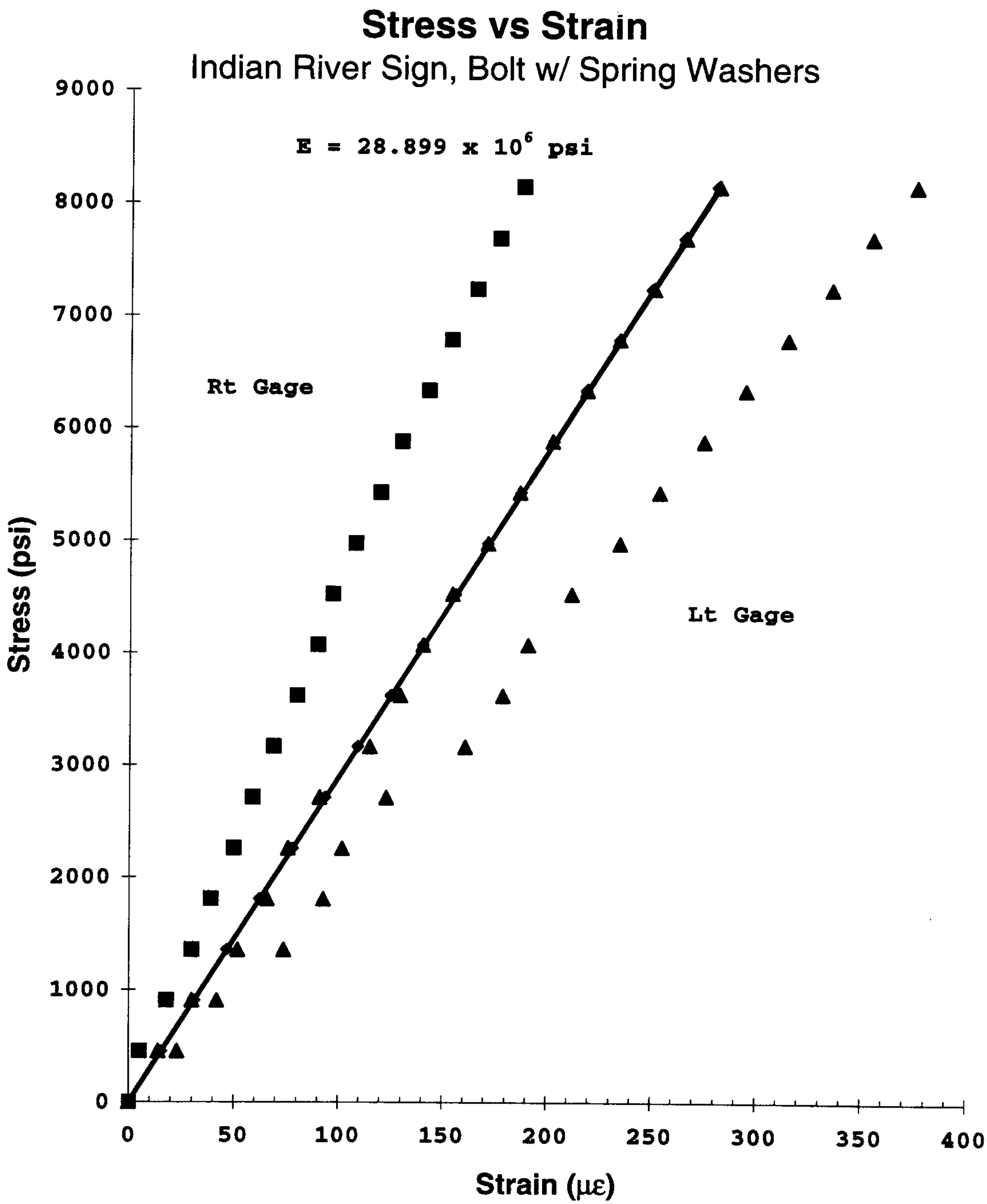



Figure 18 Stress vs Strain, Indian River Sign, Bolt with Spring Washers, May 15, 1998

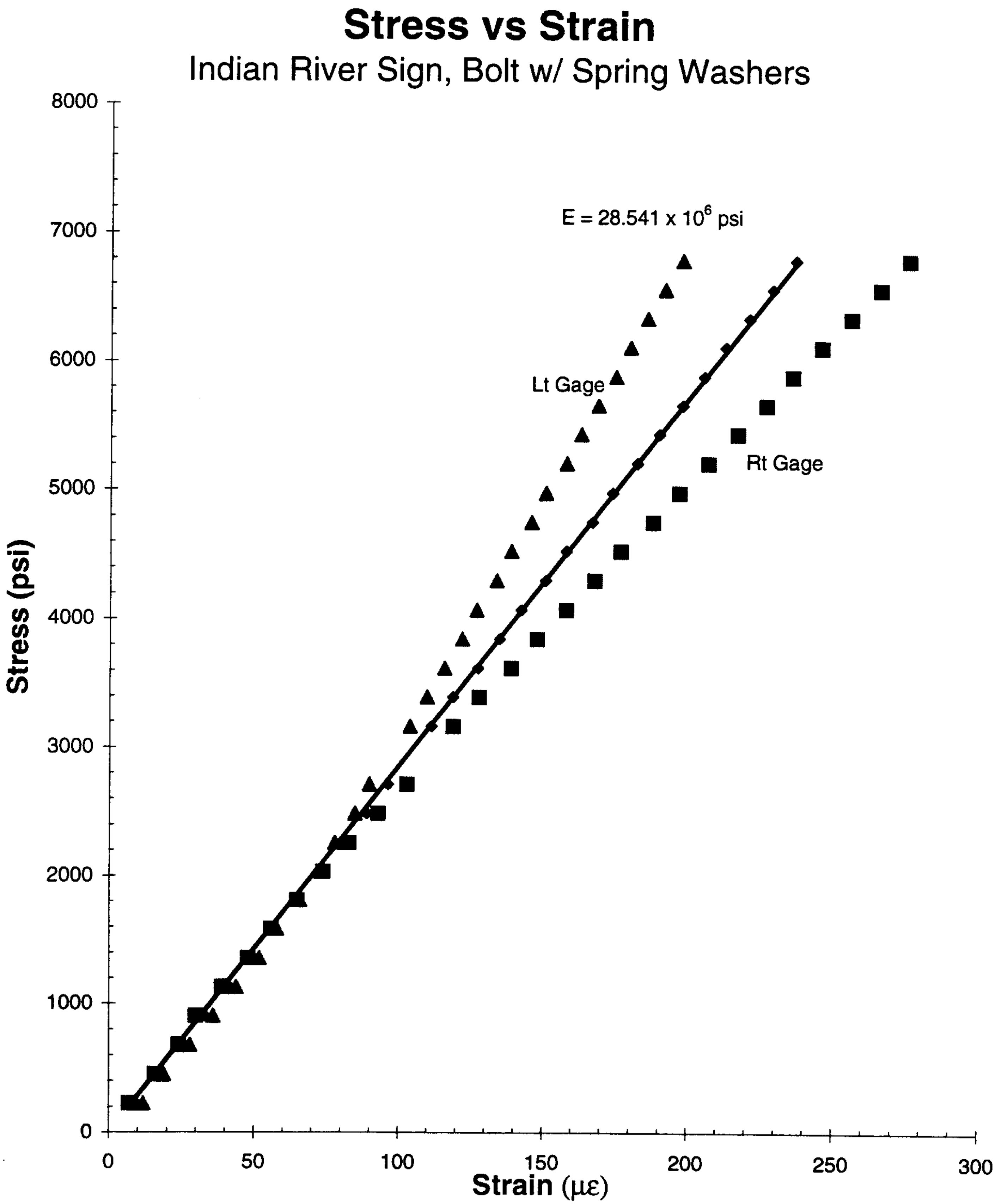



Figure 19 Stress vs Strain, Indian River Sign, Bolt with Spring Washers, February 3, 1999

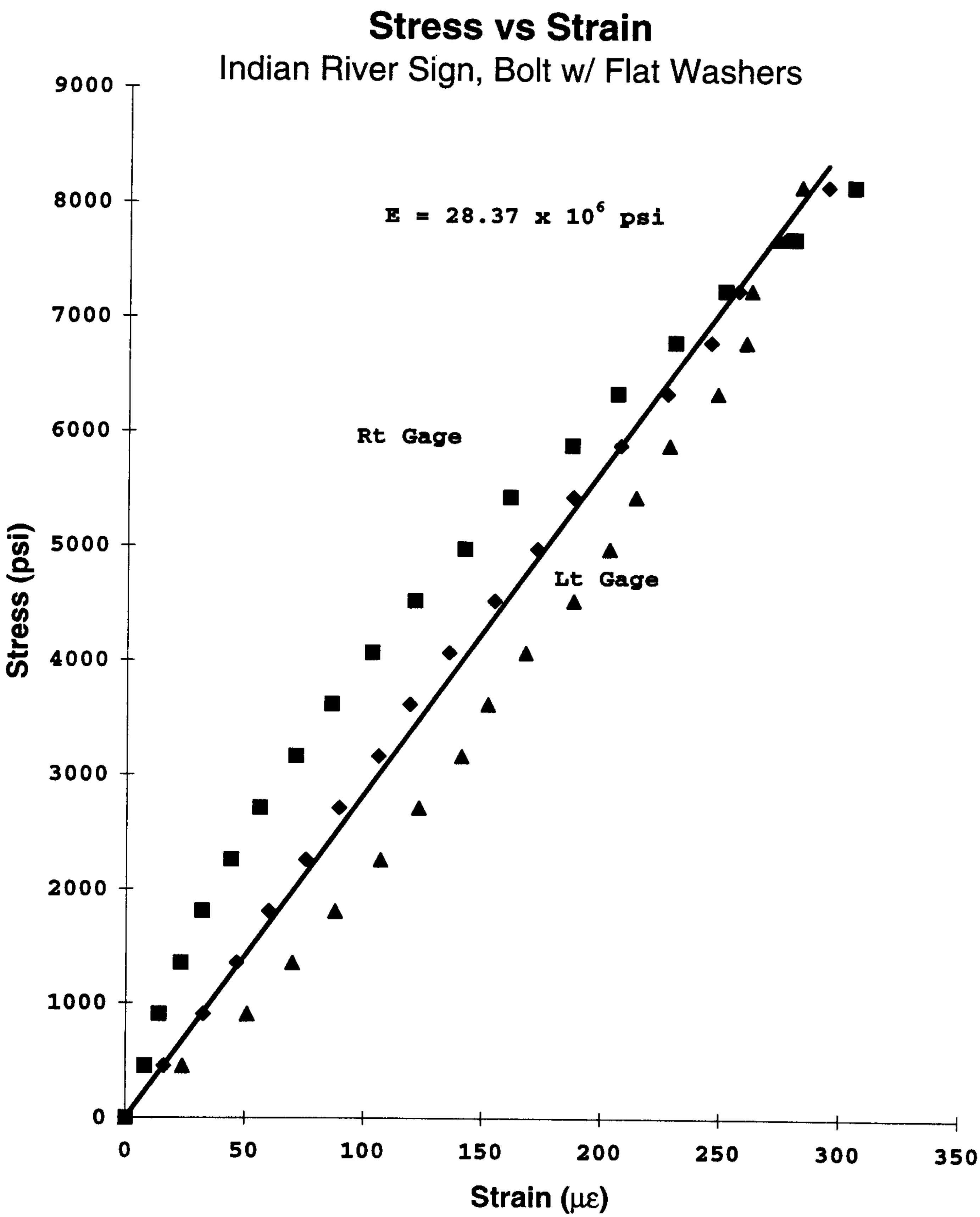



Figure 20 Stress vs Strain, Indian River Sign, Bolt with Flat Washers, May 15, 1998

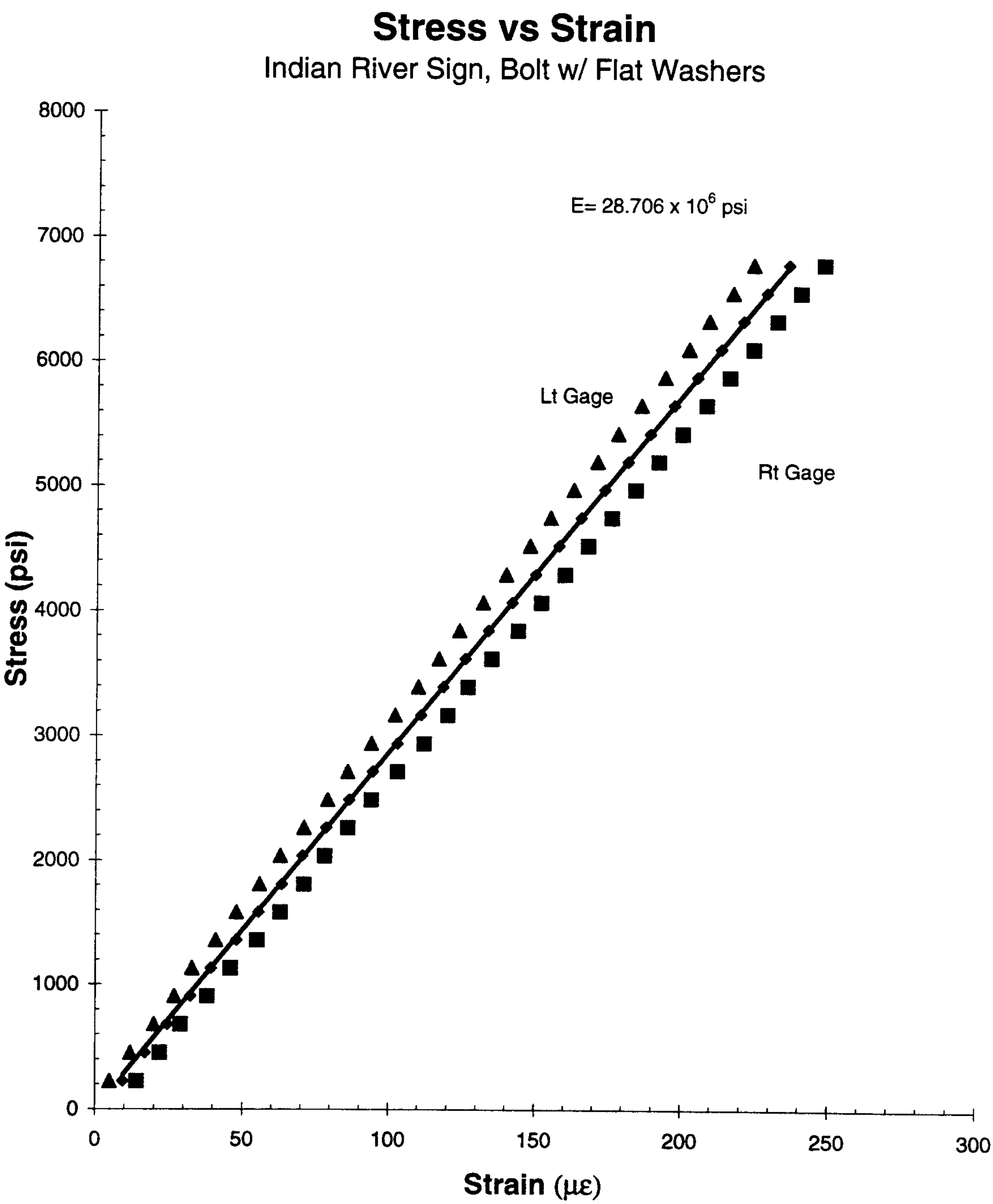



Figure 21 Stress vs Strain, Indian River Sign, Bolt with Flat Washers, December 8,1998

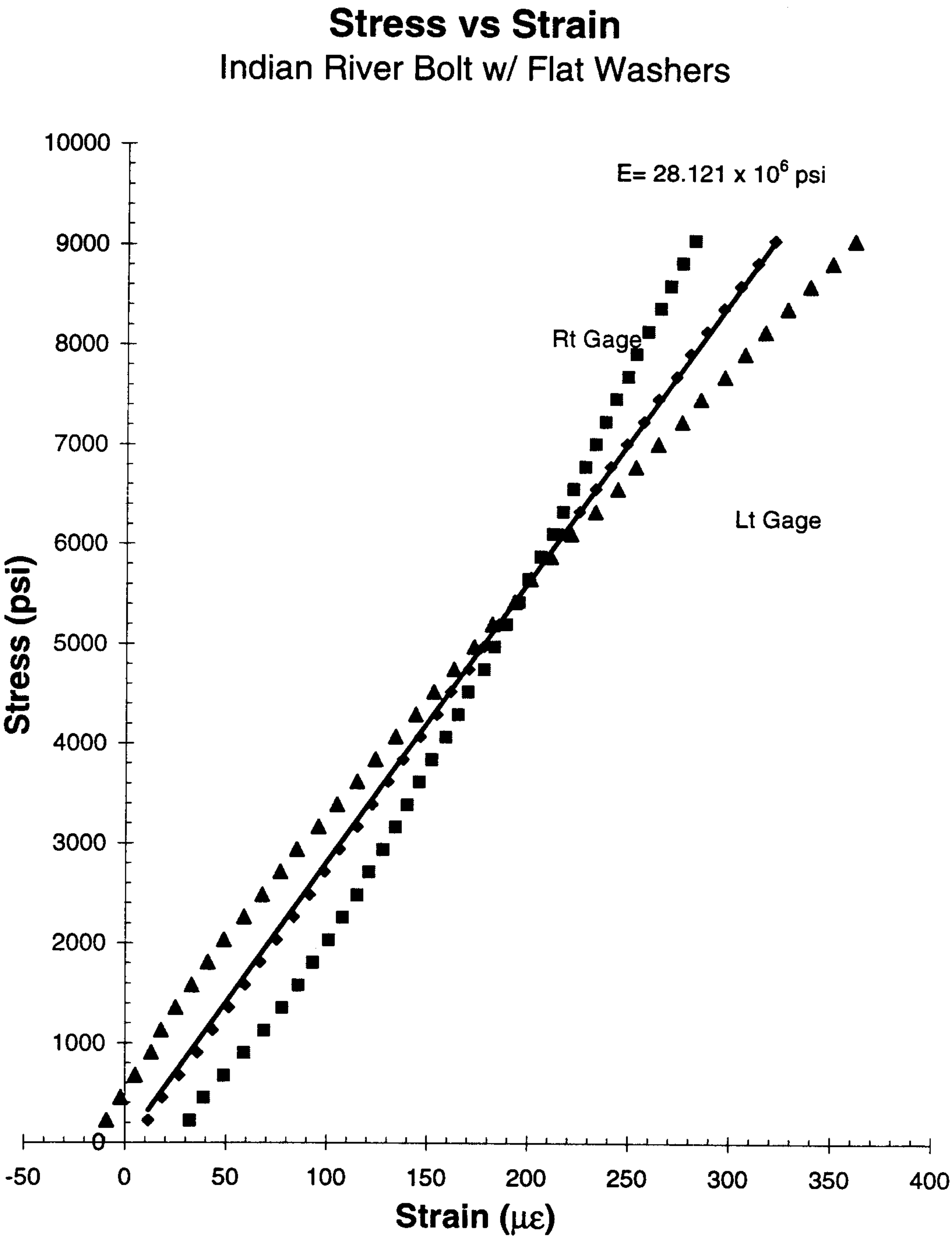



Figure 22 Stress vs Strain, Indian River Sign, Bolt with Flat Washer, February 2, 1999

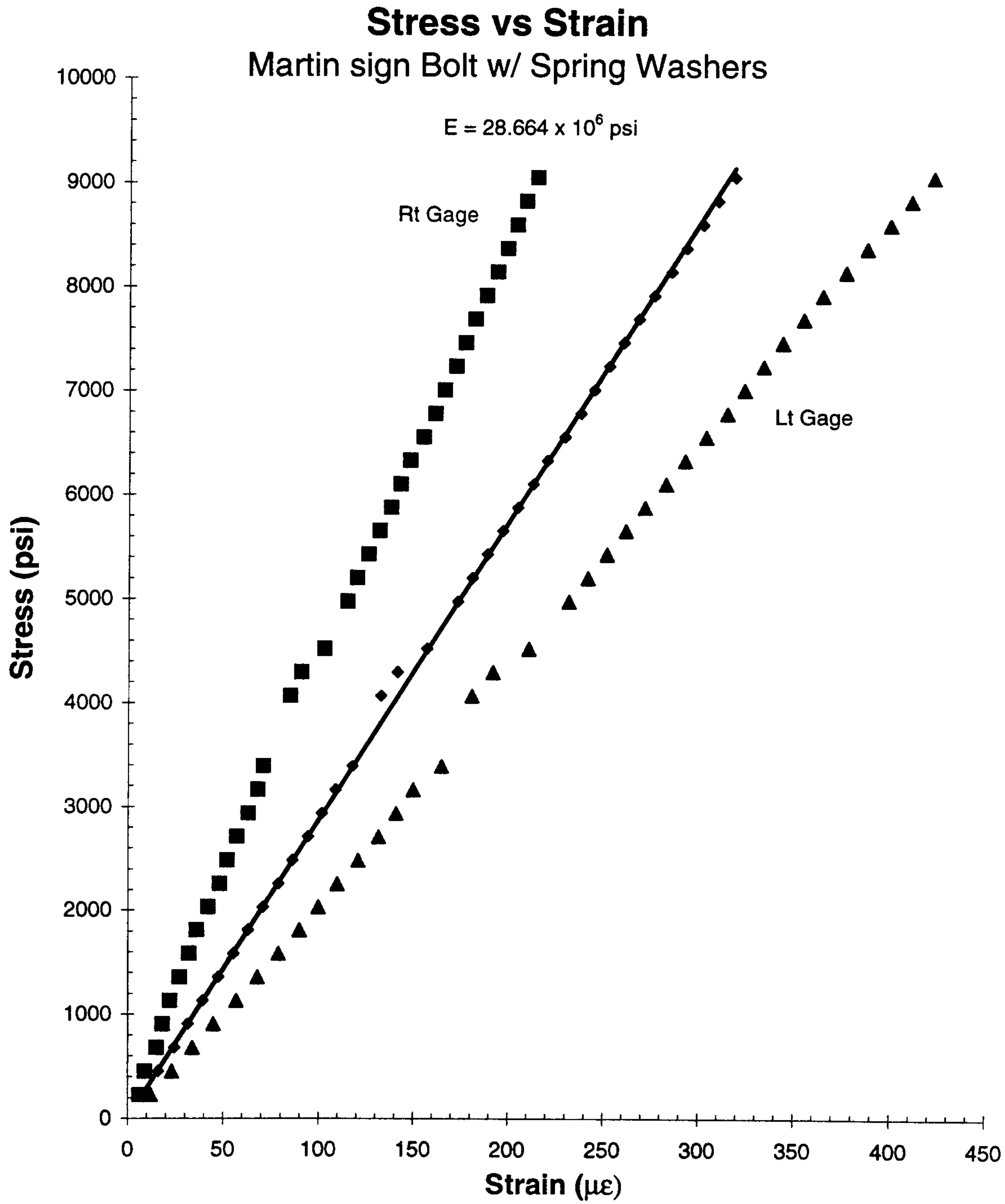



Figure 23 Stress vs Strain, Martin County Sign, Bolt with Spring Washers, December 3, 1998

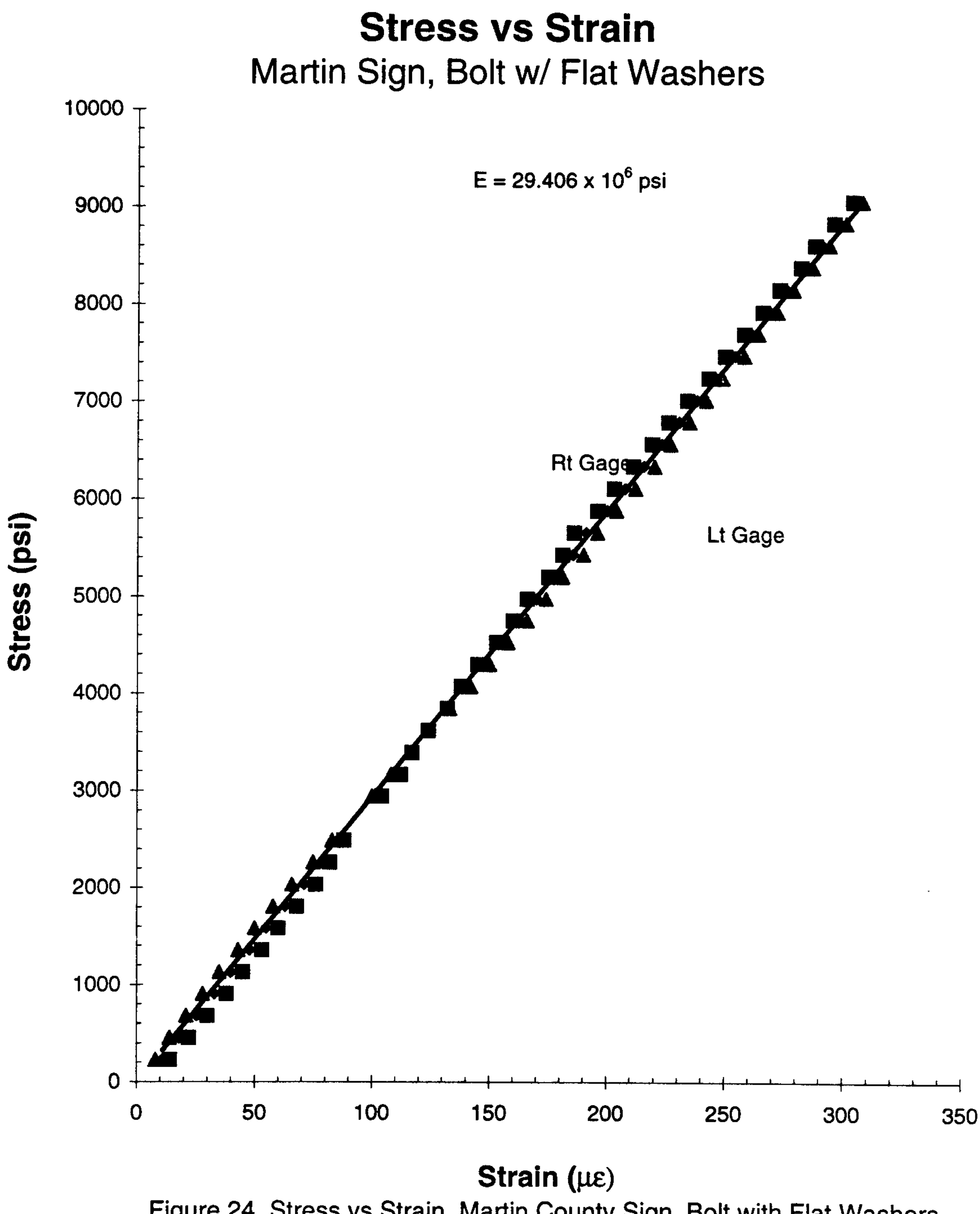



Figure 24 Stress vs Strain, Martin County Sign, Bolt with Flat Washers, December 3, 1998

# RESULTS

The results of the field monitoring are presented below for each sign. In each case, the results are tabulated for the bolt with spring washers and the bolt with flat washers. In addition, the variation of tension over time is plotted for each bolt. The plots include also the variation of the temperature over time. Temperature values are represented by white circular dots, while the tension values are represented by black symbols.

***Tampa***

The Tampa sign bolts were installed on May 18, 1998 and they have been monitored ever since. Different persons have been taking readings ever since they were installed. The sign is located northbound along I-75 just before the I-75/I-4 junction. It is bolted down using 3/4"diameter bolts. Figure 26 shows the location of the sign with respect to I-4.

Tables 4 and 5 list the results of monitoring the bolts from May 18, 1998 to July 16, 1999. Figures 27 and 28 show a plot of tension vs. time for the bolt with spring washers and the bolt with flat washers.

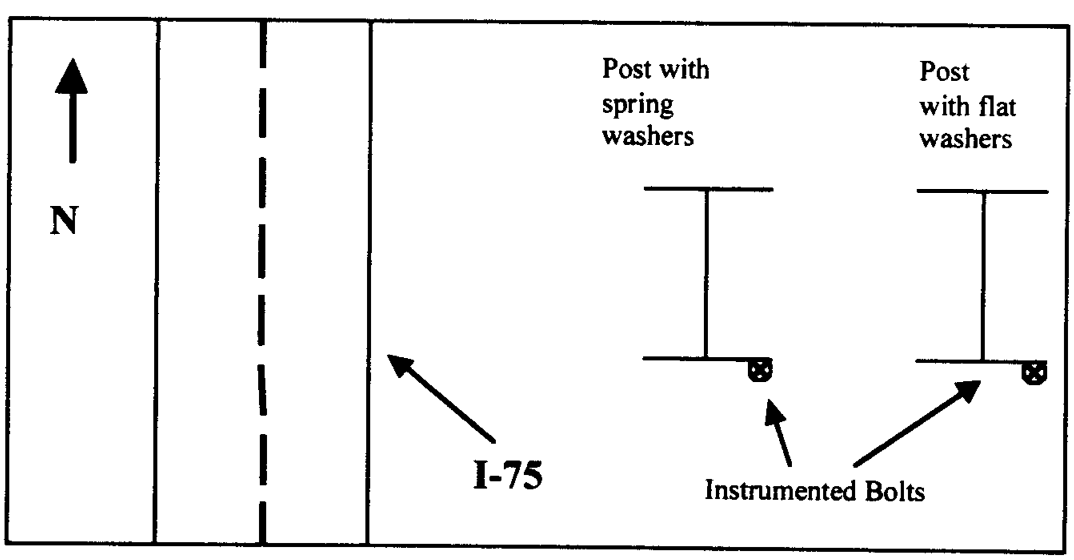



Figure 26 Location of the Tampa Sign with respect to I-75

After the initial installation, the bolt with spring washers show readings were below the lower limit of 2400 lb. The right gage readings also registered negative strains. We suspected a defective spring washer stack so the bolt was re-torqued on June 10 with a new spring washer stack.

From June 24 to October 16, the readings were within the acceptable range as indicated by the trend line Figure 27.

The left wire was cut from the bolt head on October 23. The bolt was not replaced until February 2, 1999. One of the reasons why the bolt was not replaced for almost two months was that a FDOT crew was needed to assist in lifting the sign off the base. We also decided to focus on the other signs' bolts because most of them were damaged at that time.

The bolt was replaced on February 2, 1999 and the reading that day was in the acceptable range at 2755 lb. The reading increased to 4093 lb. the week after, on February 8. To date, the readings have kept within the acceptable range.

The bolt with flat washers was also installed on May 18, 1998. The tension readings on that day and on May 21 were 2915 lb. and 3613 lb. respectively. The tension readings increased to 4856 lb. and 4375 lb. on May 28 and June 1. The bolt was brought back to the lab to be re-tested and was re-installed on June 10. From June 18, 1998 to July 3, 1999 the tension readings were mostly in the acceptable range. The reading on October 3, 1998 was 865 lb. but this unusual reading was performed by a new research assistant and it could be disregarded. At the end of July, the gage was probably damaged and behaved erratically.

The tension in the short bolt could have been affected when the bolt with the spring washers was re-installed on February 1. A crane lifted the sign up on the post with the flat washers and this could have affected the tension. The bolt was re-torqued on February 8, 1999 and the tension reading that day was still low at 2159 lb. The tension reading decreased to 1787 on February 15 after which it increased to 2703 lb. on February 22.

Location: Tampa; On I-75, south of I-4, sign on right hand when going north.

Sign reads: "Plant City, Lakeland, Exit 53"

Description: Green sign - 12' X 8' X 12' from ground, W8X24 posts

***Long Bolt***

| Operator | Date | # of Days | Time | Temp | Strain Reading (με) | | | Bolt tension | | Eccent. | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | After | | °C | Left | Right | Average | lbs | kN | (in) | |
| | | 5/18/98 | Balance Offse | | *43* | *(-2k)874* | | | | | |
| ML | 5/18/98 | 0 | - | 33 | 320 | 20 | 170 | 2178 | 9.7 | 0.083 | |
| ML | 5/21/98 | 3 | - | 32 | 294 | -12 | 141 | 1806 | 8.0 | 0.102 | |
| ML | 5/28/98 | 10 | - | 28 | 277 | -10 | 134 | 1710 | 7.6 | 0.101 | |
| SON | 6/1/98 | 13 | - | 28 | 293 | -10 | 142 | 1813 | 8.1 | 0.100 | |
| SON | 6/10/98 | 22 | 1:30 | 36 | 278 | 15 | 147 | 1877 | 8.3 | 0.084 | |
| | | | | | | | | | | | bolt retorqued with new spring washer stack |
| SON | 6/18/98 | 30 | 12:30 | 36 | 332 | -38 | 147 | 1883 | 8.4 | 0.118 | |
| SON | 6/24/98 | 36 | 12:00 | 34 | 265 | 169 | 217 | 2780 | 12.4 | 0.021 | |
| SON | 7/23/98 | 65 | 12:30 | 35 | 324 | 92 | 208 | 2665 | 11.9 | 0.052 | |
| N | 8/11/98 | 83 | 7:30 | 26 | 362 | 150 | 256 | 3280 | 14.6 | 0.039 | |
| N | 8/26/98 | 98 | 1:00 | 34 | 328 | 85 | 207 | 2646 | 11.8 | 0.055 | |
| JT | 10/3/98 | 135 | 2:30 | 35 | 319 | 84 | 202 | 2582 | 11.5 | 0.055 | wires were in plastic bag |
| JT | 10/9/98 | 141 | 1:07 | 35 | 351 | 80 | 216 | 2761 | 12.3 | 0.059 | Wires were dry and in the bag. |
| JT | 10/16/98 | 148 | 1:00 | 41 | 372 | 84 | 228 | 2921 | 13.0 | 0.059 | Wires were dry and in the bag. |
| JT | 10/23/98 | 155 | 1:40 | 32 | | | | | | | Lt wire was cut from the bolt head. **Bring crowbar and mallet.** |
| JT | 11/4/98 | 166 | 1:45 | | | | | | | | Was not able to replace instrumented bolt. |
| JT | 11/13/98 | 175 | 1:25 | | | | | | | | Was not able to replace instrumented bolt. |
| JT | 11/20/98 | 182 | 12:40 | | | | | | | | Was not able to replace instrumented bolt. |
| JT | 2/1/99 | 253 | 11:10 | 29 | 90 | 340 | 215 | 2755 | 12.3 | 0.055 | Replaced w/ instrumented bolt. New Offsets ***Lt: 44 Rt: (-2k)876*** |
| JT | 2/8/99 | 260 | 12:35 | 30 | 287 | 352 | 320 | 4093 | 18.2 | 0.010 | Retorqued,rds were low. New spring washers. ***Lt: 43 Rt: (-2k)874*** |
| JT | 2/15/99 | 267 | 12:10 | 31 | 259 | 213 | 236 | 3024 | 13.4 | 0.009 | Wires were dry and in the bag. |
| JT | 2/22/99 | 274 | 11:55 | 21 | 245 | 208 | 227 | 2902 | 12.9 | 0.008 | ibid |
| JT | 3/22/99 | 304 | 11:45 | 30 | 285 | 189 | 237 | 3036 | 13.5 | 0.019 | rusting on galvanized washers, none on stainless washers. |
| JT | 3/29/99 | 311 | 12:15 | 35 | 277 | 191 | 234 | 2998 | 13.3 | 0.017 | ibid |
| JT | 4/5/99 | 317 | 11:15 | 32 | 279 | 177 | 228 | 2921 | 13.0 | 0.021 | ibid |
| JT | 4/12/99 | 324 | 11:55 | 34 | 288 | 172 | 230 | 2947 | 13.1 | 0.024 | ibid |
| JT | 4/19/99 | 331 | 12:05 | 30 | 271 | 162 | 217 | 2774 | 12.3 | 0.024 | ibid |
| JPP | 5/31/99 | 373 | 4:00 | 34 | 287 | 158 | 223 | 2851 | 12.7 | 0.027 | |
| JPP | 6/15/99 | 387 | 2:00 | 37 | 297 | 166 | 232 | 2966 | 13.2 | 0.027 | |
| JPP | 7/3/99 | 405 | 12:20 | 35 | 285 | 147 | 216 | 2767 | 12.3 | 0.030 | |
| JPP | 7/11/99 | 413 | 2:30 | 38 | 285 | 150 | 218 | 2787 | 12.4 | 0.029 | |
| JPP | 7/16/99 | 418 | 8:35 | 23 | 271 | 99 | 185 | 2370 | 10.5 | 0.044 | |

Table 4 Tension and Eccentricity Values For Tampa Sign, Bolt with Spring Washers

Location: Tampa; On I-75, south of I-4, sign on right hand when going north.

Sign reads: "Plant City, Lakeland, Exit 53"

Description: Green sign - 12' X 8' X 12' from ground, W8X24 posts

***Short Bolt***

| Operator | Date | # of Days | Time | Temp | Strain Reading (με) | | | Bolt tension | | Eccent. | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | After | | °C | Left | Right | Average | lbs | kN | (in) | |
| | | 5/18/98 | | Balance Offse | *(-2K) 894* | *140* | | | | | |
| ML | 5/18/98 | 0 | - | 33 | 420 | 35 | 228 | 2915 | 13.0 | 0.079 | |
| ML | 5/21/98 | 3 | - | 32 | 532 | 32 | 282 | 3613 | 16.1 | 0.083 | |
| ML | 5/28/98 | 10 | - | 28 | 728 | 30 | 379 | 4856 | 21.6 | 0.086 | |
| SON | 6/1/98 | 13 | - | 28 | 651 | 32 | 342 | 4375 | 19.5 | 0.085 | |
| | | | | | | | | | | | bolt tested in lab and retorqued |
| SON | 6/10/98 | 22 | 1:30 | 36 | 390 | 277 | 334 | 4273 | 19.0 | 0.016 | |
| SON | 6/18/98 | 30 | 12:30 | 36 | 387 | 231 | 309 | 3959 | 17.6 | 0.024 | |
| SON | 6/24/98 | 36 | 12:00 | 34 | 210 | 225 | 218 | 2787 | 12.4 | 0.003 | |
| SON | 7/23/98 | 65 | 12:30 | 35 | 344 | 326 | 335 | 4292 | 19.1 | 0.003 | |
| N | 8/11/98 | 83 | 7:30 | 26 | 305 | 322 | 314 | 4017 | 17.9 | 0.003 | |
| N | 8/26/98 | 98 | 1:00 | 34 | 52 | 329 | 191 | 2441 | 10.9 | 0.068 | *check twice, it is correct |
| JT | 10/3/98 | 135 | 2:20 | 37 | -214 | 349 | 68 | 865 | 3.8 | 0.391 | wires were not in plastic bag |
| JT | 10/9/98 | 141 | 1:07 | 36 | 190 | 378 | 284 | 3639 | 16.2 | 0.031 | Checked the Lt rdg (-2K, 894 offset) 2x. Wires were dry and inbag. |
| JT | 10/16/98 | 148 | 12:55 | 39 | 162 | 387 | 275 | 3517 | 15.6 | 0.038 | Wires were dry and in the bag. Readings were solid. |
| JT | 10/23/98 | 155 | 1:30 | 28 | 99 | 322 | 211 | 2697 | 12.0 | 0.050 | Lt wire was out of bag. Cut and spliced both wires |
| JT | 11/4/98 | 166 | 1:30 | 23 | 265 | 326 | 296 | 3786 | 16.8 | 0.010 | Wires were dry and in bag. Bolts were wet. |
| JT | 11/13/98 | 175 | 1:30 | 32 | 106 | 336 | 221 | 2831 | 12.6 | 0.049 | Wires were dry and in the bag. |
| JT | 11/20/98 | 182 | 12:40 | 36 | 196 | 352 | 274 | 3510 | 15.6 | 0.027 | Wires were dry and in the bag. |
| JT | 2/1/99 | 253 | 10:55 | 26 | 190 | 343 | 267 | 3414 | 15.2 | 0.027 | Wires were dry and in the bag. |
| JT | 2/8/99 | 260 | 1:00 | 33 | 217 | 120 | 169 | 2159 | 9.6 | 0.027 | re-torqued using new torque wrench |
| JT | 2/15/99 | 267 | 12:20 | 32 | 33 | 246 | 140 | 1787 | 8.0 | 0.072 | Wires were dry and in bag. |
| JT | 2/22/99 | 274 | 12:00 | 21 | 150 | 272 | 211 | 2703 | 12.0 | 0.027 | ibid |
| JT | 3/22/99 | 304 | 11:50 | 30 | 141 | 386 | 264 | 3376 | 15.0 | 0.044 | ibid |
| JT | 3/29/99 | 311 | 12:20 | 34 | 20 | 361 | 191 | 2441 | 10.9 | 0.084 | ibid |
| JT | 4/5/99 | 317 | 11:20 | 32 | 94 | 393 | 244 | 3120 | 13.9 | 0.058 | ibid |
| JT | 4/12/99 | 324 | 12:00 | 34 | 89 | 437 | 263 | 3370 | 15.0 | 0.062 | ibid |
| JT | 4/19/99 | 331 | 12:10 | 31 | -9 | 394 | 193 | 2466 | 11.0 | 0.098 | ibid |
| JPP | 5/31/99 | 373 | 4:00 | 37 | 83 | 517 | 300 | 3844 | 17.1 | 0.068 | |
| JPP | 6/15/99 | 387 | 2:00 | 36 | -110 | 590 | 240 | 3075 | 13.7 | 0.137 | |
| JPP | 7/3/99 | 405 | 12:20 | 34 | 76 | 725 | 401 | 5131 | 22.8 | 0.076 | |
| JPP | 7/11/99 | 413 | 2:30 | 38 | -192 | 711 | 260 | 3325 | 14.8 | 0.163 | |
| JPP | 7/16/99 | 418 | 8:24 | 23 | 71 | 713 | 392 | 5022 | 22.3 | 0.077 | |
| | | | | | | | | | | | |

Table 5 Tension and Eccentricity Values For Tampa Sign, Bolt with Flat Washers

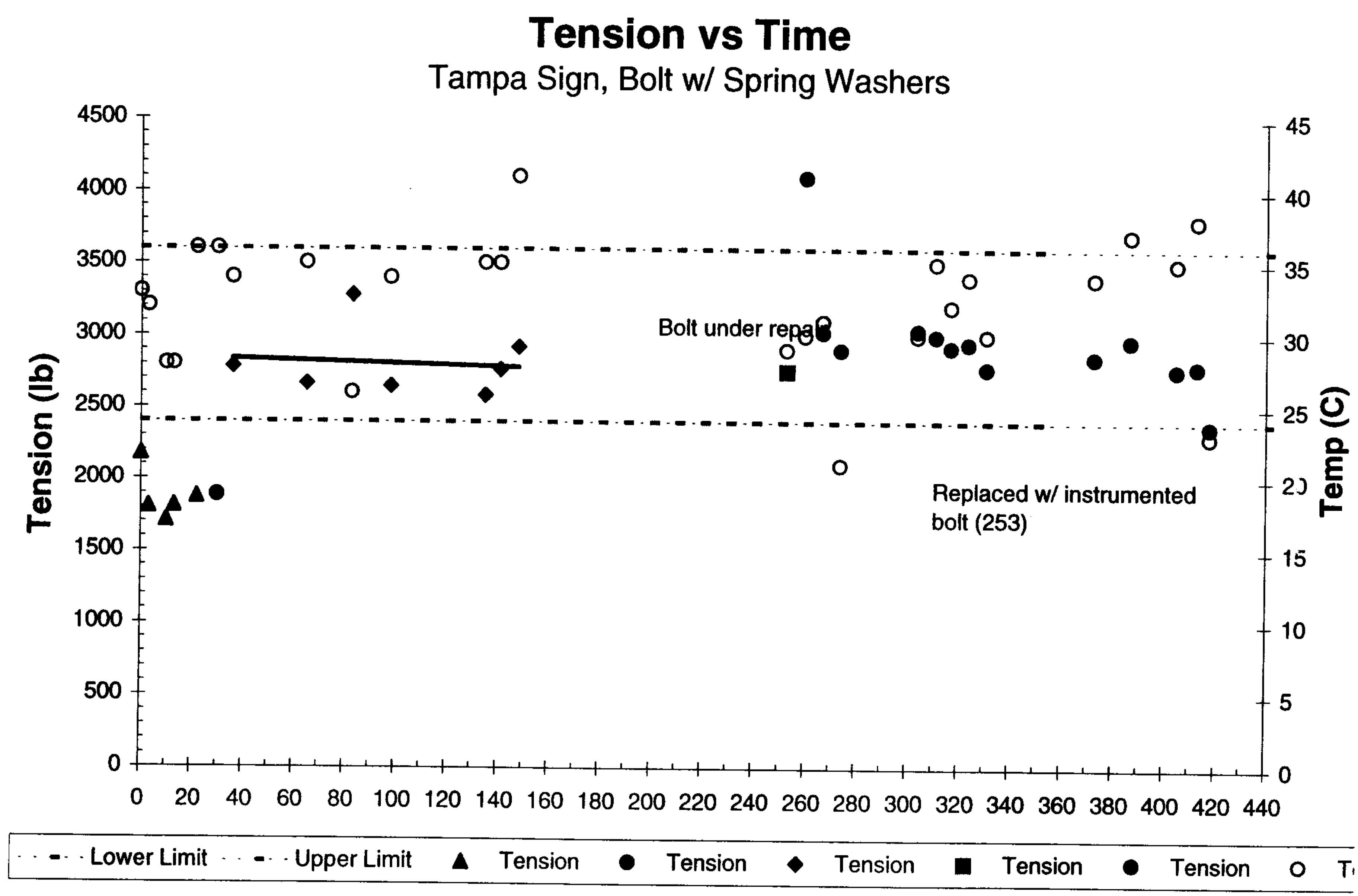



Figure 27 Tension vs Time, Tampa Sign, Bolt with Spring Washers

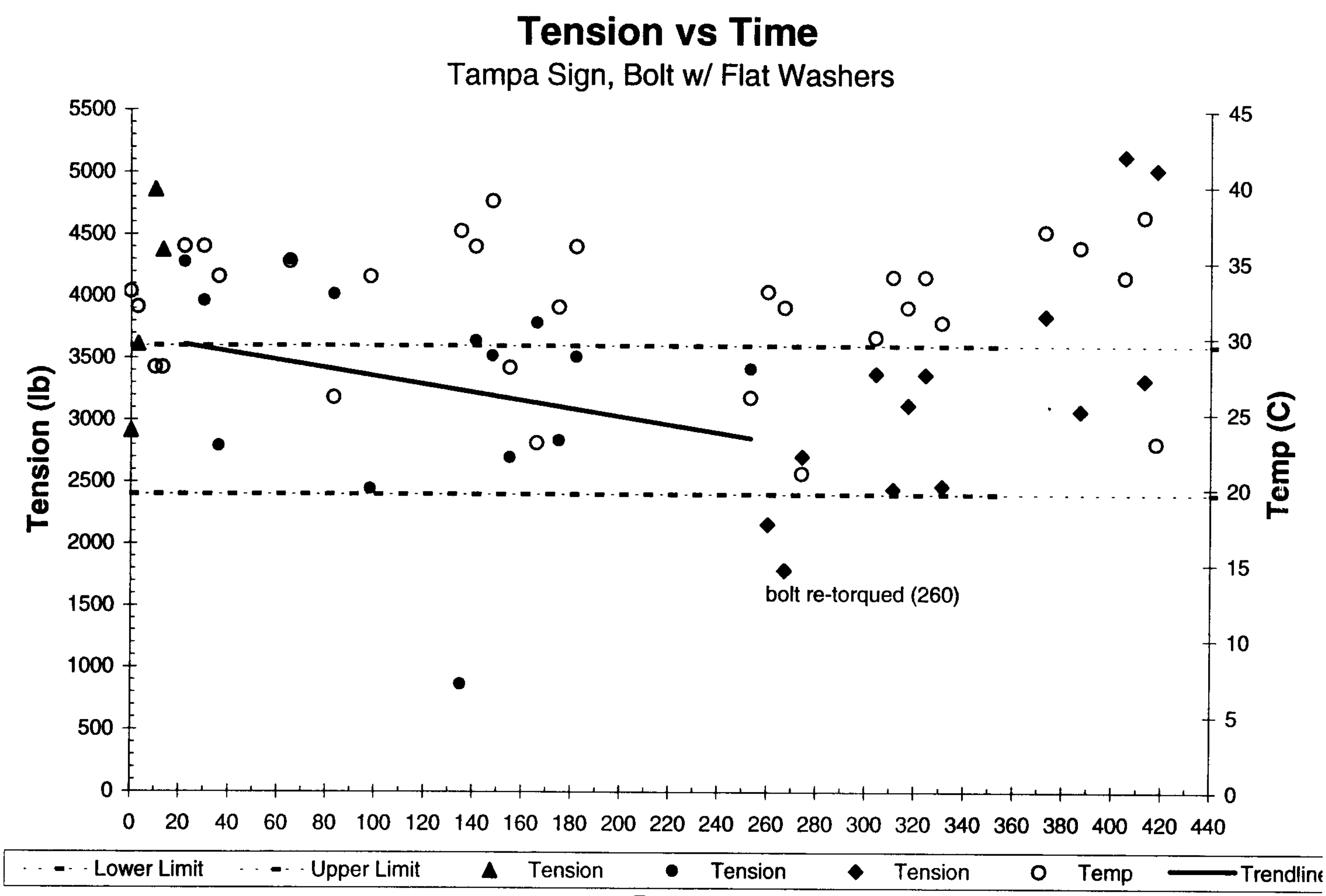



Figure 28 Tension vs Time, Tampa Sign, Bolt with Flat Washers

***Orlando***

The Orlando sign bolts were installed on May 16, 1998 and they have been monitored ever since. Different students have been taking readings ever since they were installed. The sign is located westward along I-4, just before the Highway 528 (Beeline)/I-4 junction. It is bolted down using 3/4" diameter bolts. Figure 29 shows the location of the sign with respect to I-4.

Tables 6 and 7 list the results of monitoring the bolts from May 16, 1998 to April 12, 1999. Figures 30 and 31 show a plot of tension vs. time for the bolt with the spring washers and the bolt with flat washers.

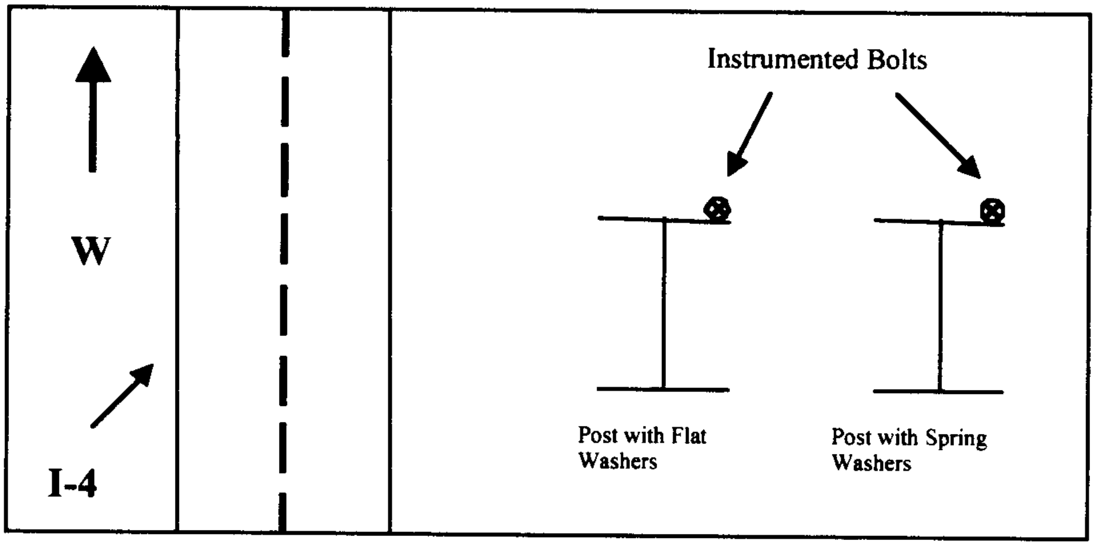



Figure 29 Location of Orlando Sign with respect to I-4

The bolt with strain gages was never replaced and the bolt was re-torqued. The spring washers were able to keep the tension within the acceptable range from May 16, 1998 to February 22, 1999. After that date, the readings were below the allowable range. On April 12, the bolt was removed. A tensile test in the lab yielded a value of 27,117 ksi for the modulus of elasticity, slightly below the expected value of 29,000 ksi, which might indicate a deterioration of the strain gage.

The initial reading for the bolt with flat washers was 2601 lb. The readings increased dramatically to 23420 lb. on May 28 and 45008 lb. on June 1. The bolt was brought back and re-instrumented. The bolt was re-installed on June 10 and a reading of 2671 lb. was recorded.

After that date, the readings were below 2400 lb. until September 26. The strain gage wires were ripped off on October 3 and the newly re-instrumented bolt was re-installed on November 4. The bolt was re-torqued on November 13 and the readings decreased to 922 lb. on November 20.

The bolt was re-installed on December 2, 1998 with new offsets and a measured modulus of elasticity of 27,761 ksi. The readings have been below the 2400 lb. until January 25, 1999.

The bolt was re-installed and re-aligned on February 1, 1999. One can notice that one of the strain readings was always negative for most of the readings. This meant that the bolt was not aligned properly and as a result, the bolt was subjected to bending. This is the reason for the re-torquing of the bolt on February 8, 15, and 22. The bolt was finally removed and brought back to the lab. A tensile test revealed a modulus of elasticity of 36,047 ksi, a 33% increase over the value measured in January. This indicate a defect in the strain gage, probably in the bond between gage and bolt. This defect explains partially the erratic behavior of the bolt during the last weeks of testing.

Location: Orlando, Last sign before exit 28 going west.

Sign reads: "Exit 28, I-4, Toll 528, Cape Canaveral, Titusville."

Description: Green Sign - 20' X 12' X 11' from ground, W8X24 posts

***Long Bolt***

| Operator | Date | # of Days | Time | Temp | Strain Reading (με) | | | Bolt tension | | Eccent. | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | After | | °C | Left | Right | Average | lbs | kN | (in) | |
| | | 5/16/98 | Balance Offset >> | | *382* | *480* | | | | | |
| ML | 5/16/98 | 0 | - | 24 | 218 | 310 | 264 | 3382 | 15.0 | 0.016 | |
| ML | 5/21/98 | 5 | - | 29 | 271 | 299 | 285 | 3651 | 16.2 | 0.005 | |
| ML | 5/28/98 | 12 | - | 29 | 248 | 315 | 282 | 3607 | 16.0 | 0.011 | |
| SON | 6/1/98 | 15 | - | 29 | 237 | 325 | 281 | 3600 | 16.0 | 0.015 | |
| SON | 6/10/98 | 24 | 12:00 | 36 | 229 | 335 | 282 | 3613 | 16.1 | 0.018 | |
| SON | 6/18/98 | 32 | 11:20 | 35 | 218 | 288 | 253 | 3241 | 14.4 | 0.013 | |
| SON | 6/24/98 | 38 | 10:35 | 35 | 200 | 313 | 257 | 3286 | 14.6 | 0.021 | |
| SON | 7/8/98 | 52 | 10:50 | 33 | 208 | 278 | 243 | 3113 | 13.8 | 0.014 | |
| SON | 7/15/98 | 59 | 10:30 | 28 | 177 | 315 | 246 | 3152 | 14.0 | 0.026 | |
| SON | 7/23/98 | 67 | 11:10 | 35 | 178 | 327 | 253 | 3235 | 14.4 | 0.028 | |
| N | 8/12/98 | 86 | 8:00 | 29 | 192 | 305 | 249 | 3184 | 14.2 | 0.021 | |
| N | 8/26/98 | 100 | 11:30 | 33 | 178 | 315 | 247 | 3158 | 14.0 | 0.026 | |
| JT | 10/3/98 | 137 | 12:51 | 37 | 144 | 275 | 210 | 2684 | 11.9 | 0.029 | Wires were not in the plastic bag. They were left on the ground entangled with the gass. |
| JT | 10/9/98 | 143 | 12:00 | 35 | 188 | 250 | 219 | 2806 | 12.5 | 0.013 | Wires were dy and in the bag; lots of ants. |
| JT | 10/16/98 | 150 | 11:35 | 33 | 178 | 241 | 210 | 2684 | 11.9 | 0.014 | Wires were dry and in the bag. |
| JT | 10/23/98 | 157 | 11:40 | 25 | 206 | 238 | 222 | 2844 | 12.7 | 0.007 | Wires were dry and in the bag. Clipped both wires. Rt Rdg fluctuated a lot. |
| JT | 11/4/98 | 168 | 11:50 | 23 | 180 | 270 | 225 | 2883 | 12.8 | 0.019 | Wires were dry and in the bag. Bolts were wet. |
| JT | 11/13/98 | 177 | 12:00 | 30 | 187 | 277 | 232 | 2972 | 13.2 | 0.018 | Bag was ripped off the post. Wires were dry and in the bag |
| JT | 11/20/98 | 184 | 11:00 | 30 | 187 | 272 | 230 | 2940 | 13.1 | 0.017 | Wires were dry and in the bag. |
| JT | 12/2/98 | 196 | 10:05 | 31 | 197 | 278 | 238 | 3043 | 13.5 | 0.016 | |
| | | 196 | 1:05 | 28 | 173 | 268 | 221 | 2825 | 12.6 | 0.020 | Wires were dry and in the bag. |
| | | 196 | 2:05 | 27 | 175 | 280 | 228 | 2915 | 13.0 | 0.022 | |
| JT | 12/11/98 | 205 | 10:00 | 21 | 212 | 265 | 239 | 3056 | 13.6 | 0.010 | Wires were dry and in the bag. |
| | | 205 | 12:40 | 27 | 195 | 299 | 247 | 3165 | 14.1 | 0.020 | ibid |
| | | 205 | 1:40 | 27 | 191 | 265 | 228 | 2921 | 13.0 | 0.015 | ibid |
| JT | 1/25/99 | 249 | 11:15 | 26 | 180 | 228 | 204 | 2614 | 11.6 | 0.011 | Wires were dry and in the bag. |
| JT | 2/1/99 | 255 | 1:05 | 24 | 148 | 342 | 245 | 3139 | 14.0 | 0.037 | ibid |
| JT | 2/8/99 | 262 | 10:45 | 27 | 166 | 282 | 224 | 2870 | 12.8 | 0.024 | ibid |
| JT | 2/15/99 | 269 | 10:25 | 23 | 190 | 206 | 198 | 2537 | 11.3 | 0.004 | ibid |
| JT | 2/22/99 | 276 | 10:15 | 12 | 225 | 167 | 196 | 2511 | 11.2 | 0.014 | ibid |
| JT | 3/22/99 | 306 | 10:20 | 24 | 172 | 43 | 108 | 1377 | 6.1 | 0.056 | rusting on all washers |
| JT | 3/29/99 | 313 | 10:30 | 31 | 139 | 103 | 121 | 1550 | 6.9 | 0.014 | ibid |
| JT | 4/5/99 | 319 | 9:55 | 27 | 142 | 184 | 163 | 2088 | 9.3 | 0.012 | ibid |
| JT | 4/12/99 | 326 | 10:15 | 30 | 202 | 110 | 156 | 1999 | 8.9 | 0.028 | readings fluctuated; replaced w/ regular bolt permanently |

Table 6 Tension and Eccentricity Values For Orlando Sign, Bolt with Spring Washers

Location: Orlando, Last sign before exit 28 going west.

Sign reads: "Exit 28, I-4, Toll 528, Cape Canaveral, Titusville."

Description: Green Sign - 20' X 12' X 11' from ground, W8X24 posts

***Short Bolt***

| Operator | Date | # of Days | Time | Temp | Strain Reading (με) | | | Bolt tension | | Eccent. | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | After | | °C | Left | Right | Average | lbs | kN | (in) | |
| | | 5/16/98 | Balance Offset >> | | *418* | *(-2k)774* | | | | | |
| ML | 5/16/98 | 0 | - | 24 | 40 | 366 | 203 | 2601 | 11.6 | 0.075 | |
| ML | 5/21/98 | 5 | - | 29 | 1116 | 399 | 758 | 9705 | 43.2 | 0.044 | |
| ML | 5/28/98 | 12 | - | 29 | 3313 | 343 | 1828 | 23420 | 104.2 | 0.076 | |
| SON | 6/1/98 | 15 | - | 29 | 6670 | 356 | 3513 | 45008 | 200.2 | 0.084 | bolt tested in lab and retorqued |
| SON | 6/10/98 | 24 | 12:00 | 36 | 736 | -319 | 209 | 2671 | 11.9 | 0.237 | |
| SON | 6/18/98 | 32 | 11:20 | 35 | 631 | -320 | 156 | 1992 | 8.9 | 0.287 | |
| SON | 6/24/98 | 38 | 10:35 | 35 | 619 | -314 | 153 | 1954 | 8.7 | 0.287 | |
| SON | 7/8/98 | 52 | 10:50 | 33 | 575 | -306 | 135 | 1723 | 7.7 | 0.307 | |
| SON | 7/15/98 | 59 | 10:30 | 28 | 545 | -310 | 118 | 1505 | 6.7 | 0.341 | |
| SON | 7/23/98 | 67 | 11:10 | 35 | 531 | -315 | 108 | 1384 | 6.2 | 0.367 | |
| N | 8/12/98 | 86 | 8:00 | 29 | 542 | -295 | 124 | 1582 | 7.0 | 0.318 | |
| N | 8/26/98 | 100 | 11:30 | 33 | 275 | *0* | 138 | 1762 | 7.8 | 0.094 | *check twice, it is correct |
| JT | 10/3/98 | 137 | 12:41 | 36 | | | | | | | Strain gage wires were ripped off from the bolts. |
| JT | 10/9/98 | 143 | 11:50 | 35 | | | | | | | Replaced instrumented bolt with regular bolt. |
| JT | 10/16/98 | 150 | 11:35 | | | | | | | | Have not replaced regular bolt with an instrumented bolt |
| JT | 10/23/98 | 157 | 12:10 | | 189 | 145 | 167 | 2140 | 9.5 | 0.012 | Replaced regular bolt with newly repaired instrumented bolt. Did not read Temp. |
| JT | 11/4/98 | 168 | 12:05 | 25 | -210 | 430 | 110 | 1409 | 6.3 | 0.273 | Re-torqued bolt. New Offsets: ***Lt:135 Rt: (-2k)719.*** Wires were dry and in bag. |
| JT | 11/13/98 | 177 | 12:05 | 29 | -55 | 249 | 97 | 1243 | 5.5 | 0.147 | Wires were dry and in the bag. |
| JT | 11/20/98 | 184 | 11:10 | 30 | 128 | 16 | 72 | 922 | 4.1 | 0.073 | Average was very low. Replaced with a regular bolt. |
| JT | 12/2/98 | 196 | 10:15 | 25 | 592 | -200 | 196 | 2404 | 10.7 | 0.189 | Replaced w/ instrumented bolt. New Offsets: Lt: ***114*** Rt: ***(-2k)722.*** New E = ***27.761x106kpsi*** |
| | | 196 | 1:10 | 28 | 524 | -200 | 162 | 1987 | 8.8 | 0.209 | |
| | | 196 | 2:10 | 27 | 517 | -200 | 159 | 1944 | 8.6 | 0.212 | |
| JT | 12/11/98 | 205 | 10:10 | 21 | 480 | -230 | 125 | 1533 | 6.8 | 0.266 | Wires were dry and in the bag. |
| | | 205 | 12:40 | 29 | 450 | -170 | 140 | 1717 | 7.6 | 0.208 | ibid |
| | | 205 | 1:40 | 26 | 448 | -170 | 139 | 1705 | 7.6 | 0.208 | ibid |
| JT | 1/25/99 | 249 | 11:25 | 26 | 366 | -197 | 84.5 | 1036 | 4.6 | 0.312 | ibid |
| JT | 2/1/99 | 255 | 1:10 | 21 | 500 | -140 | 180 | 2208 | 9.8 | 0.167 | Re-installed & re-aligned the bolt. New Offsets Lt: 120 Rt (-2k)694 |
| JT | 2/8/99 | 262 | 10:55 | 25 | -222 | 500 | 139 | 1705 | 7.6 | 0.243 | Retorqued w new wrench. New Offsets Lt: 250 Rt (-2k)678 |
| JT | 2/15/99 | 269 | 10:35 | 21 | 344 | -165 | 89.5 | 1098 | 4.9 | 0.267 | Retorqued, initial tension rdgs were negative. ***Lt:345 Rt:(-2k)781*** |
| JT | 2/22/99 | 276 | 10:25 | 12 | 678 | -242 | 218 | 2674 | 11.9 | 0.198 | Retorqued, ***Lt:418 Rt:(-2k)774*** |
| JT | 3/22/99 | 306 | 10:25 | 23 | 243 | -271 | -14 | -172 | -0.8 | -1.721 | Wires were dry and in the bag. |
| JT | 3/29/99 | 313 | 10:35 | 31 | 147 | -346 | -99.5 | -1220 | -5.4 | -0.232 | ibid |
| JT | 4/5/99 | 319 | 10:00 | 28 | 280 | -130 | 75 | 920 | 4.1 | 0.256 | ibid |
| JT | 4/12/99 | 326 | 10:20 | 29 | 360 | -100 | 130 | 1594 | 7.1 | 0.166 | readings fluctuated; replaced w/ regular bolt permanently |

Table 7 Tension and Eccentricity Values For Orlando Sign, Bolt with Flat Washers

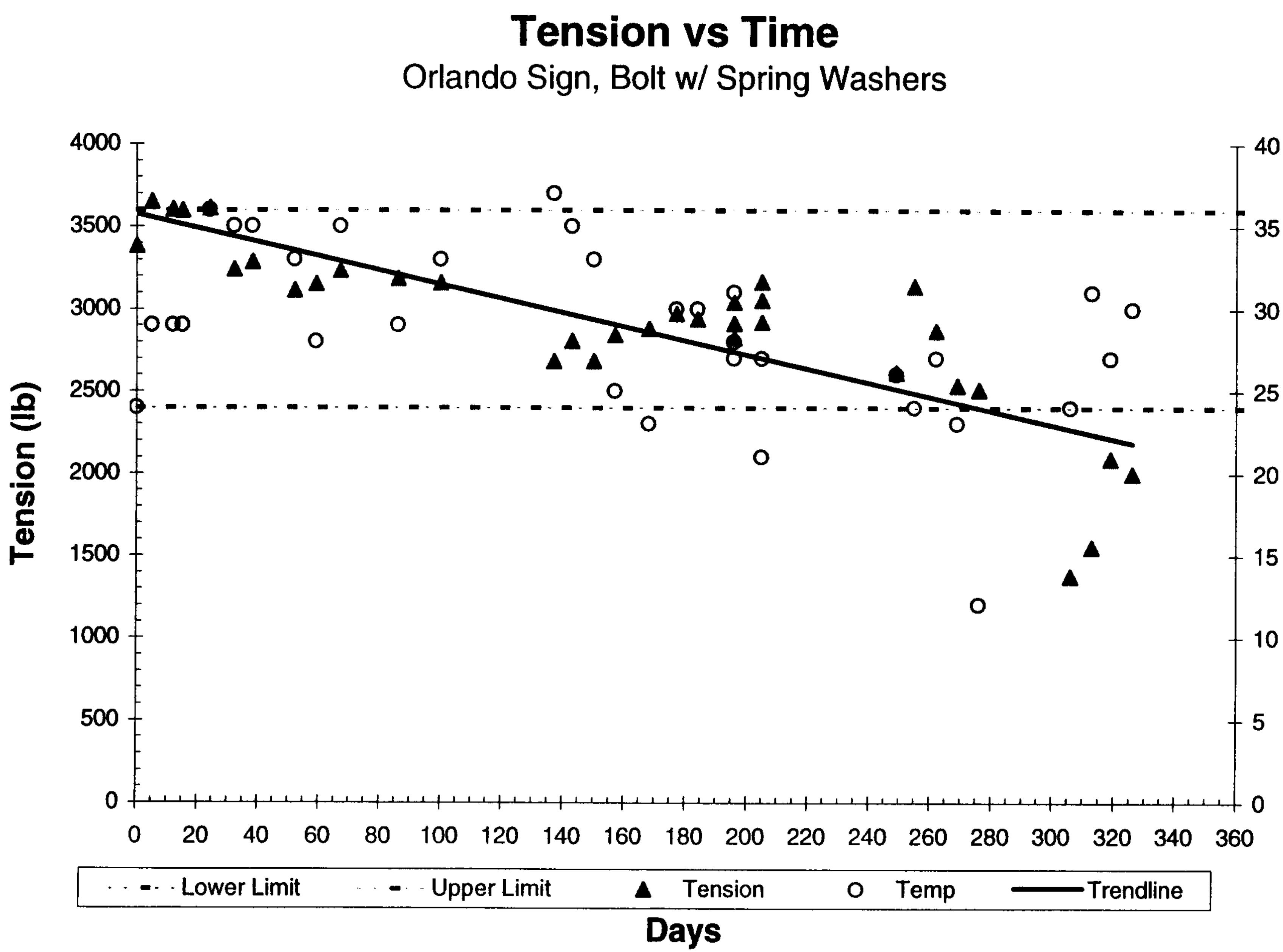



Figure 30 Tension vs Time, Orlando Sign, Bolt with Spring Washers

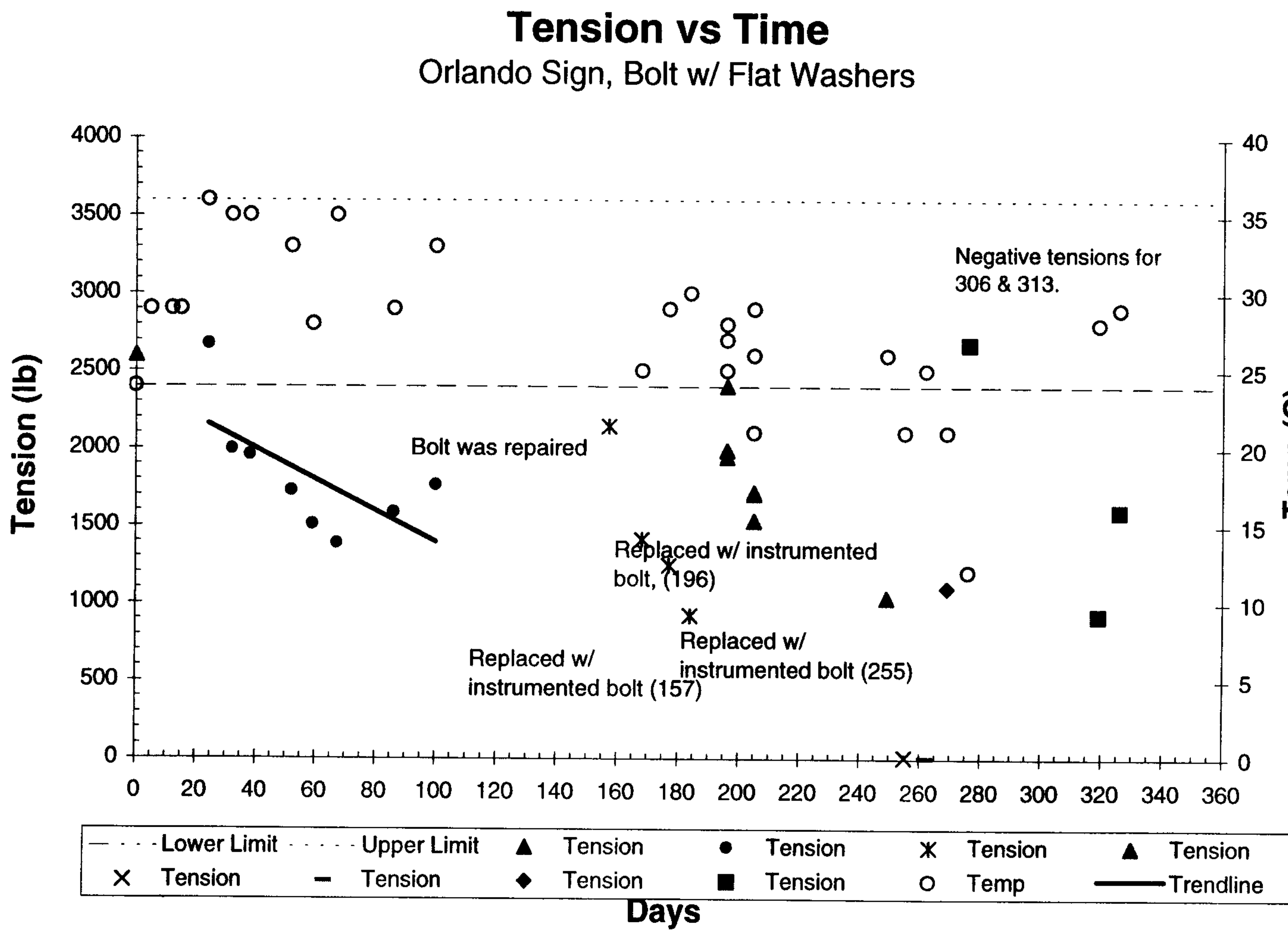



Figure 31 Tension vs Time, Orlando Sign, Bolt with Flat Washers

***Brevard (2)***

The Brevard (2) sign bolts were installed on May 16, 1998 and they have been monitored ever since. Different students have been taking readings ever since they were installed. The sign is located northbound along I-95, past Exit 74. It is bolted down using 3/4" diameter bolts. Figure 32 shows the location of the sign with respect to I-95.

Tables 8 and 9 list the results of monitoring the bolts from May 16, 1998 to April 19, 1999. Figures 33 and 34 show a plot of tension vs. time for the bolt with the spring washers and the bolt with flat washers.

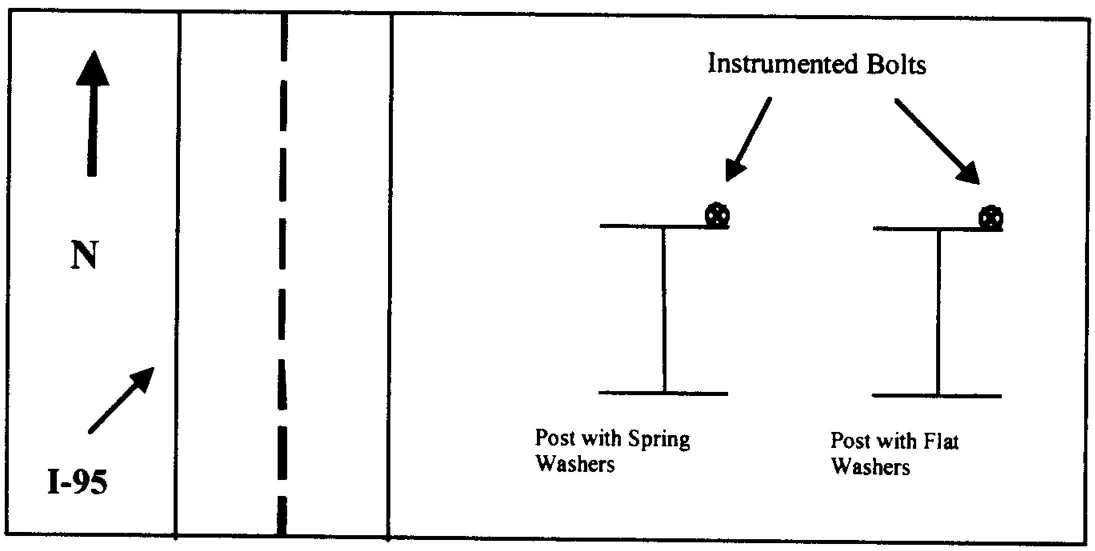



Figure 32 Location of Brevard (2) Sign with respect to I-95

The spring washers were able to hold the tension within the acceptable range from May 16, 1998 through November 20, 1998 except for two days: October 23 at 1883 lb. and November 4 at 1838 lb. These readings might have been affected by the drop in temperature in those days.

Consequently, multiple readings were done for two days to test whether the temperature had any effects on the strain gages. The readings taken on those two days, December 2 and 11, seemed to indicate that the tension varied with the temperature. However, temperature tests performed in the lab indicated that the temperature should have no effect on the strain gages. Thus, it was concluded that the gages or the adhesive might have some defects. The bolt was removed and brought back to be re-instrumented on January 25, 1999.

The newly re-instrumented bolt was re-installed on February 2, 1999 with new offsets and with a measured modulus of elasticity of 28,634 ksi. The readings have kept within the acceptable range, until April 19, 1999, when the readings were discontinued.

The bolt with the flat washers was installed on May 16, 1998. The reading on that day was 3523 lb., within the acceptable range. The readings increased to a peak of 6739 lb. on May 28. The bolt was taken back to the lab and it was re-installed on June 1 where the reading was 6009 lb.

On June 10, the bolt was re-installed after the bolt was brought back to the lab to have the lead wires resoldered. Readings were taken from June 24 to September 26 which saw the readings fluctuate from a low of 1557 lb. to a high of 6239 lb. The bolt was submerged in water for at least a day, on September 10.

From October 3 to October 23, 1998, the right gage registered and infinite resistance on the Strain Gage Tester which meant that it was disconnected. The bolt was removed on November 3 and was re-installed on November 13 with a measured modulus of elasticity of 28,112 ksi. After that date, the readings increased dramatically to 11060 lb. and 26565 lb. on December 2, 1998. The bolt was replaced and re-installed on January 25, 1999 with a modulus of elasticity of 28,112 ksi. The reading on that day was low at 1165 lb. The following reading on February 1 was even lower at 777 lb. The bolt was re-torqued using a new torque wrench on February 8. The readings have been decreasing until April 19, 1999, when the readings were discontinued. A tensile test in the lab showed a value of 28,115 ksi for the modulus of elasticity, with no change from the value measured before installation in the field. The gage was then judged to be sound.

Location: Brevard; second sign past exit 74 going north.

Sign reads: "Cocoa, Orlando, Next 2 exit."

Description: Green Sign - 12' X 8' X 15' from ground, W8X24 posts

***Long Bolt***

| Operator | Date | # of Days | Time | Temp | Strain Reading (με) | | | Bolt tension | | Eccent. | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | After | | °C | Left | Right | Average | lbs | kN | (in) | |
| | | 5/16/98 | Balance Offset >> | | (-2K) 716 | (-2k)839 | | | | | |
| ML | 5/16/98 | 0 | - | 27 | 298 | 137 | 218 | 2787 | 12.4 | 0.035 | |
| ML | 5/21/98 | 5 | - | 29 | 266 | 249 | 258 | 3299 | 14.7 | 0.003 | |
| ML | 5/28/98 | 12 | - | 27 | 246 | 262 | 254 | 3254 | 14.5 | 0.003 | |
| SON | 6/1/98 | 15 | - | 29 | 257 | 241 | 249 | 3190 | 14.2 | 0.003 | |
| SON | 6/10/98 | 24 | 10:45 | 33 | 207 | 227 | 217 | 2780 | 12.4 | 0.004 | |
| SON | 6/18/98 | 32 | 10:15 | 34 | 218 | 237 | 228 | 2915 | 13.0 | 0.004 | |
| SON | 6/24/98 | 38 | 9:30 | 33 | 170 | 277 | 224 | 2863 | 12.7 | 0.022 | |
| SON | 7/8/98 | 52 | 9:45 | 32 | 180 | 310 | 245 | 3139 | 14.0 | 0.025 | |
| SON | 7/16/98 | 60 | 8:40 | 28 | 158 | 330 | 244 | 3126 | 13.9 | 0.033 | |
| SON | 7/23/98 | 67 | 10:00 | 33 | 170 | 333 | 252 | 3222 | 14.3 | 0.030 | |
| N | 8/11/98 | 85 | 1:10 | 34 | 244 | 114 | 179 | 2293 | 10.2 | 0.034 | |
| N | 8/26/98 | 100 | 10:30 | 32 | 165 | 343 | 254 | 3254 | 14.5 | 0.033 | wires ripped off duct tape sign |
| ML | 9/10/98 | 114 | 10:18 | | | | | | | | Wires ripped off duct tape and sitting in water for quite a while |
| ML | 9/10/98 | 114 | 5:01 | | | | | | | | Bolts still under water |
| ML | 9/19/98 | 123 | 10:05 | 40 | 147 | 347 | 247 | 3165 | 14.1 | 0.038 | |
| ML | 9/19/98 | 123 | 6:45 | 31 | 135 | 379 | 257 | 3293 | 14.6 | 0.045 | |
| ML | 9/26/98 | 130 | 10:25 | 33 | 120 | 368 | 244 | 3126 | 13.9 | 0.048 | |
| ML | 9/26/98 | 130 | 2:50 | 42 | 142 | 304 | 223 | 2857 | 12.7 | 0.034 | |
| JT | 10/3/98 | 137 | 11:10 | 31 | 130 | 387 | 259 | 3312 | 14.7 | 0.047 | wires were in bag |
| JT | 10/9/98 | 143 | 10:23 | 30 | 117 | 369 | 243 | 3113 | 13.8 | 0.049 | Wires were dry and n the bag. |
| JT | 10/16/98 | 150 | 10:20 | 30 | 118 | 347 | 233 | 2979 | 13.3 | 0.046 | Wires were dry and n the bag. |
| JT | 10/23/98 | 157 | 10:25 | 23 | 89 | 205 | 147 | 1883 | 8.4 | 0.037 | Wires were dry and in the bag. Rusting on all three washers. Readings done 2x. |
| JT | 11/4/98 | 168 | 10:40 | 25 | 89 | 198 | 144 | 1838 | 8.2 | 0.036 | Wires were dry and in the bag. Bolts were wet. |
| JT | 11/13/98 | 177 | 10:45 | 27 | 132 | 392 | 262 | 3357 | 14.9 | 0.047 | |
| JT | 11/20/98 | 184 | 9:50 | 27 | 115 | 418 | 267 | 3414 | 15.2 | 0.053 | Wires were dry and in the bag. |
| JT | 12/2/98 | 196 | 9:00 | 33 | 141 | 404 | 273 | 3491 | 15.5 | 0.045 | |
| | | 196 | 12:00 | 34 | 91 | 322 | 207 | 2646 | 11.8 | 0.052 | |
| | | 196 | 3:30 | 26 | 83 | 225 | 154 | 1973 | 8.8 | 0.043 | |
| | | 196 | 4:30 | 25 | 84 | 213 | 149 | 1903 | 8.5 | 0.041 | |
| JT | 12/11/98 | 205 | 8:55 | 23 | 96 | 386 | 241 | 3088 | 13.7 | 0.056 | Wires were dry and in the bag. |
| | | 206 | 11:40 | 27 | 102 | 301 | 202 | 2582 | 11.5 | 0.046 | ibid |
| | | 206 | 3:25 | 28 | 102 | 248 | 175 | 2242 | 10.0 | 0.039 | ibid |
| JT | 1/25/99 | 249 | 10:00 | | | | | | | | Replaced instrumented bolt w/ regular bolt. |
| JT | 2/1/99 | 255 | 3:10 | | | | | | | | Still instrumenting & testing bolt. |
| JT | 2/12/99 | 266 | 10:30 | 27 | 324 | 203 | 264 | 3333 | 14.8 | 0.022 | reinstalled instrumented bolt. Offsets ***Lt: (-2k)716 Rt: (-2k)839, E=28.634x106kpsi*** |
| JT | 2/15/99 | 269 | 9:15 | 17 | 295 | 173 | 234 | 2960 | 13.2 | 0.024 | wires were dry and in bag |
| JT | 2/22/99 | 276 | 9:00 | 9 | 270 | 147 | 209 | 2638 | 11.7 | 0.028 | ibid |
| JT | 3/22/99 | 306 | 9:05 | 22 | 297 | 180 | 239 | 3017 | 13.4 | 0.023 | rusting on all washers |
| JT | 3/29/99 | 313 | 9:15 | 28 | 306 | 196 | 251 | 3175 | 14.1 | 0.021 | ibid |
| JT | 4/5/99 | 319 | 8:50 | 25 | 293 | 185 | 239 | 3023 | 13.4 | 0.021 | posts were wet, sign in shadows |
| JT | 4/12/99 | 326 | 9:10 | 26 | 304 | 184 | 244 | 3087 | 13.7 | 0.023 | wires were in bag |
| JT | 4/19/99 | 333 | 9:35 | 25 | 293 | 181 | 237 | 2998 | 13.3 | 0.022 | replaced w/ regular bolt permanently |

Table 8 Tension and Eccentricity Values For Brevard (2) Sign, Bolt with Spring Washers

Location: Brevard; second sign past exit 74 going north.

Sign reads: "Cocoa, Orlando, Next 2 exit."

Description: Green Sign - 12' X 8' X 15' from ground, W8X24 posts

***Short Bolt***

| Operator | Date | # of Days | Time | Temp | Strain Reading (με) | | | Bolt tension | | Eccent. | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | After | | °C | Left | Right | Average | lbs | kN | (in) | |
| | | 5/16/98 | Balance Offset >> | | *228* | *(-2k)844* | | | | | |
| ML | 5/16/98 | 0 | - | 27 | 157 | 393 | 275 | 3523 | 15.7 | 0.040 | |
| ML | 5/21/98 | 5 | - | 29 | 415 | 477 | 446 | 5714 | 25.4 | 0.007 | |
| ML | 5/28/98 | 12 | - | 27 | 532 | 520 | 526 | 6739 | 30.0 | 0.001 | |
| SON | 6/1/98 | 15 | - | 29 | 452 | 486 | 469 | 6009 | 26.7 | 0.003 | bolt tested in lab and retorqued |
| SON | 6/10/98 | 24 | 10:45 | 33 | -60 | 712 | 326 | 4177 | 18.6 | 0.111 | bolt removed, lead wire resoldered and bolt retorqued |
| SON | 6/24/98 | 38 | 9:30 | 33 | -87 | 330 | 122 | 1557 | 6.9 | 0.161 | |
| SON | 7/8/98 | 52 | 9:45 | 32 | 295 | 475 | 385 | 4933 | 21.9 | 0.022 | |
| SON | 7/16/98 | 60 | 8:40 | 28 | 367 | 607 | 487 | 6239 | 27.8 | 0.023 | |
| SON | 7/23/98 | 67 | 10:00 | 33 | 335 | 570 | 453 | 5797 | 25.8 | 0.024 | |
| N | 8/11/98 | 85 | 1:10 | 34 | 208 | 541 | 375 | 4798 | 21.3 | 0.042 | |
| N | 8/26/98 | 100 | 10:30 | 32 | 270 | 550 | 410 | 5253 | 23.4 | 0.032 | |
| ML | 9/10/98 | 114 | 10:18 | | | | | | | | Wires ripped off duct tape and sitting in water for quite a while |
| ML | 9/10/98 | 114 | 5:01 | | | | | | | | Bolts still under water |
| ML | 9/19/98 | 123 | 10:05 | 40 | 301 | 268 | 285 | 3645 | 16.2 | 0.005 | |
| ML | 9/19/98 | 123 | 6:45 | 31 | 389 | 335 | 362 | 4638 | 20.6 | 0.007 | |
| ML | 9/26/98 | 130 | 10:25 | 33 | 443 | 297 | 370 | 4740 | 21.1 | 0.018 | |
| ML | 9/26/98 | 130 | 2:50 | 42 | 320 | 232 | 276 | 3536 | 15.7 | 0.015 | |
| JT | 10/3/98 | 137 | 11:20 | 32 | 500 | | | | | | wires were in the bag but were wet |
| JT | 10/9/98 | 143 | 10:32 | 31 | 509 | | | | | | Right gage still registered an infinite resistance, |
| JT | 10/16/98 | 150 | 10:30 | 28 | 361 | | | | | | Wires were dry and in the bag. Right gage read an infinite resistance. |
| JT | 10/23/98 | 157 | 10:35 | 23 | 150 | | | | | | Rt wire cut and spliced and still read an infinite resistance. |
| JT | 11/4/98 | 168 | 10:50 | | | | | | | | Replaced instrumented bolt with regular bolt. |
| JT | 11/13/98 | 177 | 4:10 | 26 | 171 | 363 | 267 | 3316 | 14.8 | 0.034 | Replaced w/ instrumented bolt. New Ofsets: ***Lt: 274 Rt: (-2k) 699*** New ***E=28.112x10$^6$ kpsi*** |
| JT | 11/20/98 | 184 | 9:40 | 25 | 232 | 620 | 426 | 5291 | 23.5 | 0.043 | Wires were dry and in the bag. Measured 2x. |
| JT | 12/2/98 | 196 | 11:55 | 31 | 224 | 1557 | 891 | 11060 | 49.2 | 0.070 | |
| | | 196 | 3:25 | 25 | 246 | 4032 | 2139 | 26565 | 118.2 | 0.083 | Will replace this next week. |
| JT | 12/11/98 | 205 | | | | | | | | | Replaced w/ regular bolt |
| JT | 1/25/99 | 249 | 9:50 | 24 | 108 | 78 | 93 | 1165 | 5.2 | 0.015 | Replaced w/ instrumented bolt. New Ofsets: ***Lt: 228 Rt: (-2k) 844*** New ***E=28.112x10$^6$ kpsi*** |
| JT | 2/1/99 | 255 | 3:15 | 20 | 24 | 100 | 62 | 777 | 3.5 | 0.057 | |
| JT | 2/8/99 | 262 | 9:05 | 22 | 242 | 5 | 124 | 1547 | 6.9 | 0.090 | Re-torqued w/ new torque wrench |
| JT | 2/15/99 | 269 | 9:05 | 14 | 163 | 3 | 83 | 1040 | 4.6 | 0.090 | wires were dry and in bag |
| JT | 2/22/99 | 276 | 8:55 | 10 | 149 | -19 | 65 | 814 | 3.6 | 0.121 | ibid |
| JT | 3/22/99 | 306 | 9:00 | 21 | 132 | 35 | 84 | 1046 | 4.7 | 0.054 | ibid |
| JT | 3/29/99 | 313 | 9:10 | 26 | 137 | 54 | 96 | 1196 | 5.3 | 0.041 | ibid |
| JT | 4/5/99 | 319 | 8:45 | 23 | 121 | 68 | 95 | 1184 | 5.3 | 0.026 | posts were wet, sign in shadows |
| JT | 4/12/99 | 326 | 9:05 | 28 | 130 | 98 | 114 | 1428 | 6.4 | 0.013 | wires were in the bag |
| JT | 4/19/99 | 333 | 9:30 | 26 | 84 | 97 | 91 | 1134 | 5.0 | 0.007 | Replaced w/ regular bolt permanently |

Table 9 Tension and Eccentricity Values For Brevard (2) Sign, Bolt with Flat Washers

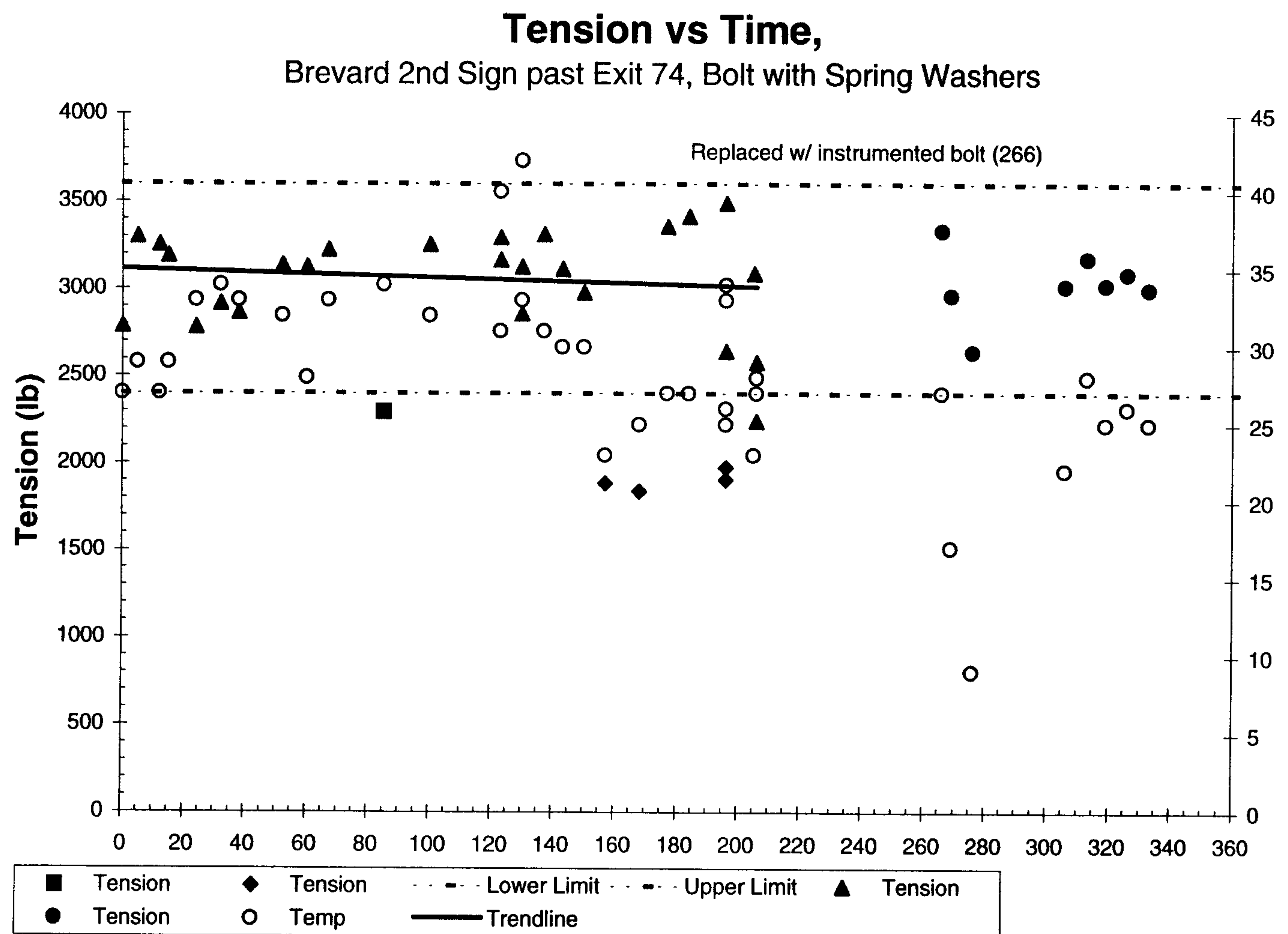



Figure 33 Tension vs Time, Brevard (2) Sign, Bolt with Spring Washers

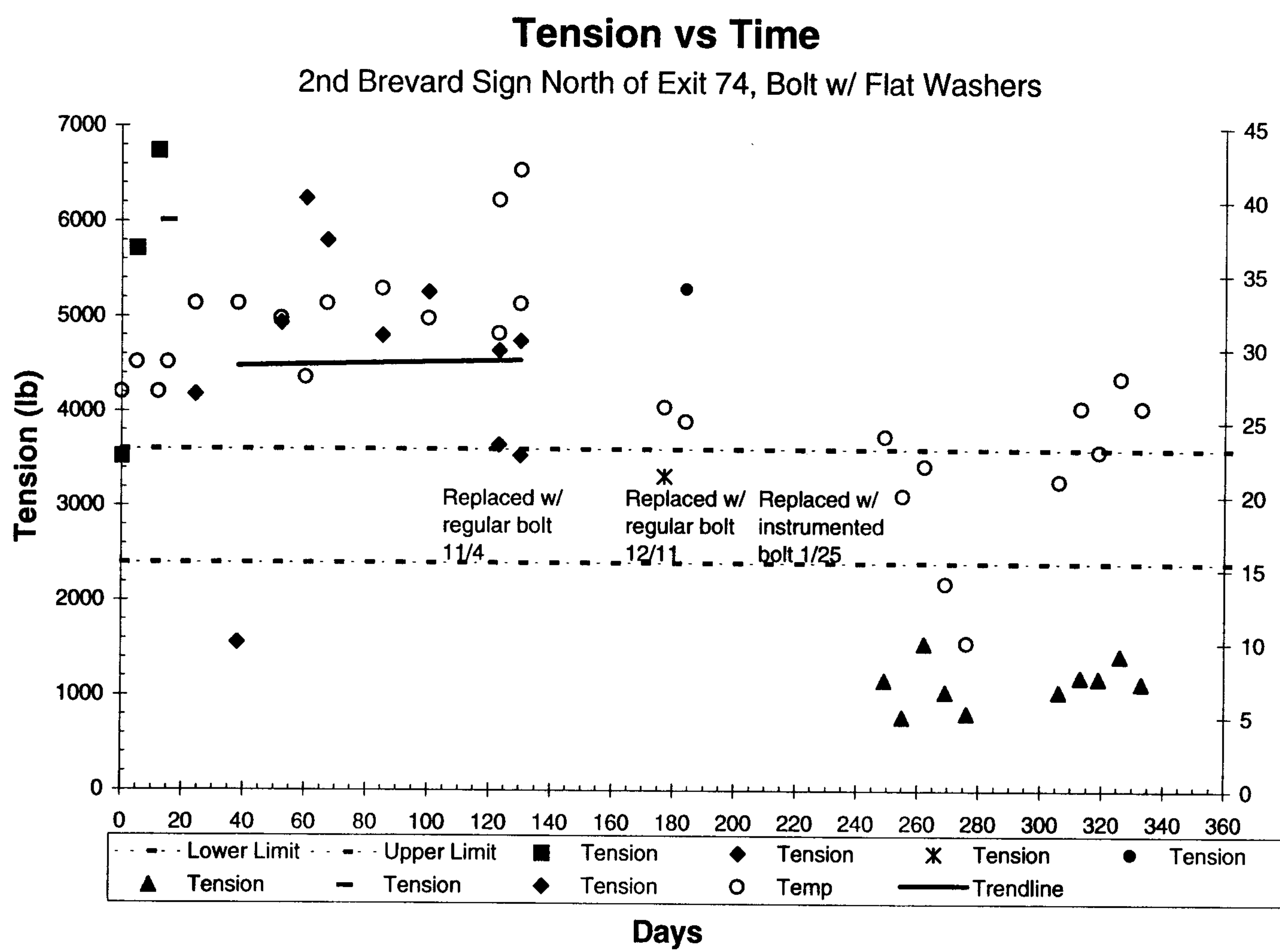



Figure 34 Tension vs Time, Brevard (2) Sign, Bolt with Flat Washers

***Brevard (1)***

The Brevard 1 sign bolts were installed on July 14, 1998 and it they have been monitored ever since. Different students have been taking readings ever since they were installed. The sign is located northbound along I-95, past Exit 74. It is bolted down using 7/8" diameter bolts. Figure 35 shows the location of the sign with respect to I-95.

Tables 10 and 11 list the results of monitoring the bolts from July14, 1998 to July 15, 1999. Figures 36 and 37 show a plot a plot of tension vs. time for the bolt with the spring washers and the bolt with flat washers.

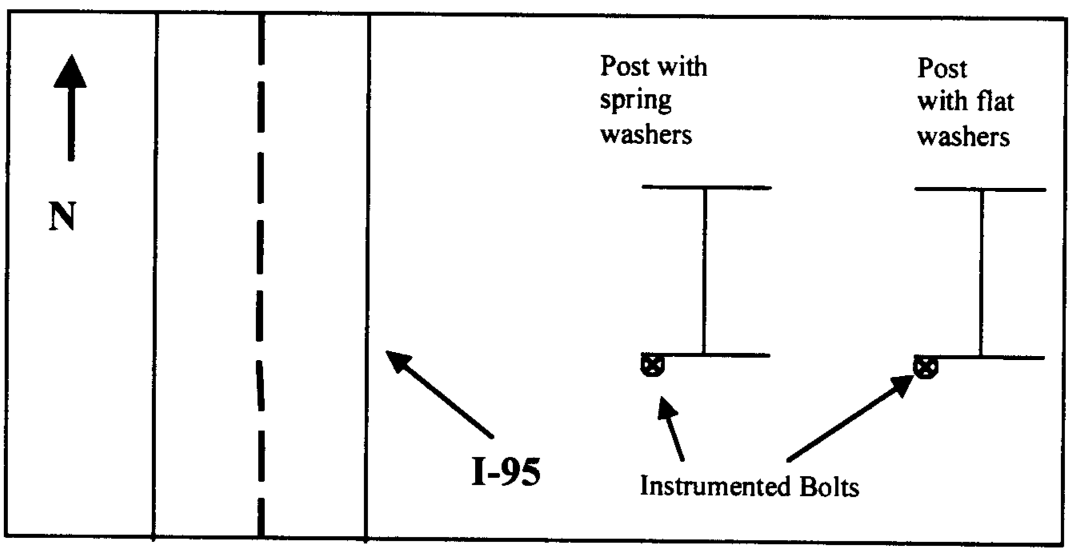



Figure 35 Location of Brevard (1) Sign with respect to I-95

The bolt with spring washers remained in the acceptable range from July 1998 to November 1998 except for one day: September 26 at 3915 lb. and 3749 lb.

The bolt was replaced on November 4, 1998 because the right strain gage became loose. The newly re-instrumented bolt was re-installed on November 20, 1998 along with a new spring washer stack. After that date, the readings were initially above the upper limit of 3600 lb. until February 15, 1999. From then on, the reading were in the allowable range. On June 15, 1999, the wires were found cut. Therefore the readings were interupted.

The bolt with flat washers was also installed on July 14, 1998. The washers were only able to hold the tension within the acceptable range on July 14 and on July 16. Since then, the readings have always been below the allowable range with a substantial reduction in tension of the bolt. One can notice that negative strain readings were periodically recorded which is reflected in the relatively large eccentricities of the tensions.

The bolt was submerged in water once on February 1, 1999 but it was still possible to get readings that day.

Location: Brevard; first sign past exit 74 going north.

Sign reads: "Highway 520 - 4 miles, Jacksonville - 151 miles"

Description: Green Sign - 19'-6" X 6' X 21' from ground, W10X45 posts, 7/8" bolts

***Long Bolt***

| Operator | Date | # of Days | Time | Temp | Strain Reading (με) | | | Bolt tension | | Eccent. | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | After | | °C | Left | Right | Average | lbs | kN | (in) | |
| | | 7/14/98 | Balance Offset >> | | 392 | 59 | | | | | |
| SON | 7/14/98 | 0 | - | - | 352 | 72 | 212 | 3697 | 16.4 | 0.072 | |
| SON | 7/16/98 | 2 | 9:00 | 30 | 284 | 55 | 170 | 2956 | 13.1 | 0.074 | |
| SON | 7/23/98 | 9 | 9:45 | 32 | 338 | 60 | 199 | 3470 | 15.4 | 0.076 | |
| N | 8/11/98 | 27 | 1:00 | 36 | 237 | 57 | 147 | 2563 | 11.4 | 0.067 | |
| N | 8/26/98 | 42 | 10:30 | 35 | 265 | 92 | 179 | 3113 | 13.8 | 0.053 | |
| ML | 9/19/98 | 65 | 10:25 | 41 | 267 | 112 | 190 | 3305 | 14.7 | 0.045 | |
| ML | 9/19/98 | 65 | 7:10 | 32 | 248 | 156 | 202 | 3523 | 15.7 | 0.025 | |
| ML | 9/26/98 | 72 | 10:45 | 32 | 259 | 190 | 225 | 3915 | 17.4 | 0.017 | |
| ML | 9/26/98 | 72 | 3:10 | 36 | 254 | 176 | 215 | 3749 | 16.7 | 0.020 | |
| JT | 10/3/98 | 79 | 10:32 | 29 | 204 | 176 | 190 | 3313 | 14.7 | 0.008 | wires left out of the bag & exposed |
| JT | 10/9/98 | 85 | 9:55 | 32 | 191 | 221 | 206 | 3592 | 16.0 | 0.008 | Wires were in the bag and dry. |
| JT | 10/16/98 | 92 | 9:55 | 27 | 199 | 0 | | | | | Wires were dry and in the bag. Right gage read an infinite resistance |
| JT | 10/23/98 | 99 | 10:03 | 20 | | | | | | | Cut and spliced both wires. Rt gage read infinite resistance. Will replace next week. |
| JT | 11/4/98 | 110 | 10:25 | | | | | | | | Replaced instrumented bolt wit regular bolt |
| JT | 11/13/98 | 119 | 10:25 | | | | | | | | Still repairing the bolt |
| JT | 11/20/98 | 126 | 9:00 | 25 | 355 | 90 | 223 | 3880 | 17.3 | 0.065 | Replaced with new instrumented bolt and new spring washer stack. |
| JT | 12/2/98 | 138 | 8:50 | 28 | 350 | 90 | 220 | 3836 | 17.1 | 0.065 | |
| | | 138 | 11:40 | 27 | 355 | 99 | 227 | 3958 | 17.6 | 0.062 | |
| | | 138 | 3:20 | 26 | 349 | 83 | 216 | 3767 | 16.8 | 0.067 | |
| | | 138 | 4:20 | 26 | 347 | 84 | 216 | 3758 | 16.7 | 0.067 | |
| JT | 12/11/98 | 147 | 8:45 | 22 | 340 | 99 | 220 | 3828 | 17.0 | 0.060 | Wires were dry and in the bag. |
| | | 147 | 11:35 | 28 | 340 | 110 | 225 | 3924 | 17.5 | 0.056 | ibid |
| | | 147 | 3:05 | 26 | 340 | 109 | 225 | 3915 | 17.4 | 0.056 | ibid |
| JT | 1/25/99 | 191 | 9:30 | 25 | 342 | 112 | 227 | 3958 | 17.6 | 0.055 | wires were dry and in the bag. |
| JT | 2/1/99 | 197 | 3:10 | 21 | 340 | 124 | 232 | 4046 | 18.0 | 0.051 | ibid |
| JT | 2/8/99 | 204 | 8:50 | 21 | 300 | 118 | 209 | 3645 | 16.2 | 0.048 | ibid |
| JT | 2/15/99 | 211 | 8:50 | 17 | 289 | 100 | 195 | 3392 | 15.1 | 0.053 | ibid |
| JT | 2/22/99 | 218 | 8:40 | 12 | 239 | 121 | 180 | 3139 | 14.0 | 0.036 | ibid |
| JT | 3/22/99 | 248 | 8:45 | 24 | 265 | 125 | 195 | 3400 | 15.1 | 0.039 | rust on all washers |
| JT | 3/29/99 | 255 | 9:00 | 28 | 290 | 116 | 203 | 3540 | 15.7 | 0.047 | ibid |
| JT | 4/5/99 | 261 | 8:35 | 35 | 284 | 116 | 200 | 3488 | 15.5 | 0.046 | ibid |
| JT | 4/12/99 | 268 | 8:55 | 26 | 262 | 134 | 198 | 3453 | 15.4 | 0.035 | ibid |
| JT | 4/19/99 | 275 | 9:20 | 28 | 220 | 114 | 167 | 2912 | 13.0 | 0.035 | ibid |
| JT | 4/23/99 | 279 | 10:20 | 32 | 268 | 133 | 201 | 3496 | 15.6 | 0.037 | ibid |
| JPP | 5/31/99 | 317 | 11:30 | 33 | 70 | 274 | 172 | 2999 | 13.3 | 0.065 | |
| JPP | 6/15/99 | 331 | 11:30 | | | | | | | | wires were cut |

Table 10 Tension and Eccentricity Values For Brevard (1) Sign, Bolt with Spring Washers

Location: Brevard; first sign past exit 74 going north.

Sign reads: "Highway 520 - 4 miles, Jacksonville - 151 miles"

Description: Green Sign - 19'-6" X 6' X 21' from ground, W10X45 posts, 7/8" bolts

***Short Bolt***

| Operator | Date | # of Days | Time | Temp | Strain Reading (με) | | | Bolt tension | | Eccent. | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | After | | °C | Left | Right | Average | lbs | kN | (in) | |
| | | 7/14/98 | Balance Offset >> | | 374 | 399 | | | | | |
| SON | 7/14/98 | 0 | - | - | -33 | 337 | 152 | 2651 | 11.8 | 0.133 | |
| SON | 7/16/98 | 2 | 9:00 | 30 | -50 | 340 | 145 | 2529 | 11.2 | 0.147 | |
| SON | 7/23/98 | 9 | 9:45 | 32 | -47 | 293 | 123 | 2145 | 9.5 | 0.151 | |
| N | 8/11/98 | 27 | 1:00 | 36 | -73 | 240 | 84 | 1456 | 6.5 | 0.205 | |
| N | 8/26/98 | 42 | 10:30 | 35 | 32 | 203 | 118 | 2049 | 9.1 | 0.080 | *check twice, it is correct |
| ML | 9/19/98 | 65 | 10:25 | 41 | 19 | 198 | 109 | 1892 | 8.4 | 0.090 | |
| ML | 9/19/98 | 65 | 7:10 | 32 | 23 | 205 | 114 | 1988 | 8.8 | 0.087 | |
| ML | 9/26/98 | 72 | 10:45 | 32 | 8 | 181 | 95 | 1648 | 7.3 | 0.100 | |
| ML | 9/26/98 | 72 | 3:10 | 36 | 4 | 176 | 90 | 1569 | 7.0 | 0.105 | |
| JT | 10/3/98 | 79 | 10:52 | 29 | -4 | 184 | 90 | 1569 | 7.0 | 0.114 | wires were kept in the plastic bag |
| JT | 10/9/98 | 85 | 10:05 | 30 | -14 | 152 | 69 | 1203 | 5.4 | 0.132 | Wires were dry and in the bag. |
| JT | 10/16/98 | 92 | 10:05 | 31 | -7 | 136 | 65 | 1125 | 5.0 | 0.121 | Wires were dry and in the bag. Both readings fluctuated a lot |
| JT | 10/23/98 | 99 | 9:51 | 21 | -20 | 145 | 63 | 1090 | 4.8 | 0.144 | Wires were dry and in the bag. |
| JT | 11/4/98 | 110 | 10:15 | 22 | -20 | 155 | 68 | 1177 | 5.2 | 0.142 | Wires were dry and in the bag. Bolts were wet. |
| JT | 11/13/98 | 119 | 10:25 | 25 | -6 | 150 | 72 | 1256 | 5.6 | 0.118 | |
| JT | 11/20/98 | 126 | 8:55 | 25 | 6 | 176 | 91 | 1587 | 7.1 | 0.102 | Wires were dry and in the bag. |
| JT | 12/2/98 | 138 | 8:40 | 23 | 0 | 151 | 76 | 1317 | 5.9 | 0.109 | ibid |
| | | 138 | 11:35 | 27 | 12 | 141 | 77 | 1334 | 5.9 | 0.092 | |
| | | 138 | 3:15 | 26 | 8 | 137 | 73 | 1264 | 5.6 | 0.097 | |
| | | 138 | 4:15 | 25 | 12 | 145 | 79 | 1369 | 6.1 | 0.093 | |
| JT | 12/11/98 | 147 | 8:40 | 22 | 20 | 126 | 73 | 1273 | 5.7 | 0.079 | ibid |
| | | 147 | 11:30 | 27 | 28 | 130 | 79 | 1378 | 6.1 | 0.071 | ibid |
| | | 147 | 3:05 | 25 | 24 | 117 | 71 | 1229 | 5.5 | 0.072 | ibid |
| JT | 1/25/99 | 191 | 9:25 | 22 | 9 | 95 | 52 | 907 | 4.0 | 0.090 | Wires were dry and in the bag. |
| JT | 2/1/99 | 197 | 3:00 | | 26 | 111 | 69 | 1195 | 5.3 | 0.068 | bolts were submerged in water |
| JT | 2/8/99 | 204 | 8:45 | 21 | 18 | 123 | 71 | 1229 | 5.5 | 0.081 | Wires were dry and in the bag. |
| JT | 2/15/99 | 211 | 8:40 | 15 | -24 | 116 | 46 | 802 | 3.6 | 0.166 | ibid |
| JT | 2/22/99 | 218 | 8:35 | 11 | -4 | 78 | 37 | 645 | 2.9 | 0.121 | ibid |
| JT | 3/22/99 | 248 | 8:40 | 22 | 4 | 138 | 71 | 1238 | 5.5 | 0.103 | ibid |
| JT | 3/29/99 | 255 | 9:00 | 26 | 15 | 145 | 80 | 1395 | 6.2 | 0.089 | ibid |
| JT | 4/5/99 | 261 | 8:30 | 26 | 17 | 129 | 73 | 1273 | 5.7 | 0.084 | ibid |
| JT | 4/12/99 | 268 | 8:50 | 26 | 24 | 88 | 56 | 977 | 4.3 | 0.063 | ibid |
| JT | 4/19/99 | 275 | 9:15 | 25 | 32 | 130 | 81 | 1413 | 6.3 | 0.066 | ibid |
| JT | 4/23/99 | 279 | 10:15 | 29 | 46 | 136 | 91 | 1587 | 7.1 | 0.054 | ibid |
| JPP | 5/31/99 | 317 | 11:30 | 33 | 81 | 123 | 102 | 1779 | 7.9 | 0.023 | values fluctuated widly |
| JPP | 6/15/99 | 331 | 11:30 | 30 | 57 | 160 | 109 | 1892 | 8.4 | 0.052 | |
| JPP | 7/2/99 | 348 | 1:15 | 30 | 60 | 161 | 111 | 1927 | 8.6 | 0.050 | |
| JPP | 7/15/99 | 361 | 10:10 | 34 | 46 | 120 | 83 | 1447 | 6.4 | 0.049 | |

Table 11 Tension and Eccentricity Values For Brevard (1) Sign, Bolt with Flat Washers

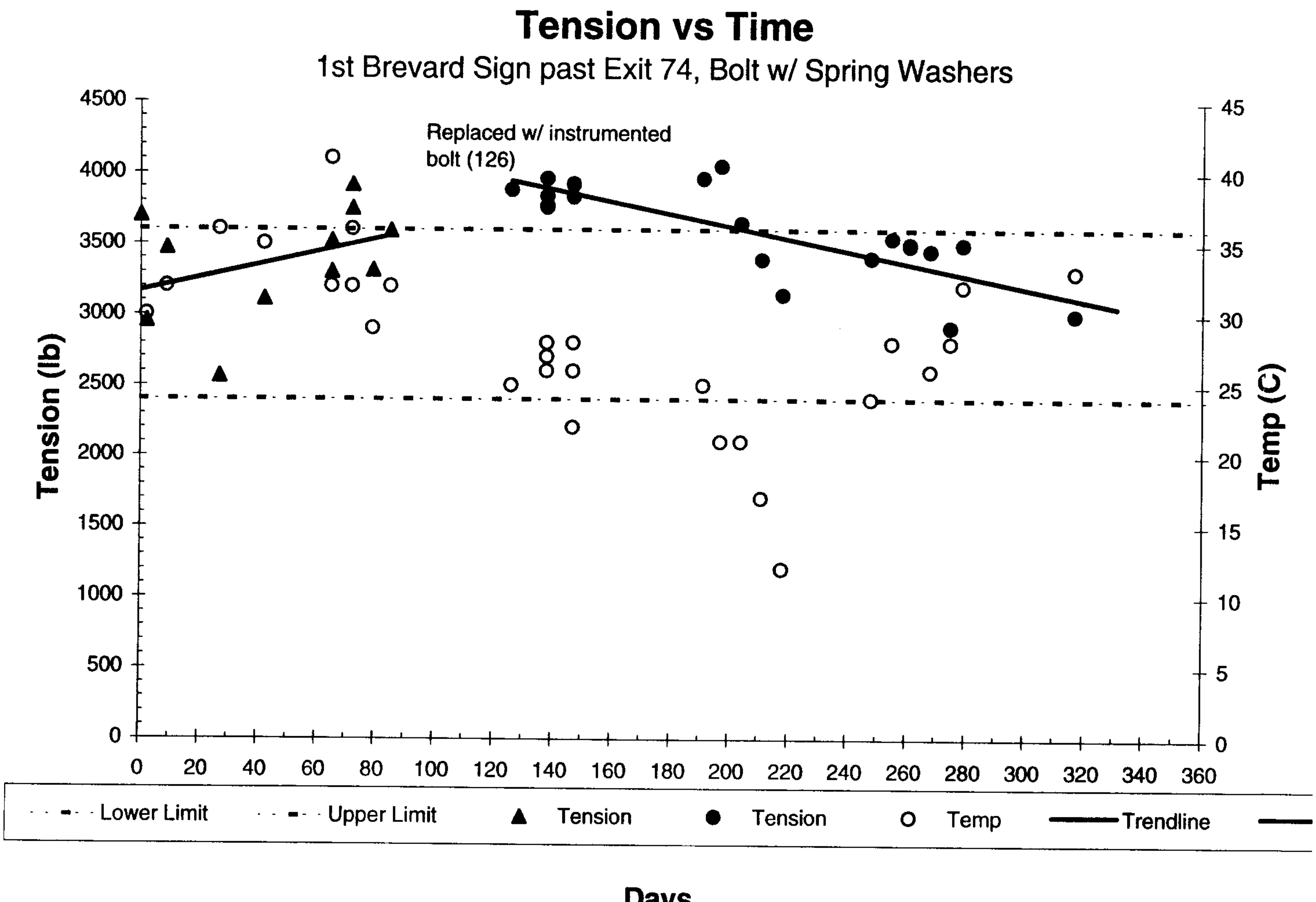



Figure 36 Tension vs Time, Brevard (1) Sign, Bolt with Spring Washers

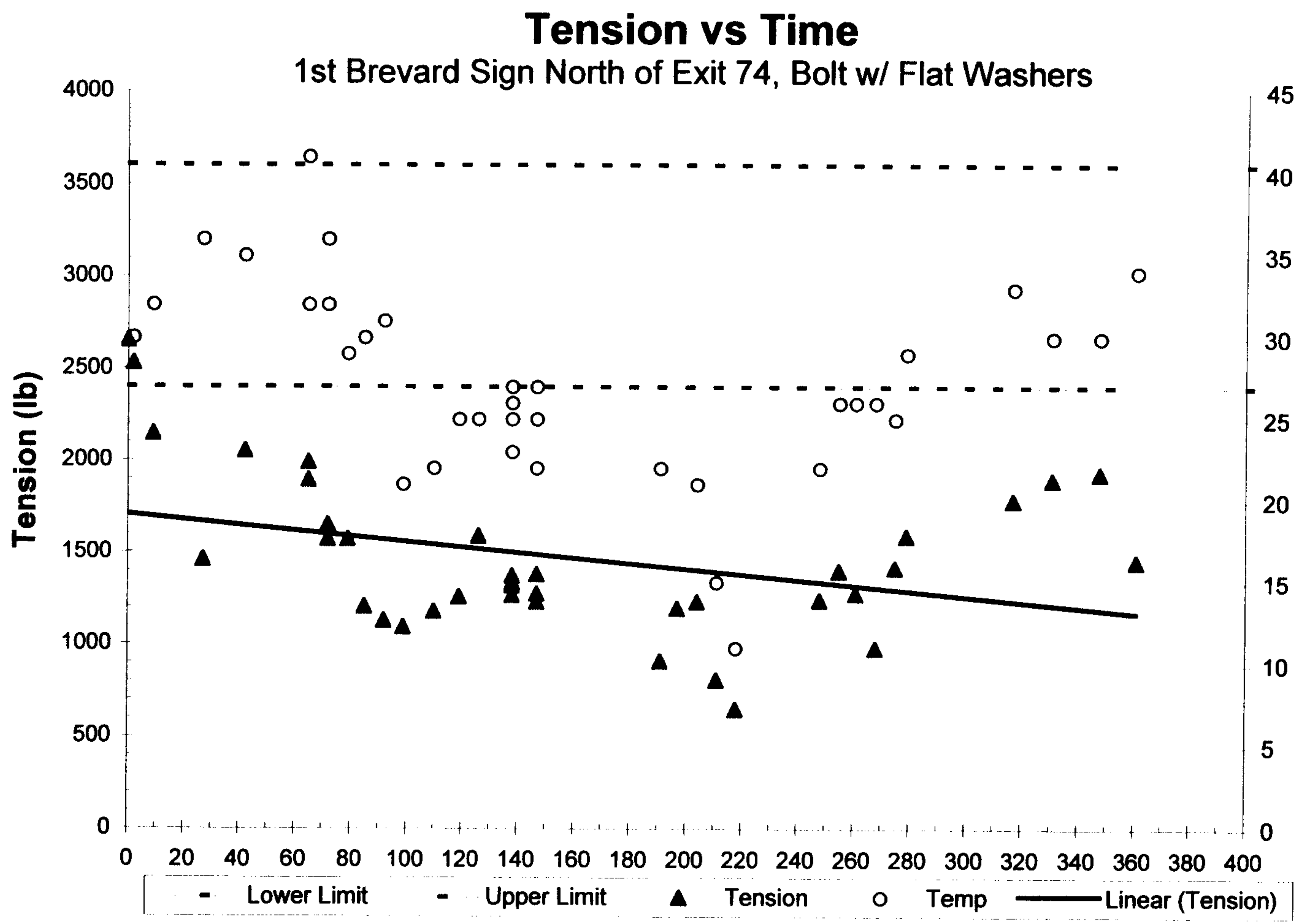



Figure 37 Tension vs Time, Brevard (1) Sign, Bolt with Flat Washers

### *Sebastian Inlet*

The Sebastian Inlet sign bolts were installed on May 15, 1998 and they have been monitored ever since. Different students have been taking readings ever since they were installed. The sign is located northbound along A1A just south of the Sebastian Inlet Bridge. It is bolted down using 3/4" diameter bolts. Figure 38 shows the location of the sign with respect to A1A.

Tables 12 and 13 list the results of monitoring the bolts from May 15, 1998 until June 11, 1999. Figures 41 and 42 show a plot of the tension vs. time the bolt with the spring washers and the bolt with the flat washers.

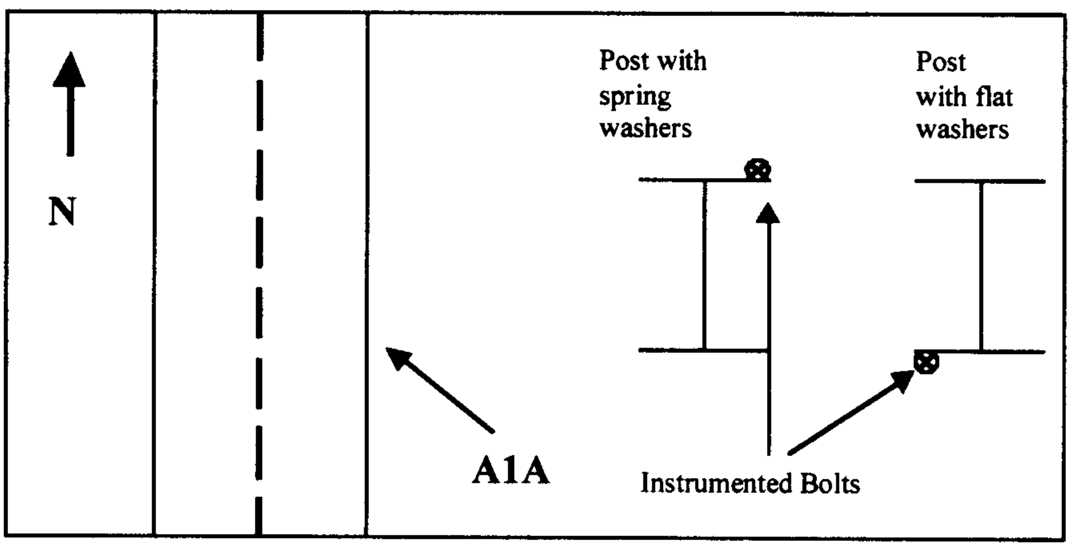



Figure 38 Location of Sebastian Inlet Sign with respect to A1A

The Sebastian Inlet bolt with spring washers was able to maintain the tension within the acceptable range until June 25 with only one reading dipping below the lower limit; on May 27, 1998 at 2146 lb. After that date the tension readings until September 20 were above the upper limit, peaking at 6098 lb. on August 11, 1998.

The wires were ripped off from the bolt head in September. The instrumented bolt was removed on October 21 and was a newly instrumented bolt with a measured modulus of elasticity of 28,074 ksi. was re-installed on December 4, 1998.

The post with the bolt with spring washers was found dislodged on December 9, 1998. It was hit by a car and the base connection of the post broke away. Neither the bolts nor the spring washers were damaged and they were found scattered on the ground. Figures 39 and 40 show the sign after it was hit by a car. This event, totally unexpected, provided a clear demonstration of the effectiveness of the spring washers. The post separated neatly from the base and as far as we know, no major damage was reported for the car. The sign was re-installed afterwards and since then, the readings were initially within the acceptable range. However the last readings are not reliable, because the bolt was not galvanized. The bolt deteriorated very quickly, and became completely corroded.

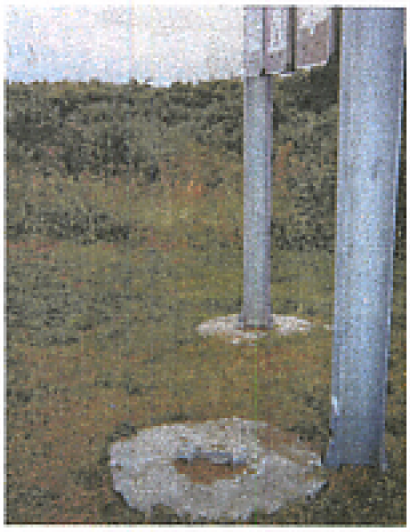


Figure 39 Sebastian Sign after it was hit by a car, 1st view

Figure 40 Sebastian Sign after it was hit by a car 2nd view

The bolt with flat washers was able to maintain the tension within the acceptable range until July 22. From September 11 to November 6, the readings were above 3600 lb. and the bolt started to show erratic behavior. A test to determine if the torque and strains had a linear relationship was performed on November 11 and on November 18. We concluded that the strain gages were faulty so we took the bolt back to the lab to be re-instrumented and re-tested.

The bolt was re-installed on December 4, 1998, with a measured modulus of elasticity of 29,406 ksi. That day's reading was 3774 lb. and has been decreasing until January 29, 1999.

It was suspected that the torque wrench being used may have been inaccurate. A new torque wrench was bought and it was used to re-torque the bolt on February 5, 1999. That day's reading was high at 4300 lb. but went down to 3449 lb. on February 12. No readings were taken on February 19 because the readings were negative numbers in the thousands range. The gages were probably damaged. Subsequent readings were either below or above the allowable range. The bolt was finally removed and brought back to the lab. A tensile test showed a value of 29,276 ksi for the modulus of elasticity. Consequently, the erratic beahior of the bolt could not be attributed directly to a defect of the strain gages.

Location: Sebastian Inlet; Directly after the bridge on A1A going south.

Sign reads: "Sebastian Inlet State Recreation Area."

Description: Brown Sign - 15.5' X 5' X 9' from ground, W8X18 posts

***Long Bolt***

| Operator | Date | # of Days | Time | Temp | Strain Reading (με) | | | Bolt tension | | Eccent. | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | After | | °C | Left | Right | Average | lbs | kN | (in) | |
| | | 5/15/98 | Balance Offset >> | | *479* | *494* | | | | | |
| ML | 5/15/98 | 0 | - | 29 | 370 | 47 | 209 | 2671 | 11.9 | 0.073 | |
| ML | 5/20/98 | 5 | - | 34 | 346 | 45 | 196 | 2505 | 11.1 | 0.072 | |
| ML | 5/27/98 | 12 | - | 28 | 296 | 39 | 168 | 2146 | 9.5 | 0.072 | |
| SON | 6/9/98 | 24 | 3:40 | 33 | 357 | 74 | 216 | 2761 | 12.3 | 0.062 | |
| SON | 6/17/98 | 32 | 12:15 | 36 | 369 | 111 | 240 | 3075 | 13.7 | 0.050 | |
| SON | 6/25/98 | 40 | 11:10 | 31 | 378 | 141 | 260 | 3325 | 14.8 | 0.043 | |
| SON | 7/9/98 | 54 | 11:00 | 34 | 412 | 246 | 329 | 4215 | 18.7 | 0.024 | |
| SON | 7/16/98 | 61 | 11:30 | 35 | 463 | 280 | 372 | 4760 | 21.2 | 0.023 | |
| SON | 7/22/98 | 67 | 11:00 | 32 | 468 | 326 | 397 | 5086 | 22.6 | 0.017 | |
| N | 8/11/98 | 86 | 11:45 | 34 | 502 | 450 | 476 | 6098 | 27.1 | 0.005 | |
| N | 8/26/98 | 101 | 8:00 | 32 | 469 | 335 | 402 | 5150 | 22.9 | 0.016 | |
| ML | 9/20/98 | 125 | 9:15 | 31 | 506 | 328 | 417 | 5343 | 23.8 | 0.020 | |
| ML | 9/26/98 | 131 | | | | | | | | | Wires ripped off the bolt |
| JT | 10/2/98 | 137 | | | | | | | | | Did not proceed. Wires were supposedly ripped off. |
| JT | 10/7/98 | 142 | | | | | | | | | Wires ripped off. Tried to replace bolt, washer was stuck; need help in replacing the damaged bolt. |
| JT | 10/14/98 | 149 | | | | | | | | | Wires were still ripped off. |
| JT | 10/21/98 | 156 | | | | | | | | | Replaced instrumented bolt with a regular bolt. |
| JT | 11/6/98 | 171 | 5:10 | | | | | | | | Replaced regular bolt with instrumented bolt Lt: 193 Rt: 463 |
| JT | 11/11/98 | 176 | 2:30 | 31 | 239 | 184 | 212 | 3148 | 14.0 | 0.012 | Replaced w/ new bolt, Retorqued w/ new offsets: ***Lt: 93 Rt: 270;*** New ***E=33.691x10^6 kpsi*** |
| JT | 11/18/98 | 183 | 1:30 | 31 | 160 | -200 | -20 | -298 | -1.3 | -0.844 | Rt reading changed a lot. Lt took a while to stabilize. Wires were dry and in the bag. |
| JT | 12/4/98 | 199 | 1:15 | 35 | 382 | 46 | 214 | 2654 | 11.8 | 0.074 | Replaced w/ instrumented bolt. New Offsets: Lt: ***479*** Rt: ***494*** New ***E=28.074x10^6 kpsi*** |
| JT | 12/9/98 | 204 | 12:00 | | | | | | | | Post was dislodged w/ bolts detached. Took back the instrumented bolt |
| JT | 1/22/99 | 247 | 4:15 | 26 | -586 | 973 | 194 | 2400 | 10.7 | 0.378 | Re-installed the instrumented bolt |
| JT | 1/29/99 | 254 | 12:30 | 29 | 275 | 215 | 245 | 3039 | 13.5 | 0.011 | Re-installed & re-aligned the instrumented bolt |
| JT | 2/5/99 | 260 | 1:30 | 28 | 295 | 164 | 230 | 2846 | 12.7 | 0.027 | Re-installed the rest of the bolts & re-torqued the instrumented bolt |
| JT | 2/12/99 | 267 | 9:05 | 27 | 272 | 140 | 206 | 2555 | 11.4 | 0.030 | wires were dry and in the bag |
| JT | 2/19/99 | 274 | 8:40 | 20 | 208 | 128 | 168 | 2084 | 9.3 | 0.022 | ibid |
| JT | 3/26/99 | 311 | 12:15 | 30 | 279 | 159 | 219 | 2716 | 12.1 | 0.026 | rusting on all washers, bolt w/ instrumented bolt is rusted. |
| JT | 4/2/99 | 317 | 12:00 | 31 | 261 | 167 | 214 | 2654 | 11.8 | 0.021 | wires were dry and in the bag |
| JT | 4/10/99 | 325 | 10:05 | 29 | 233 | 75 | 154 | 1910 | 8.5 | 0.048 | ibid |
| JT | 4/16/99 | 331 | 12:15 | 32 | 334 | 156 | 245 | 3039 | 13.5 | 0.034 | ibid |
| JT | 4/23/99 | 338 | 9:10 | 33 | 418 | 180 | 299 | 3708 | 16.5 | 0.037 | ibid |
| JPP | 5/25/99 | 370 | 15:00 | 34 | 464 | 218 | 341 | 4229 | 18.8 | 0.034 | |
| JPP | 6/2/99 | 377 | 13:00 | 32 | 460 | 160 | 310 | 3845 | 17.1 | 0.045 | bolt completely rusted |
| JPP | 6/11/99 | 386 | 1:00 | 28 | 828 | 488 | 658 | 8161 | 36.3 | 0.024 | |

Table 12 Tension and Eccentricity Values For Sebastian Inlet Sign, Bolt with Spring Washers

Location: Sebastian Inlet; Directly after the bridge on A1A going south.

Sign reads: "Sebastian Inlet State Recreation Area."

Description: Brown Sign - 15.5' X 5' X 9' from ground, W8X18 posts

***Short Bolt***

| Operator | Date | # of Days | Time | Temp | Strain Reading (με) | | | Bolt tension | | Eccent. | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | After | | °C | Left | Right | Average | lbs | kN | (in) | |
| | | 5/15/98 | Balance Offset >> | | ***282*** | ***821*** | | | | | |
| ML | 5/15/98 | 0 | - | 29 | 498 | 160 | 329.0 | 4215 | 18.7 | 0.048 | |
| ML | 5/20/98 | 5 | - | 34 | 448 | 109 | 278.5 | 3568 | 15.9 | 0.057 | |
| ML | 5/27/98 | 12 | - | 28 | 441 | 104 | 272.5 | 3491 | 15.5 | 0.058 | |
| SON | 6/9/98 | 24 | 3:40 | 33 | 430 | 98 | 264.0 | 3382 | 15.0 | 0.059 | |
| SON | 6/17/98 | 32 | 12:15 | 36 | 431 | 103 | 267.0 | 3421 | 15.2 | 0.058 | |
| SON | 6/25/98 | 40 | 11:10 | 31 | 418 | 98 | 258.0 | 3305 | 14.7 | 0.058 | |
| SON | 7/9/98 | 54 | 11:00 | 34 | 421 | 106 | 263.5 | 3376 | 15.0 | 0.056 | |
| SON | 7/16/98 | 61 | 11:30 | 35 | 411 | 102 | 256.5 | 3286 | 14.6 | 0.056 | |
| SON | 7/22/98 | 67 | 11:00 | 32 | 445 | 114 | 279.5 | 3581 | 15.9 | 0.056 | |
| N | 8/11/98 | 86 | 11:45 | 34 | 473 | 132 | 302.5 | 3876 | 17.2 | 0.053 | |
| N | 8/26/98 | 101 | 8:00 | 32 | 450 | 135 | 292.5 | 3747 | 16.7 | 0.050 | |
| ML | 9/20/98 | 125 | 9:15 | 31 | 496 | 129 | 312.5 | 4004 | 17.8 | 0.055 | |
| ML | 9/26/98 | 131 | 8:35 | 31 | 542 | 124 | 333.0 | 4266 | 19.0 | 0.059 | |
| ML | 9/26/98 | 131 | 12:55 | 41 | 565 | 133 | 349.0 | 4471 | 19.9 | 0.058 | |
| JT | 10/2/98 | 137 | | | | | | | | | Did not proceed. Wires were supposedly ripped off. |
| JT | 10/7/98 | 142 | 3:00 | 43 | 542 | 111 | 326.5 | 4183 | 18.6 | 0.062 | Wires were in the bag. |
| JT | 10/14/98 | 149 | 1:25 | 36 | 536 | 112 | 324.0 | 4151 | 18.5 | 0.061 | Wires were in the bag. |
| JT | 10/21/98 | 156 | 3:50 | 29 | 550 | 287 | 418.5 | 5362 | 23.9 | 0.029 | Wires were in the bag. |
| JT | 11/6/98 | 171 | 4:50 | 20 | 556 | 421 | 488.5 | 6259 | 27.8 | 0.013 | Bag was ripped off the post. |
| JT | 11/11/98 | 176 | 2:50 | 32 | 330 | 248 | 289.0 | 3703 | 16.5 | 0.013 | Bag was ripped off the post. ITT. Re-installed same bolt & washers w/ new ofsets: ***Lt: 350 Rt: 270*** |
| JT | 11/18/98 | 183 | 2:50 | 35 | 526 | 539 | 532.5 | 6822 | 30.3 | 0.001 | Wires were dry and in the bag. ITT 2x. Replaced instrumented bolt w/ regular bolt. |
| JT | 12/4/98 | 199 | 2:00 | 34 | 81 | 500 | 290.5 | 3774 | 16.8 | 0.068 | Replaced w/ instrumented bolt. New Offsets: Lt: ***282*** Rt: ***821*** New E=***29.406x10⁶ kpsi*** |
| JT | 12/9/98 | 204 | 12:10 | 35 | 17 | 565 | 291.0 | 3780 | 16.8 | 0.088 | Wires were dry and in the bag. |
| JT | 1/22/99 | 247 | 4:25 | 26 | 118 | 112 | 115.0 | 1494 | 6.6 | 0.002 | Ibid |
| JT | 1/29/99 | 254 | 12:50 | 31 | 133 | 59 | 96.0 | 1247 | 5.5 | 0.036 | Ibid |
| JT | 2/5/99 | 260 | 1:45 | 29 | 302 | 360 | 331.0 | 4300 | 19.1 | 0.008 | Re-torqued using a new torque wrench. |
| JT | 2/12/99 | 267 | 9:10 | 27 | 271 | 260 | 265.5 | 3449 | 15.3 | 0.002 | wires were dry and in the bag |
| JT | 2/19/99 | 274 | 8:45 | 20 | | | | | | | Bolt was wet. Got big (-) readings |
| JT | 3/26/99 | 311 | 12:20 | 29 | 227 | -74 | 76.5 | 994 | 4.4 | 0.184 | Wires were dry and in the bag. |
| JT | 4/2/99 | 317 | 12:05 | 35 | 261 | 45 | 153.0 | 1988 | 8.8 | 0.066 | Ibid |
| JT | 4/10/99 | 325 | 10:10 | 30 | 175 | 509 | 342.0 | 4443 | 19.8 | 0.046 | Ibid |
| JT | 4/16/99 | 331 | 12:20 | 33 | 219 | 450 | 334.5 | 4346 | 19.3 | 0.032 | replaced w/ regular bolt permanently |

Table 13 Tension and Eccentricity Values For Sebastian Inlet Sign, Bolt with Flat Washers

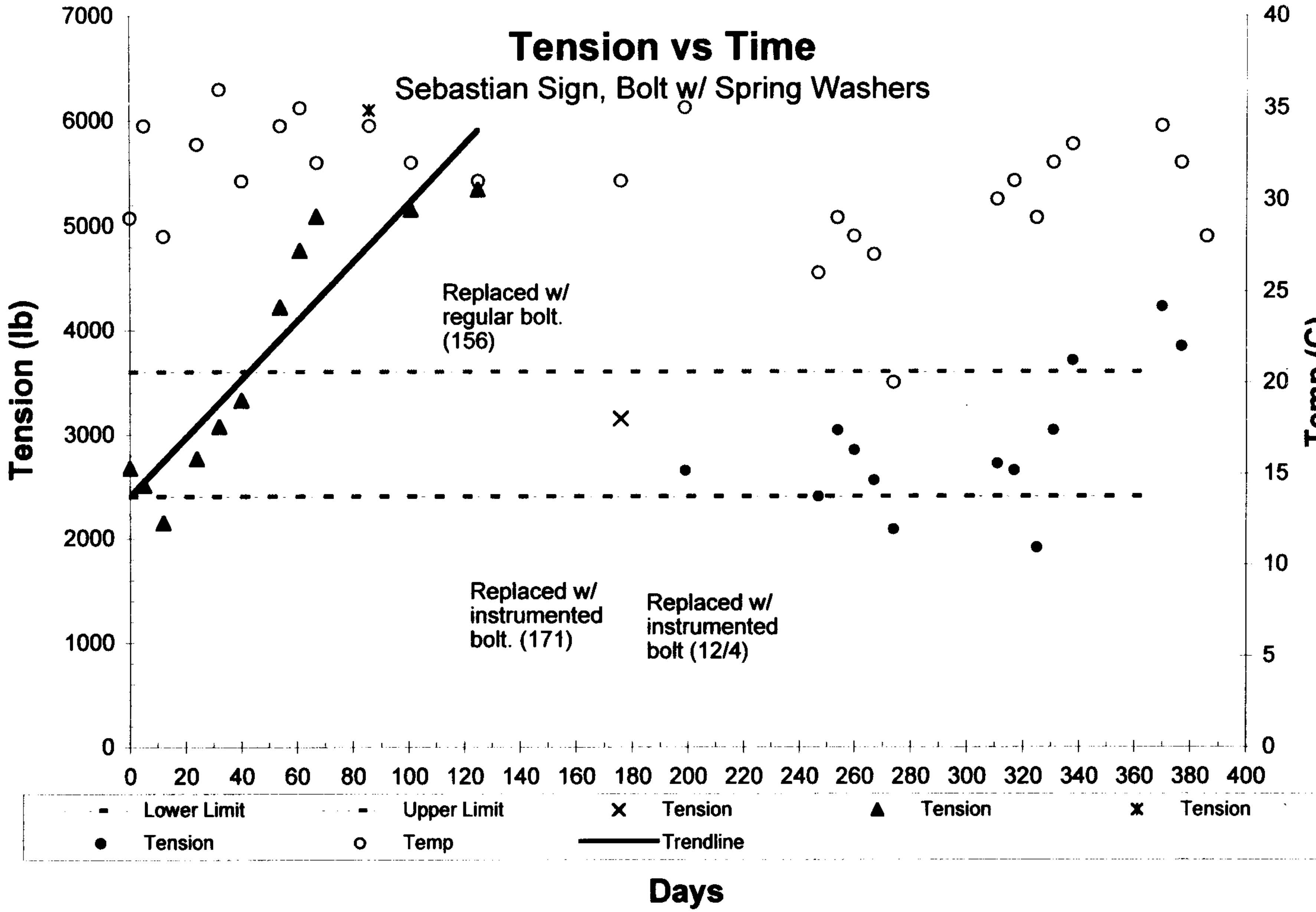



Figure 41 Tension vs Time,Sebastian Inlet Sign, Bolt with Spring Washers

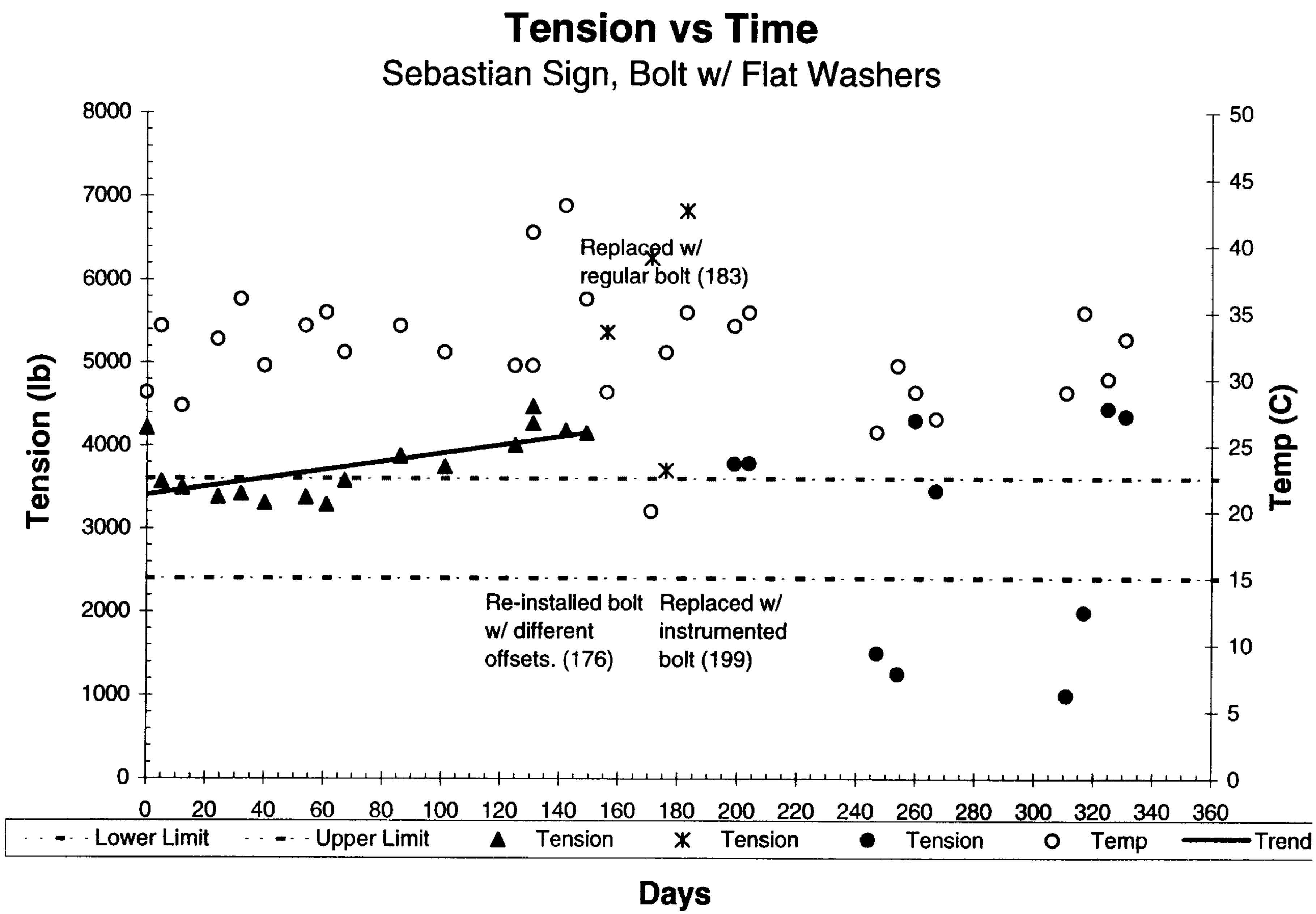



Figure 42 Tension vs Time, Sebastian Inlet Sign, Bolt with Flat Washers

***Indian River***

The Indian River sign bolts were installed on May 15, 1998 and they have been monitored ever since. Different students have been taking readings ever since they were installed. The sign is located southbound along I-95 just south of the 146-mile marker. It is bolted down using 3/4" diameter bolts. Figure 43 shows the location of the sign with respect to I-95.

Tables 14 and 15 list the results of monitoring the bolt from May 15, 1998 until July 6, 1999. Figures 44 and 45 show a plot of the tension vs. time for the bolt with the spring washers and the bolt with flat washers.

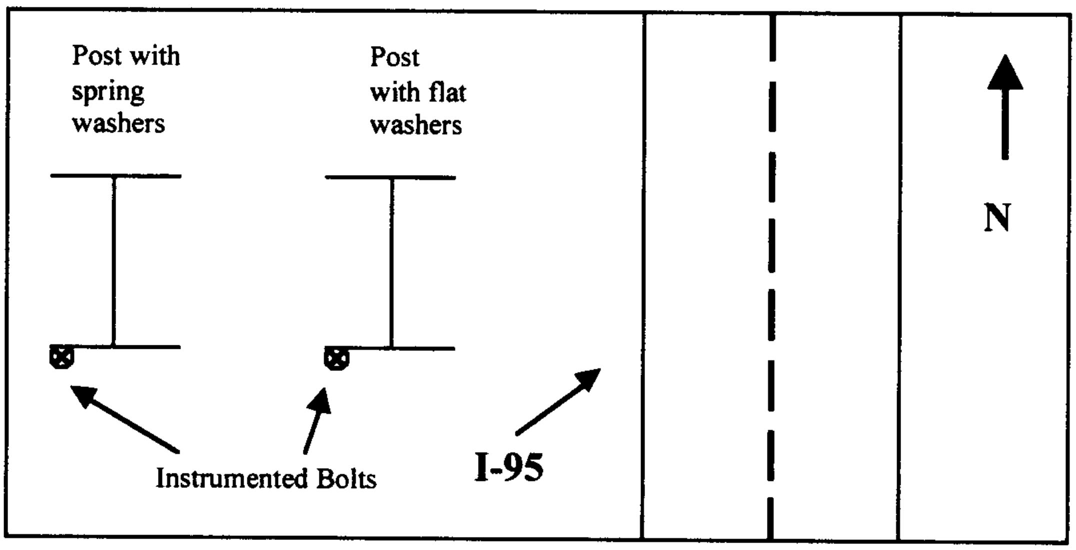



Figure 43 Location of Indian River Sign with respect to I-95

For the Indian River bolt with spring washers, the readings from May 15, 1998 through June 9, 1998 were all under the lower limit of 2400 lb. The bolt was then re-installed and it maintained the tension within the acceptable range (2400 lb. to 3600 lb.) from June 1998 through early December 1998. From June 17, 1998 through January 18, 1999 the left strain gage read a negative strain indicating that the bolt was subjected to a combination of tension and bending. This is reflected in the big eccentricities in the readings.

The initial readings taken during January 1999 showed that the tension increased, so we brought the bolt back to have the strain gages replaced. After replacing the strain gages, the spring washers were able to maintain the tension within the acceptable range until this date.

The Indian River bolt with flat washers was not able to maintain tension within the acceptable range. The eccentricities from May 15, 1998 through February 19, 1999 were small which meant that the bolt was not subjected to any significant bending.

This bolt has been re-installed four times. It was removed on June 17 because that day's readings were too high. The bolt was re-installed in June 25, 1998 and the readings had been below 2400 lb. up to August 26. After that date, the readings were well above the upper limit. It was replaced on October 21 and a new one was re-installed on November 6. The reading on that day was high while the following reading on November 11 was low. The bolt was re-instrumented and re-installed on December 9 with a modulus of elasticity of 28,706 ksi. The readings after that date were low until January 18, 1999 when the wires were ripped off. A newly instrumented bolt was re-installed on February 5, 1999 with a measured modulus of elasticity of 28,120 ksi. The readings since then have been low up to July 6, 1999.

Location: Indian River; I-95 South of Vero Beach (mile post 146)

Sign reads: "Indrio Rd. 8, Miami 146."

Description: Green Sign - 14' X 5.5' X 10' from ground, W8X24 posts

***Long Bolt***

| Operator | Date | # of Days | Time | Temp | Strain Reading (µε) | | | Bolt tension | | Eccent. | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | After | | °C | Left | Right | Average | lbs | kN | (in) | |
| | | 5/15/98 | Balance Offset >> | | *(-2k)858* | *(-2k)700* | | | | | |
| ML | 5/15/98 | 0 | - | 29 | 218 | 97 | 158 | 2018 | 9.0 | 0.036 | |
| ML | 5/20/98 | 5 | - | 28 | 197 | 82 | 140 | 1787 | 8.0 | 0.039 | |
| ML | 5/27/98 | 12 | - | 27 | 192 | 84 | 138 | 1768 | 7.9 | 0.037 | |
| SON | 6/9/98 | 24 | 12:40 | 40 | 195 | 88 | 142 | 1813 | 8.1 | 0.035 | |
| | bolt removed, tested and retorqued | | | | | | | | | | |
| SON | 6/17/98 | 32 | 10:00 | 35 | -252 | 788 | 268 | 3434 | 15.3 | 0.182 | |
| SON | 6/25/98 | 40 | 9:00 | 28 | -247 | 666 | 210 | 2684 | 11.9 | 0.204 | |
| SON | 7/9/98 | 54 | 9:00 | 32 | -244 | 660 | 208 | 2665 | 11.9 | 0.204 | |
| SON | 7/16/98 | 61 | 9:45 | 32 | -242 | 661 | 210 | 2684 | 11.9 | 0.202 | |
| SON | 7/22/98 | 67 | 9:00 | 25 | -258 | 642 | 192 | 2460 | 10.9 | 0.220 | |
| N | 8/11/98 | 86 | 9:30 | 33 | -256 | 655 | 200 | 2556 | 11.4 | 0.214 | |
| N | 8/26/98 | 101 | 8:45 | 30 | -230 | 657 | 214 | 2735 | 12.2 | 0.195 | |
| ML | 9/26/98 | 131 | 9:30 | 42 | -264 | 702 | 219 | 2806 | 12.5 | 0.207 | |
| ML | 9/26/98 | 131 | 1:45 | 41 | -248 | 698 | 225 | 2883 | 12.8 | 0.197 | |
| JT | 10/2/98 | 137 | 3:05 | 34 | -251 | 688 | 219 | 2799 | 12.5 | 0.201 | Left & right labels were removed |
| JT | 10/7/98 | 142 | 10:50 | 37 | -227 | 692 | 233 | 2979 | 13.3 | 0.185 | Wires were dry and in the bag |
| JT | 10/14/98 | 149 | 10:00 | 31 | -235 | 695 | 230 | 2947 | 13.1 | 0.190 | Wires were dry and in the bag |
| JT | 10/21/98 | 156 | 10:20 | 30 | -233 | 713 | 240 | 3075 | 13.7 | 0.185 | Wires were dry and in the bag |
| JT | 11/6/98 | 171 | 1:55 | 28 | -247 | 732 | 243 | 3107 | 13.8 | 0.189 | Wires were dry and in the bag |
| JT | 11/11/98 | 176 | 10:30 | 29 | -237 | 734 | 249 | 3184 | 14.2 | 0.183 | Wires were dry and in the bag |
| JT | 11/18/98 | 183 | 9:35 | 32 | -234 | 756 | 261 | 3344 | 14.9 | 0.178 | Wires were dry and in the bag |
| JT | 12/4/98 | 199 | 9:10 | 19 | -241 | 743 | 251 | 3216 | 14.3 | 0.184 | ibid |
| JT | 12/9/98 | 204 | 8:50 | 13 | -300 | 757 | 229 | 2927 | 13.0 | 0.217 | unsure about the temperature reading. |
| JT | 12/14/98 | 209 | 9:00 | 23 | -245 | 752 | 254 | 3248 | 14.4 | 0.184 | Wires were dry and in the bag |
| | | 209 | 11:00 | 26 | -246 | 757 | 256 | 3273 | 14.6 | 0.184 | ibid |
| | | 209 | 12:00 | 22 | -252 | 759 | 254 | 3248 | 14.4 | 0.187 | ibid |
| JT | 1/18/99 | 243 | 9:50 | 26 | -204 | 1484 | 640 | 8200 | 36.5 | 0.124 | Wires were dry and in the bag |
| | | 243 | 11:55 | 29 | -158 | 1130 | 486 | 6227 | 27.7 | 0.124 | |
| | | 243 | 5:30 | 24 | -182 | 878 | 348 | 4459 | 19.8 | 0.143 | |
| JT | 1/29/99 | 254 | 9:20 | | | | | | | | Replaced instrumented bolt with regular bolt |
| JT | 2/5/99 | 260 | 9:05 | 26 | 396 | 134 | 265 | 3341 | 14.9 | 0.046 | Re-installed new instrumented bolt. ***Lt: (-2k)858 Rt: (-2k)700, New E=28.541x106kpsi*** |
| JT | 2/12/99 | 267 | 11:45 | 36 | 317 | 138 | 228 | 2869 | 12.8 | 0.037 | Wires were dry and in the bag |
| JT | 2/19/99 | 274 | 10:35 | 26 | 334 | 121 | 228 | 2869 | 12.8 | 0.044 | ibid |
| JT | 3/26/99 | 311 | 9:05 | 30 | 298 | 122 | 210 | 2648 | 11.8 | 0.039 | rusting on all washers |
| JT | 4/2/99 | 317 | 9:05 | 32 | 304 | 130 | 217 | 2736 | 12.2 | 0.038 | Wires were dry and in the bag |
| JT | 4/10/99 | 325 | 11:45 | 36 | 306 | 134 | 220 | 2774 | 12.3 | 0.037 | ibid |
| JT | 4/16/99 | 331 | 8:55 | 28 | 252 | 118 | 185 | 2333 | 10.4 | 0.034 | ibid |
| JT | 4/23/99 | 338 | 11:35 | 37 | 298 | 140 | 219 | 2761 | 12.3 | 0.034 | ibid |
| JPP | 6/2/99 | 377 | 11:30 | 31 | 302 | 121 | 212 | 2667 | 11.9 | 0.040 | |
| JPP | 6/11/99 | 386 | 1:00 | 28 | 292 | 123 | 208 | 2616 | 11.6 | 0.038 | |
| JPP | 7/6/99 | 411 | 7:15 | 29 | 251 | 117 | 184 | 2320 | 10.3 | 0.034 | |
| JPP | | | | | | | | | | | |

Table 14 Tension and Eccentricity Values For Indian River Sign, Bolt with Spring Washers

Location: Indian River; I-95 South of Vero Beach (mile post 146)

Sign reads: "Indrio Rd. 8, Miami 146."

Description: Green Sign - 14' X 5.5' X 10' from ground, W8X24 posts

***Short Bolt***

| Operator | Date | # of Days | Time | Temp | Strain Reading (με) | | | Bolt tension | | Eccent. | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | After | | °C | Left | Right | Average | lbs | kN | (in) | |
| | | 5/15/98 | Balance Offset >> | | *(-2k)796* | *(-2k)477* | | | | | |
| ML | 5/15/98 | 0 | - | 29 | 226 | 126 | 176 | 2255 | 10.0 | 0.027 | |
| ML | 5/20/98 | 5 | - | 28 | 790 | 117 | 454 | 5810 | 25.8 | 0.070 | |
| ML | 5/27/98 | 12 | - | 27 | 366 | 116 | 241 | 3088 | 13.7 | 0.049 | |
| SON | 6/9/98 | 24 | 12:40 | 40 | 70 | 123 | 97 | 1236 | 5.5 | 0.026 | |
| SON | 6/17/98 | 32 | 10:00 | 35 | 700 | 120 | 410 | 5253 | 23.4 | 0.066 | bolt removed and re-instrumented (bolt very sticky, a lot of friction when retorqued) |
| SON | 6/25/98 | 40 | 9:00 | 28 | 149 | 112 | 131 | 1672 | 7.4 | 0.013 | |
| SON | 7/9/98 | 54 | 9:00 | 32 | 133 | 160 | 147 | 1877 | 8.3 | 0.009 | |
| SON | 7/16/98 | 61 | 9:45 | 32 | 133 | 159 | 146 | 1871 | 8.3 | 0.008 | |
| SON | 7/22/98 | 67 | 9:00 | 25 | 167 | 152 | 160 | 2043 | 9.1 | 0.004 | |
| N | 8/11/98 | 86 | 9:30 | 33 | 162 | 155 | 159 | 2031 | 9.0 | 0.002 | |
| N | 8/26/98 | 101 | 8:45 | 30 | 163 | 154 | 159 | 2031 | 9.0 | 0.003 | |
| ML | 9/26/98 | 131 | 9:30 | 42 | 859 | 568 | 714 | 9141 | 40.7 | 0.019 | |
| ML | 9/26/98 | 131 | 1:45 | 41 | 846 | 582 | 714 | 9148 | 40.7 | 0.017 | |
| JT | 10/2/98 | 137 | 3:05 | 34 | 874 | 575 | 725 | 9282 | 41.3 | 0.019 | |
| JT | 10/7/98 | 142 | 10:38 | 37 | 845 | 567 | 706 | 9045 | 40.2 | 0.018 | Wires were in the bag. |
| JT | 10/14/98 | 149 | 10:10 | 30 | 830 | 552 | 691 | 8853 | 39.4 | 0.019 | Wires were in the bag. |
| JT | 10/21/98 | 156 | 10:30 | | | | | | | | Replaced Instrumented bolt with a regular bolt. |
| JT | 11/6/98 | 171 | 2:10 | 30 | 49 | 774 | 412 | 6455 | 28.7 | 0.083 | Replaced regular bolt with an instrumented bolt. Lt: 78 Rt (490) |
| JT | 11/11/98 | 176 | 10:45 | 34 | 95 | 63 | 79 | 1239 | 5.5 | 0.019 | Tension was low. Torqued again and average stayed roughly the same. |
| JT | 11/18/98 | 183 | 9:30 | | | | | | | | Replaced instrumented bolt with short bolt. |
| JT | 12/4/98 | 199 | 9:15 | | | | | | | | Have not replaced the regular bolt with an instrumented bolt yet. |
| JT | 12/9/98 | 204 | 9:00 | 20 | 83 | 70 | 77 | 970 | 4.3 | 0.008 | Replaced regular bolt with an instrumented bolt. ***Lt: 8 Rt (-2k)845, New E=28.706x106kpsi*** |
| JT | 12/14/98 | 209 | 9:10 | 20 | 62 | 44 | 53 | 672 | 3.0 | 0.016 | Wires were in the bag. |
| | | 209 | 11:00 | 25 | 70 | 52 | 61 | 774 | 3.4 | 0.014 | ibid |
| | | 209 | 12:00 | 23 | 82 | 49 | 66 | 831 | 3.7 | 0.024 | ibid |
| JT | 1/18/99 | 243 | 9:55 | | | | | | | | Wires were ripped off. Replaced with regular bolt. |
| JT | 1/29/99 | 254 | 9:20 | | | | | | | | Was not able to re-install intrumented bolt. After testing, E=25.796 (too low) |
| JT | 2/5/99 | 260 | 9:25 | 27 | 18 | 336 | 177 | 2199 | 9.8 | 0.084 | Reinstalled inst. bolt w new wrench. ***Lt: (-2k)796 Rt: (-2k)477, New E=28.121x106kpsi*** |
| JT | 2/12/99 | 267 | 11:55 | 35 | 16 | 326 | 171 | 2124 | 9.4 | 0.085 | wires were dry and in the bag |
| JT | 2/19/99 | 274 | 10:40 | 28 | 11 | 293 | 152 | 1888 | 8.4 | 0.087 | ibid |
| JT | 3/26/99 | 311 | 9:10 | 31 | 14 | 284 | 149 | 1851 | 8.2 | 0.085 | ibid |
| JT | 4/2/99 | 317 | 9:10 | 33 | 47 | 289 | 168 | 2087 | 9.3 | 0.068 | ibid |
| JT | 4/10/99 | 325 | 11:50 | 35 | 21 | 307 | 164 | 2037 | 9.1 | 0.082 | ibid |
| JT | 4/16/99 | 331 | 9:00 | 30 | 20 | 260 | 140 | 1739 | 7.7 | 0.080 | ibid |
| JT | 4/23/99 | 338 | 11:40 | 37 | 28 | 298 | 163 | 2025 | 9.0 | 0.078 | ibid |
| JPP | 6/2/99 | 377 | 11:30 | 33 | 50 | 300 | 175 | 2174 | 9.7 | 0.067 | |
| JPP | 6/11/99 | 386 | 1:00 | 28 | 35 | 265 | 150 | 1863 | 8.3 | 0.072 | |
| JPP | 7/6/99 | 411 | 7:15 | 30 | -79 | 257 | 89 | 1106 | 4.9 | 0.177 | |
| JPP | | | | | | | | | | | |

Table 15 Tension and Eccentricity Values For Indian River Sign, Bolt with Flat Washers

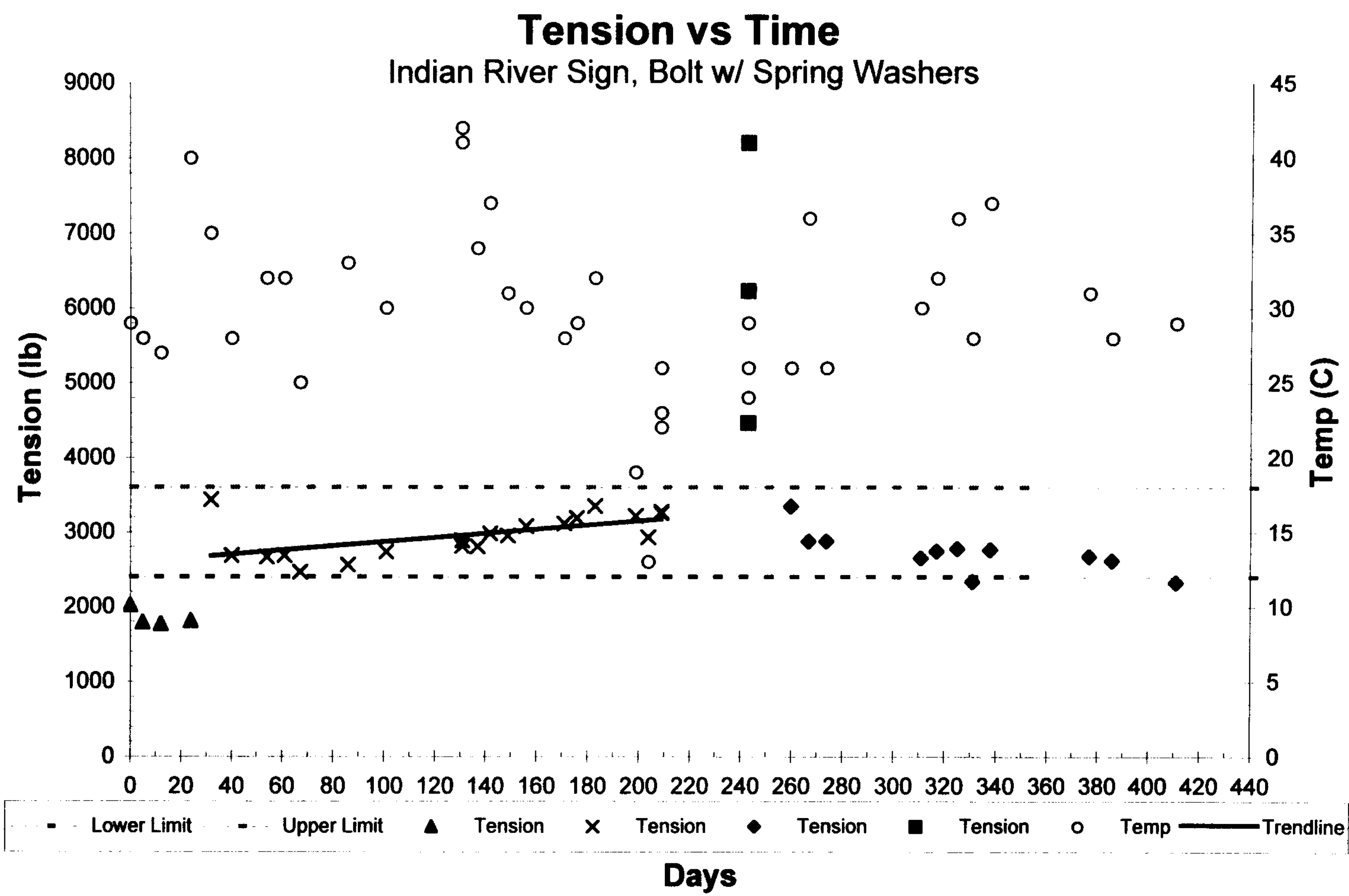



Figure 44 Tension vs Time, Indian River Sign, Bolt with Spring Washers

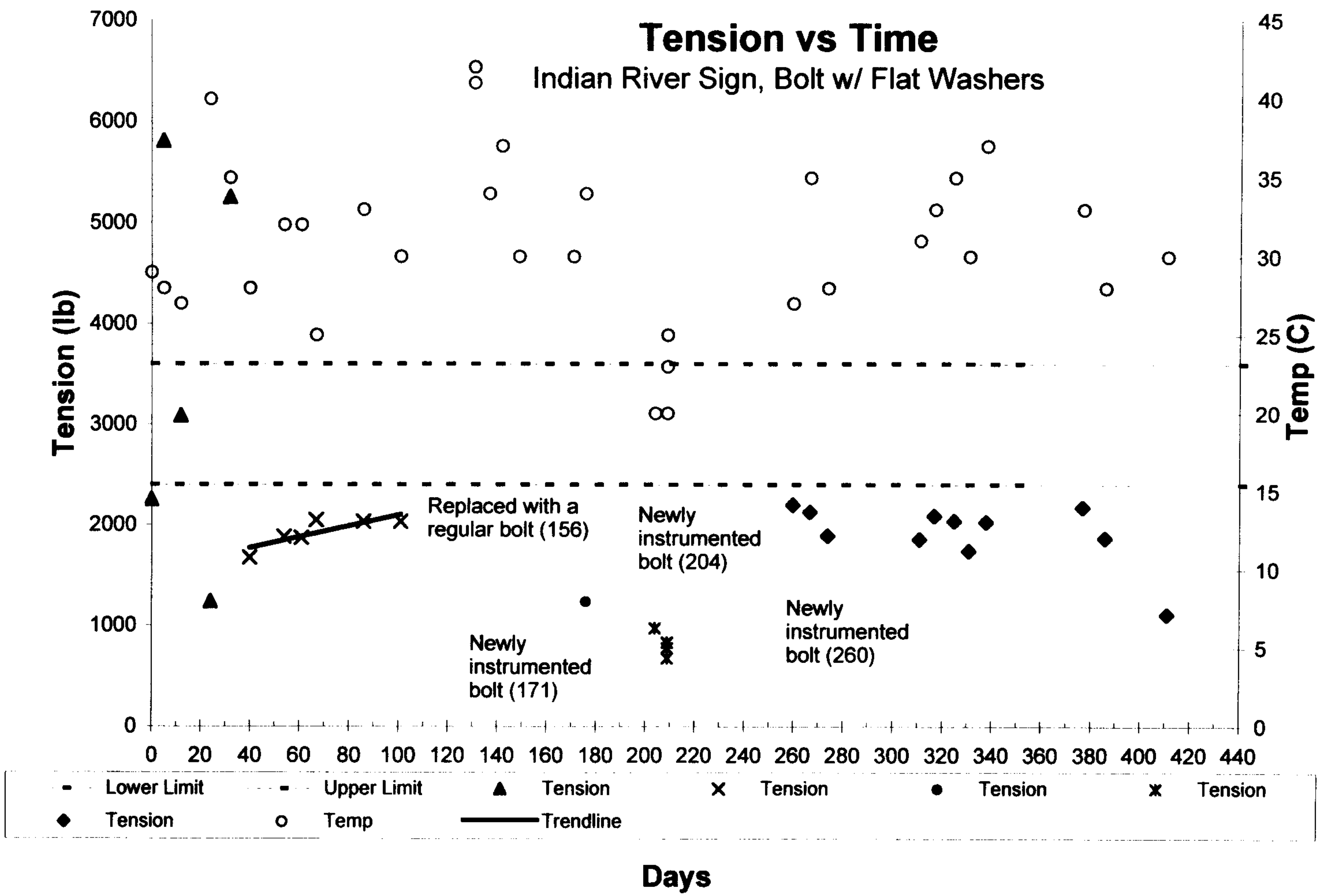



Figure 45 Tension vs Time, Indian River Sign, Bolt with Flat Washers

*Martin County*

The Martin County sign bolts were installed on May 15, 1998 and they have been monitored ever since. Different students have been taking readings ever since they were installed. The sign is located northbound along I-95 just south of the Exit 62. It is bolted down using 3/4" diameter bolts. Figure 46 shows the location of the sign with respect to I-95.

Tables 16 and 17 list the results of monitoring the bolts from May 15, 1998 until April 16, 1999. Figures 47 and 48 show a plot of the tension vs. time for the bolt with the spring washers and the bolt with flat washers.

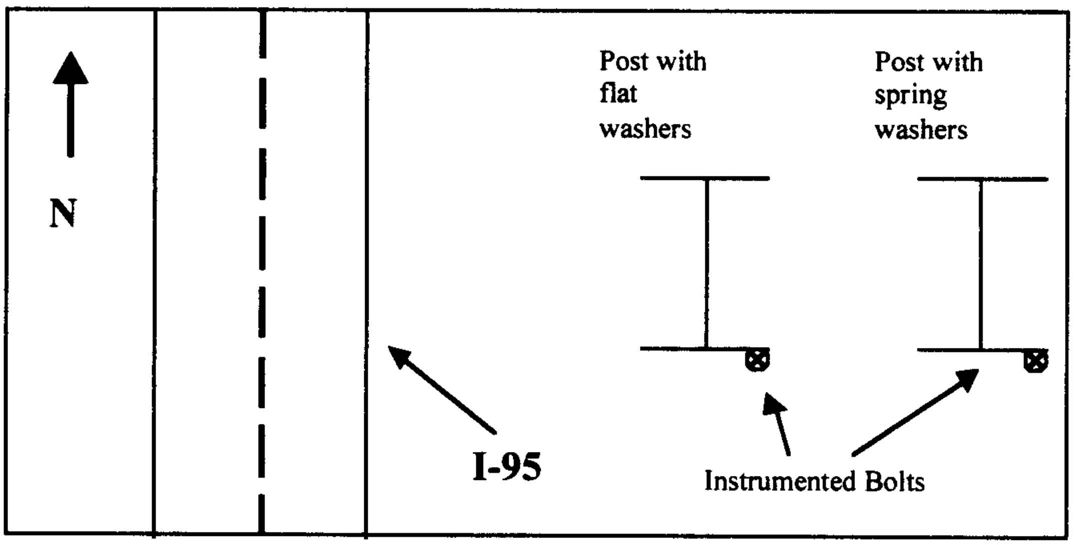



Figure 46 Location of Martin County Sign with respect to I-95

The Martin County bolt with spring washers was able to maintain the tension close to the acceptable range until August 8. It was submerged under water for at least a day on August 11 after which on August 26, the tension reading was 3786 lb. It was again submerged under water on September 10, 1998. From October 2 to October 21, 1998, the tension readings ranged from 4638 lb. to 4894 lb. Again, the bolt was submerged in water on November 6, 1998.

On November 11, 1998, a test was performed to determine if the torque and the strains had a linear relationship and check if the strain gages were working properly. Another test was performed on November 18 and the torque and strain registered a non-linear relationship. Thus we concluded from the tests that the bolt had to be replaced. The bolt was taken back to the lab to be re-instrumented and re-tested.

The newly instrumented bolt was re-installed on December 4, 1998 with a measured modulus of elasticity of 28,664 ksi. Since then the tension readings were out of the acceptable range on four occasions, two of which were over the 5000 lb. Mark. On April 16, the reading was abnormally high, and the bolt was removed. A tensile test in the lab yielded a value of 30,054 ksi for the modulus of elasticity, a 5% increase over the initial value measured before installation in the field.

The bolt with flat washers was able to maintain the tension within the acceptable range until August 26 even though the bolt was submerged in water on August 10 and 11. The bolts were again submerged in water on September 7. In between those dates, a reading was attempted; however, the right gage read an infinite resistance, which prevented a reading to be taken. The readings fluctuated from 1826 lb. on October 14 to 4683 lb. on October 21.

The bolts were again submerged in water on November 6 and 11. On November 18, the right gage was shorted out and so the bolt was taken back to the lab. The bolt was re-installed on December 4, 1998 with a measured modulus of elasticity of 29,687 ksi. Since then, the readings fluctuated with a downward trend, until the bolt was removed on April 10, 1999. A tensile test in the lab yielded a value of 31,912 ksi for the modulus of elasticity, a 9% increase over the initial value measured before installation in the field.

Location: Martin; After mile post 109 going north.

Sign reads "Exit 62, 714,714,1/2 mile."

Descriptior Green Sign - 10' X 10' X 12' from ground, W8X24 posts

***Long Bolt***

| Operator | Date | # of Days | Time | Temp | Strain Reading (με) | | | Bolt tension | | Eccent. | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | After | | °C | Left | Right | Average | lbs | kN | (in) | |
| | | 5/15/98 | Balance Offset >> | | *210* | *118* | | | | | |
| ML | 5/15/98 | 0 | - | 32 | 268 | 211 | 240 | 3068 | 13.6 | 0.011 | |
| ML | 5/20/98 | 5 | - | 30 | 350 | 195 | 273 | 3491 | 15.5 | 0.027 | |
| ML | 5/27/98 | 12 | - | 27 | 358 | 186 | 272 | 3485 | 15.5 | 0.030 | |
| SON | 6/9/98 | 24 | - | 35 | 396 | 205 | 301 | 3850 | 17.1 | 0.030 | |
| SON | 6/17/98 | 32 | 11:00 | 37 | 412 | 205 | 309 | 3952 | 17.6 | 0.031 | |
| SON | 6/25/98 | 40 | 10:00 | 34 | 402 | 189 | 296 | 3786 | 16.8 | 0.034 | |
| SON | 7/9/98 | 54 | 10:00 | 35 | 419 | 198 | 309 | 3952 | 17.6 | 0.034 | |
| SON | 7/16/98 | 61 | 10:30 | 34 | 427 | 193 | 310 | 3972 | 17.7 | 0.035 | |
| SON | 7/22/98 | 67 | 9:50 | 30 | 393 | 186 | 290 | 3709 | 16.5 | 0.034 | |
| N | 8/11/98 | 86 | | | | | | | | | Sign Bolts under water |
| N | 8/26/98 | 101 | 9:30 | 30 | 399 | 192 | 296 | 3786 | 16.8 | 0.033 | |
| ML | 9/10/98 | 115 | 1:29 | | | | | | | | Sign Bolts under water |
| ML | 9/10/98 | 115 | 7:34 | | | | | | | | Bolts unaccessable due to muddy conditions |
| JT | 10/2/98 | 137 | 4:45 | 34 | 507 | 223 | 365 | 4676 | 20.8 | 0.036 | Wires were in the bag |
| JT | 10/7/98 | 142 | 12:20 | | 506 | 218 | 362 | 4638 | 20.6 | 0.037 | Wires were in the bag. Was not able to take temperature. |
| | | | | | | | | | | | left the thermocouple at the Indian River site |
| JT | 10/14/98 | 149 | 11:25 | 32 | 505 | 220 | 363 | 4644 | 20.7 | 0.037 | Wires were in the bag |
| JT | 10/21/98 | 156 | 11:25 | 35 | 530 | 234 | 382 | 4894 | 21.8 | 0.036 | Wires were in the bag |
| JT | 11/6/98 | 171 | | | | | | | | | Bolts were totally submerged |
| JT | 11/11/98 | 176 | 12:00 | 34 | 81 | 470 | 276 | 3530 | 15.7 | 0.066 | ITT. Re-installed same bolt & washer with new offsets: ***Lt: 236 Rt: 114*** |
| JT | 11/18/98 | 183 | 10:40 | 35 | | | | | | | ITT. Non-linear results. Replaced instrumented bolt with regular one. |
| JT | 12/4/98 | 199 | 10:15 | 25 | 217 | 206 | 212 | 2678 | 11.9 | 0.002 | Replaced with instrumented bolt. New Offsets: Lt: ***210*** Rt: ***118.*** |
| | | | | | | | | | | | ***New E = 28.664x10^6 kpsi*** |
| JT | 12/9/98 | 204 | 10:10 | 35 | 264 | 385 | 325 | 4109 | 18.3 | 0.017 | Wires were in the bag |
| JT | 12/14/98 | 209 | 10:10 | 24 | 230 | 312 | 271 | 3432 | 15.3 | 0.014 | ibid |
| JT | 1/18/99 | 243 | 11:00 | 31 | 375 | 203 | 289 | 3660 | 16.3 | 0.028 | Wires were in the bag |
| JT | 1/29/99 | 254 | 10:20 | 31 | 357 | 196 | 277 | 3501 | 15.6 | 0.027 | ibid |
| JT | 2/5/99 | 260 | 10:45 | 33 | 493 | 321 | 407 | 5154 | 22.9 | 0.020 | ibid |
| JT | 2/12/99 | 267 | 12:50 | 30 | 369 | 169 | 269 | 3406 | 15.2 | 0.035 | ibid |
| JT | 2/19/99 | 274 | 11:35 | 31 | 573 | 341 | 457 | 5787 | 25.7 | 0.024 | ibid |
| JT | 3/26/99 | 311 | 10:10 | 30 | 409 | 67 | 238 | 3014 | 13.4 | 0.067 | rusting on all washers |
| JT | 4/2/99 | 317 | 10:00 | 33 | 459 | 73 | 266 | 3368 | 15.0 | 0.068 | ibid |
| JT | 4/10/99 | 325 | 12:40 | 36 | 452 | 58 | 255 | 3229 | 14.4 | 0.072 | ibid |
| JT | 4/16/99 | 331 | 10:05 | 30 | 691 | 313 | 502 | 6357 | 28.3 | 0.035 | replaced w/ regular bolt permanently |

Table 16 Tension and Eccentricity Values For Martin County Sign, Bolt with Spring Washers

Location: Martin; After mile post 109 going north.

Sign reads "Exit 62, 714,714,1/2 mile."

Descriptior Green Sign - 10' X 10' X 12' from ground, W8X24 posts

***Short Bolt***

| Operator | Date | # of Days | Time | Temp | Strain Reading (με) | | | Bolt tension | | Eccent. | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | After | | °C | Left | Right | Average | lbs | kN | (in) | |
| | | 5/15/98 | Balance Offset >> | | ***298*** | ***208*** | | | | | |
| ML | 5/15/98 | 0 | - | 32 | 280 | 316 | 298 | 3818 | 17.0 | 0.006 | |
| ML | 5/20/98 | 5 | - | 30 | 240 | 270 | 255 | 3267 | 14.5 | 0.006 | |
| ML | 5/27/98 | 12 | - | 27 | 229 | 268 | 249 | 3184 | 14.2 | 0.007 | |
| SON | 6/9/98 | 24 | 2:00 | 35 | 230 | 284 | 257 | 3293 | 14.6 | 0.010 | |
| SON | 6/17/98 | 32 | 11:00 | 37 | 217 | 283 | 250 | 3203 | 14.2 | 0.012 | |
| SON | 6/25/98 | 40 | 10:00 | 34 | 212 | 274 | 243 | 3113 | 13.8 | 0.012 | |
| SON | 7/9/98 | 54 | 10:00 | 35 | 204 | 275 | 240 | 3068 | 13.6 | 0.014 | |
| SON | 7/16/98 | 61 | 10:30 | 34 | 213 | 282 | 248 | 3171 | 14.1 | 0.013 | |
| SON | 7/22/98 | 67 | 9:50 | 30 | 202 | 285 | 244 | 3120 | 13.9 | 0.016 | |
| N | 8/11/98 | 86 | | | | | | | | | Sign Bolts under water |
| N | 8/26/98 | 101 | 9:30 | 30 | 220 | 292 | 256 | 3280 | 14.6 | 0.013 | |
| ML | 9/10/98 | 115 | 1:29 | | | | | | | | Sign Bolts under water |
| ML | 9/10/98 | 115 | 7:34 | | | | | | | | Bolts inaccessible due to muddy conditions. |
| JT | 10/2/98 | 137 | 4:55 | | 295 | | | | | | Right gage was possibly shorted out. It read an infinite resistance |
| JT | 10/7/98 | 142 | 12:30 | Bolts were inaccessible, they were totally submerged. | | | | | | | |
| JT | 10/14/98 | 149 | 11:35 | 33 | 285 | 0 | 143 | 1826 | 8.1 | 0.094 | Wires were in dry and in the bag. Right gage read a resistance of 25 ohms. |
| JT | 10/21/98 | 156 | 11:30 | 34 | 292 | 439 | 366 | 4683 | 20.8 | 0.019 | Wires were in dry and in the bag. Cut and spliced both wires |
| | | | | | | | | | | | Right gage initially 439 then it fluctuated. |
| JT | 11/06/98 | 171 | | | | | | | | | Bolts were totally submerged. |
| JT | 11/11/98 | 176 | 11:55 | | | | | | | | Bolts were totally submerged. |
| JT | 11/18/98 | 183 | 11:10 | | | | | | | | Wires were wet. Rt Gage was shorted out. Replaced with regular bolt. |
| JT | 12/4/98 | 199 | 10:45 | 29 | 136 | 394 | 265 | 3476 | 15.5 | 0.046 | Replaced with instrumented bolt. New Offsets: Lt: ***298*** Rt: ***208***. |
| | | | | | | | | | | | New ***E = 29.687x10⁶ kpsi*** |
| JT | 12/9/98 | 204 | 10:15 | 34 | 72 | 648 | 360 | 4722 | 21.0 | 0.075 | wires were dry and in the bag |
| JT | 12/14/98 | 209 | 10:15 | 23 | 101 | 460 | 281 | 3679 | 16.4 | 0.060 | ibid |
| JT | 1/18/99 | 243 | 11:05 | 31 | 96 | 218 | 157 | 2059 | 9.2 | 0.036 | ibid |
| JT | 1/29/99 | 254 | 10:25 | 30 | 36 | 176 | 106 | 1390 | 6.2 | 0.062 | ibid |
| JT | 2/5/99 | 260 | 10:55 | 32 | 29 | 231 | 130 | 1705 | 7.6 | 0.073 | ibid |
| JT | 2/12/99 | 267 | 12:55 | 35 | 42 | 132 | 87 | 1141 | 5.1 | 0.048 | ibid |
| JT | 2/19/99 | 274 | 11:40 | 31 | 9 | 590 | 300 | 3928 | 17.5 | 0.091 | ibid |
| JT | 3/26/99 | 311 | 10:15 | 32 | 43 | 4 | 24 | 308 | 1.4 | 0.078 | ibid |
| JT | 4/2/99 | 317 | 10:05 | 35 | 52 | -30 | 11 | 144 | 0.6 | 0.349 | ibid |
| JT | 4/10/99 | 325 | 12:45 | 36 | 51 | -94 | -22 | -282 | -1.3 | -0.316 | replaced with regular bolt permanently |

Table 17 Tension and Eccentricity Values For Martin County Sign, Bolt with Flat Washers

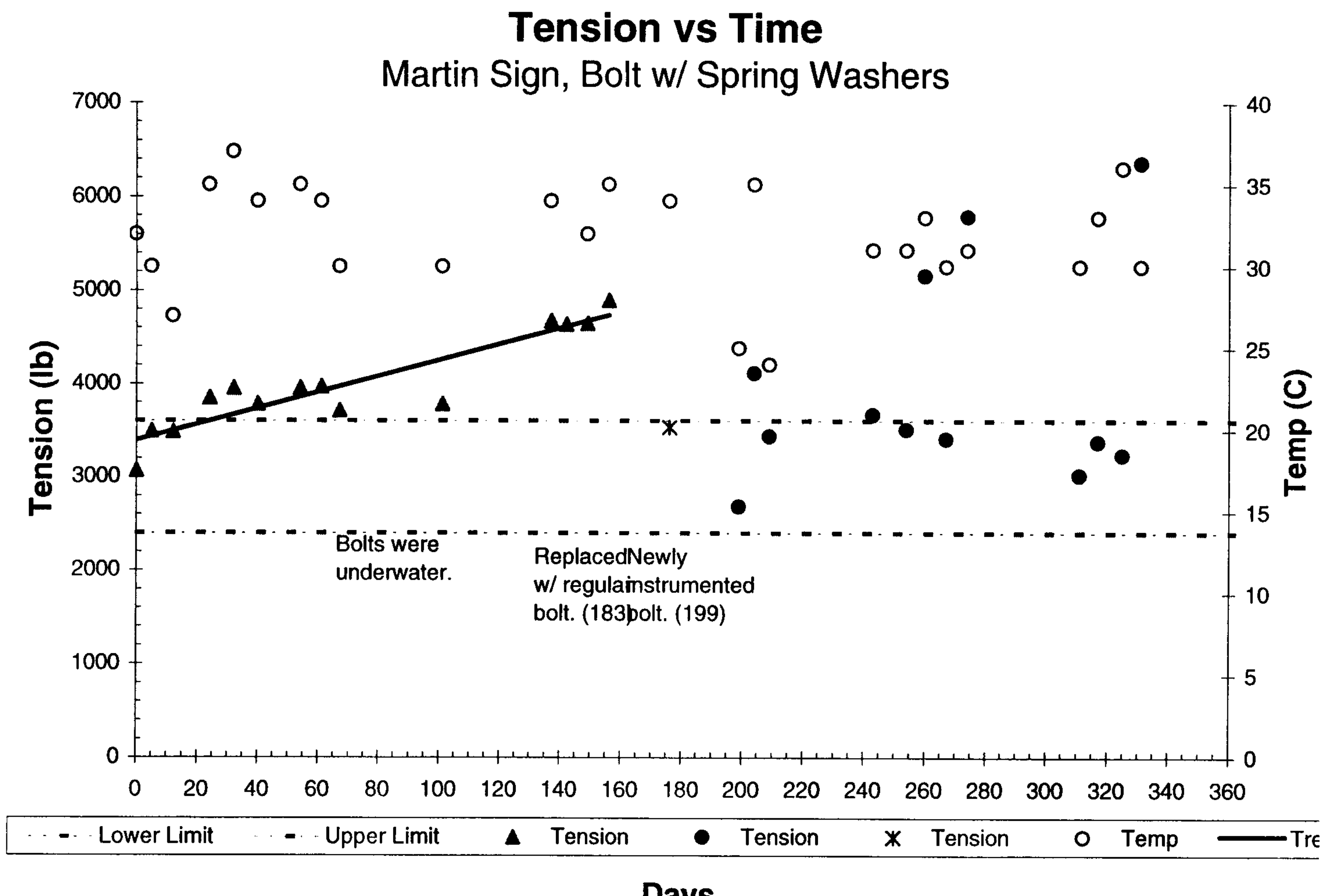



Figure 47 Tension vs Time, Martin County Sign, Bolt with Spring Washers

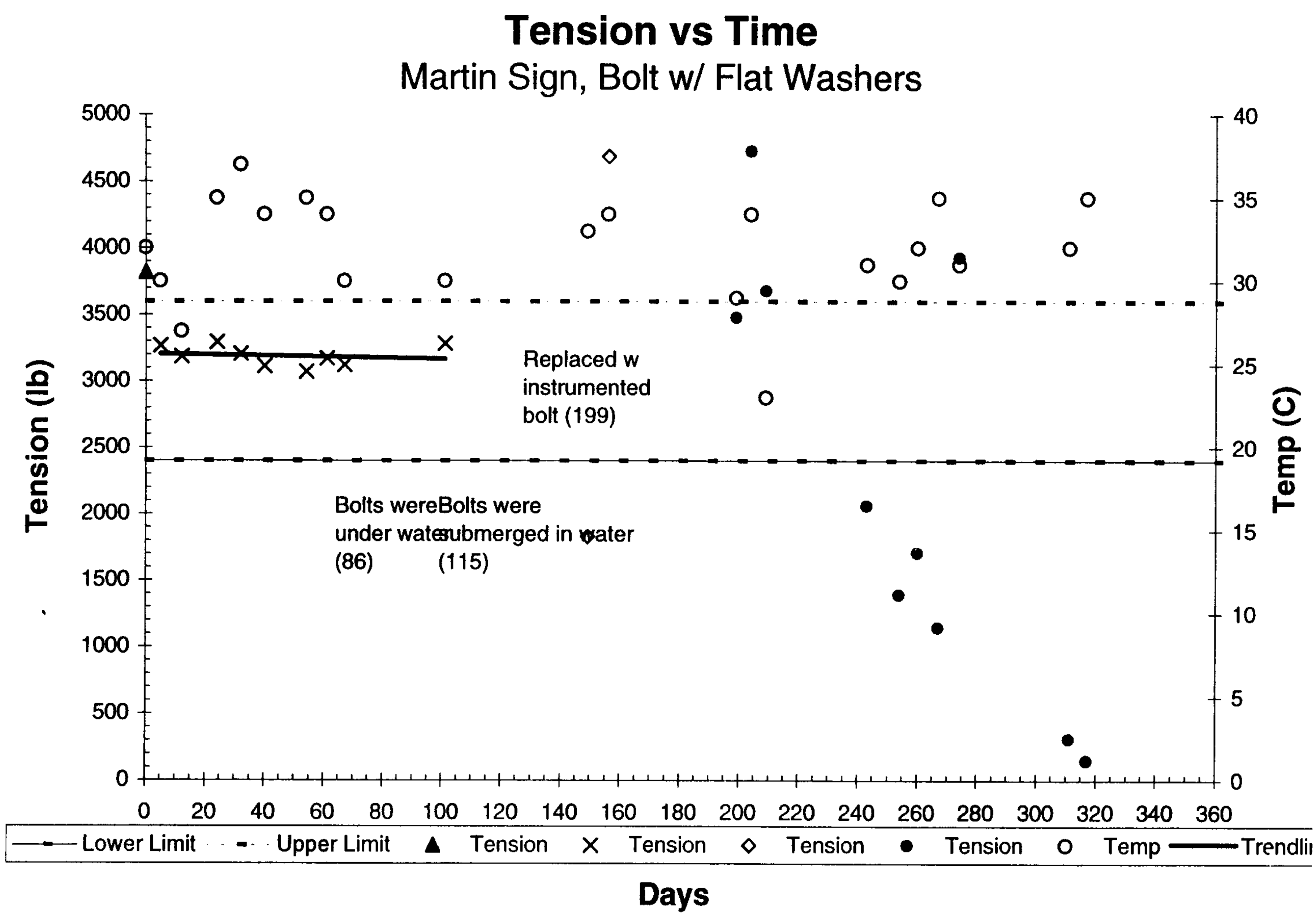



Figure 48 Tension vs Time, Martin County Sign, Bolt with Flat Washers

## TEMPERATURE TESTS

In some cases it appeared that there was some correlation between the tension readings and the temperature readings. The tension in the bolt goes up or down with the temperature. In particular, this happened for the Sebastian sign bolts both with spring washers (Figures 41); for the First Brevard sign bolts both with and without spring washers (Figures 36 and 37); for the 2nd Brevard sign bolts both with and without spring washers (Figures 33 and 34); and, for the Orlando sign bolt with spring washers (Figure 30). It must be noted, though, that the temperature readings, measured on the surface of the bolt, were indicative of the ambient temperature, and that the temperature of the bolt core was impossible to record in the field.

There were some concerns that the strain gages or the adhesive between the gage and the bolt could be affected by the temperature variations despite the manufacturer assurances to the contrary. Consequently, temperature tests were performed to determine the temperature effects, if any, on the strain gage readings. Several temperature tests were performed on bolts when they were returned from the field.

The procedure for the temperature tests was as follows:

- The untensioned bolts were placed into an Equatherm Oven manufactured by Curtin Matheson Scientific Inc. The bolts were connected to a P-3500 strain indicator to record the strain as the temperature was increased. An Acu-rite oven thermometer measured the temperature of the bolt.
- The temperature was increased from an initial ambient bolt temperature of around 24 °C to a maximum temperature of above 80 °C. The strains were measured for temperature increments of around 10 °C. The strain readings were also taken at similar decrements back to the ambient temperature of the bolt.

The results for the tests performed on the Orlando long bolt are shown below. The bolt was tested in three different settings. Figure 49 shows the result of the temperature test for the stand alone bolt, untensioned. Figure 50 shows the result of the temperature test for the bolt installed and tensioned on an aluminum fixture with spring washers. Figure 51 shows the result of the temperature test for the bolt installed and tensioned on an aluminum fixture with flat washers. In all the tests, it can be seen that the variation in strain is small, consistent with the expected thermal expansion of the steel bolt for this range of temperature. It was then concluded that the strain gages were not adversely affected by the expected temperature changes, and that the bolts could be used as intended in the field.

However, the results of the test do show that the slope of the strain-temperature curve varied for each test. This is to be expected, since the aluminum fixture, the galvanized steel flat washers, the spring washers, and the bolt itself are made of different alloys with different coefficient of thermal expansions. The interactions between the different elements of the connection result therefore in a different rate of thermal expansion or contraction, which may explain the variation of tension with the temperature.

Consequently, the observed variation in tension with the temperature cannot be attributed to the strain gages. The probable explanation is that the sign structures themselves expand or contract non uniformly when subjected to the action of the sun. One face of the posts might be warmer than the other, or one post might be in the shadows of trees while the other is fully exposed to the sun. The differential expansion and/or contraction of the sign might induce additional forces on the break-away connections. These in turn will result in changes in tension of the bolts.

These changes were also documented over a one day period by taking measurements of the same bolt at different times the same day. See readings for days 138 and 147 of the First Brevard sign in Tables 10 and 11; for days 196 and 205 of the 2nd Brevard sign in Tables 8 and 9; for days 196 and 205 of the Orlando sign in Table 6; for days 209 and 243 of the Indian River sign in Tables 14 and 15. Depending on the sign sun exposure and location of the bolt, the changes in tension during the day can be large or small. That will also explain in part the better performance of the spring washers. By design, the spring washers can accommodate these changes in tension and bring back the tension in the allowable range. On the contrary, after several of these temperature cycles, the bolts with flat washers might tend to permanently loosen.

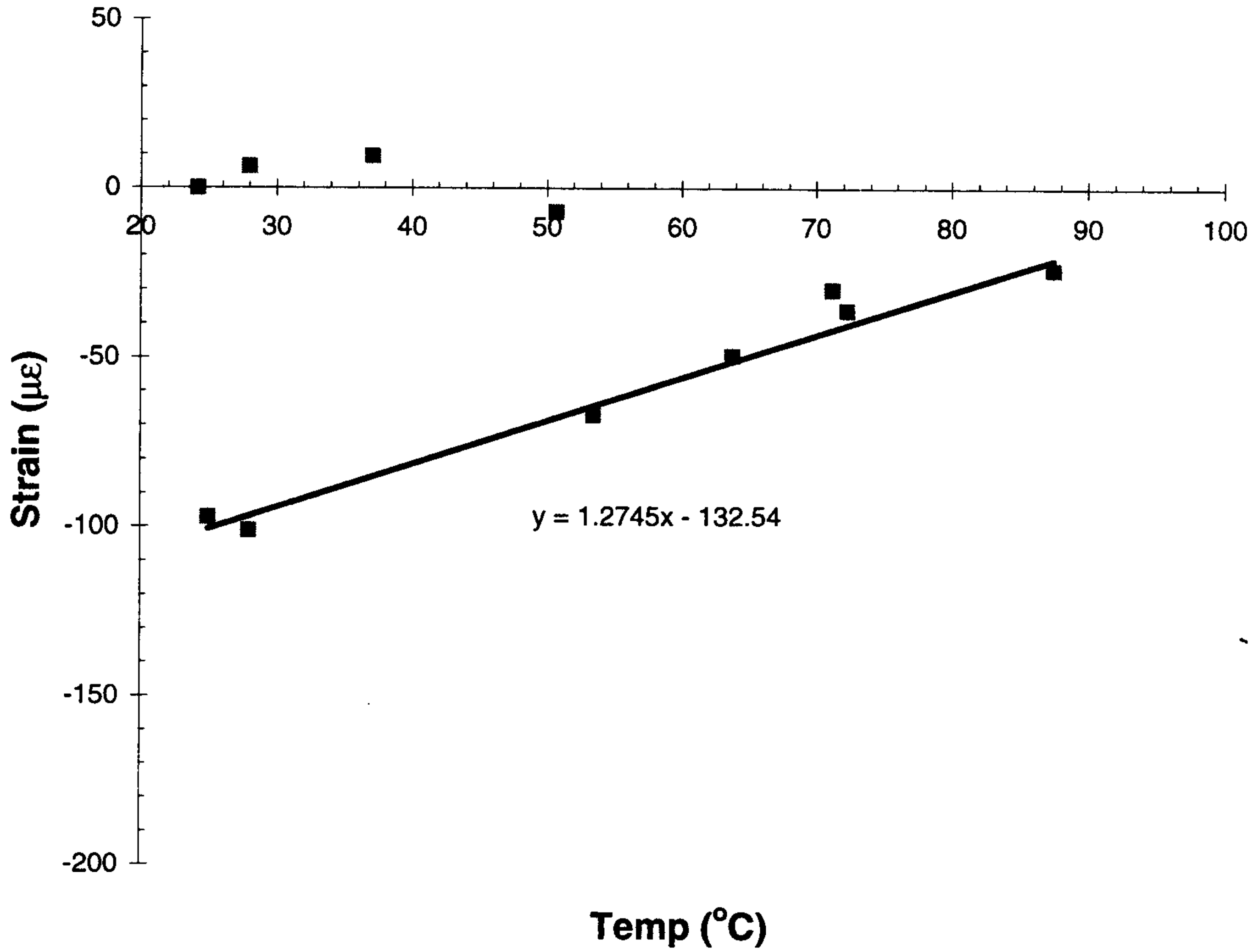



Figure 49: Strain vs Temperature, Orlando Sign, Long Bolt Untensioned, 5/13/99

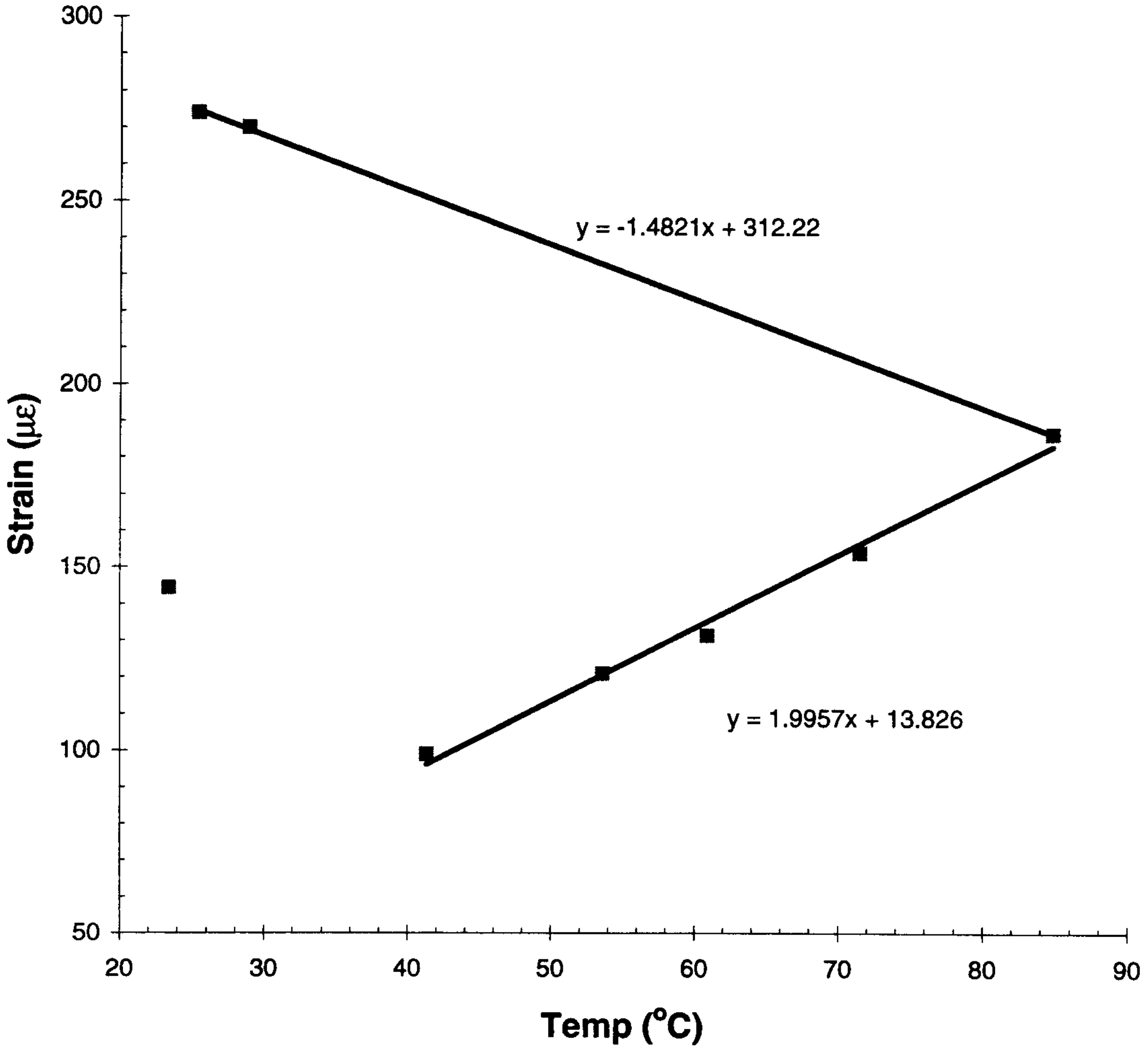



Figure 50: Strain vs Temperature
Orlando Sign, Bolt w/ Spring Washers, Tensioned, 5/6/99

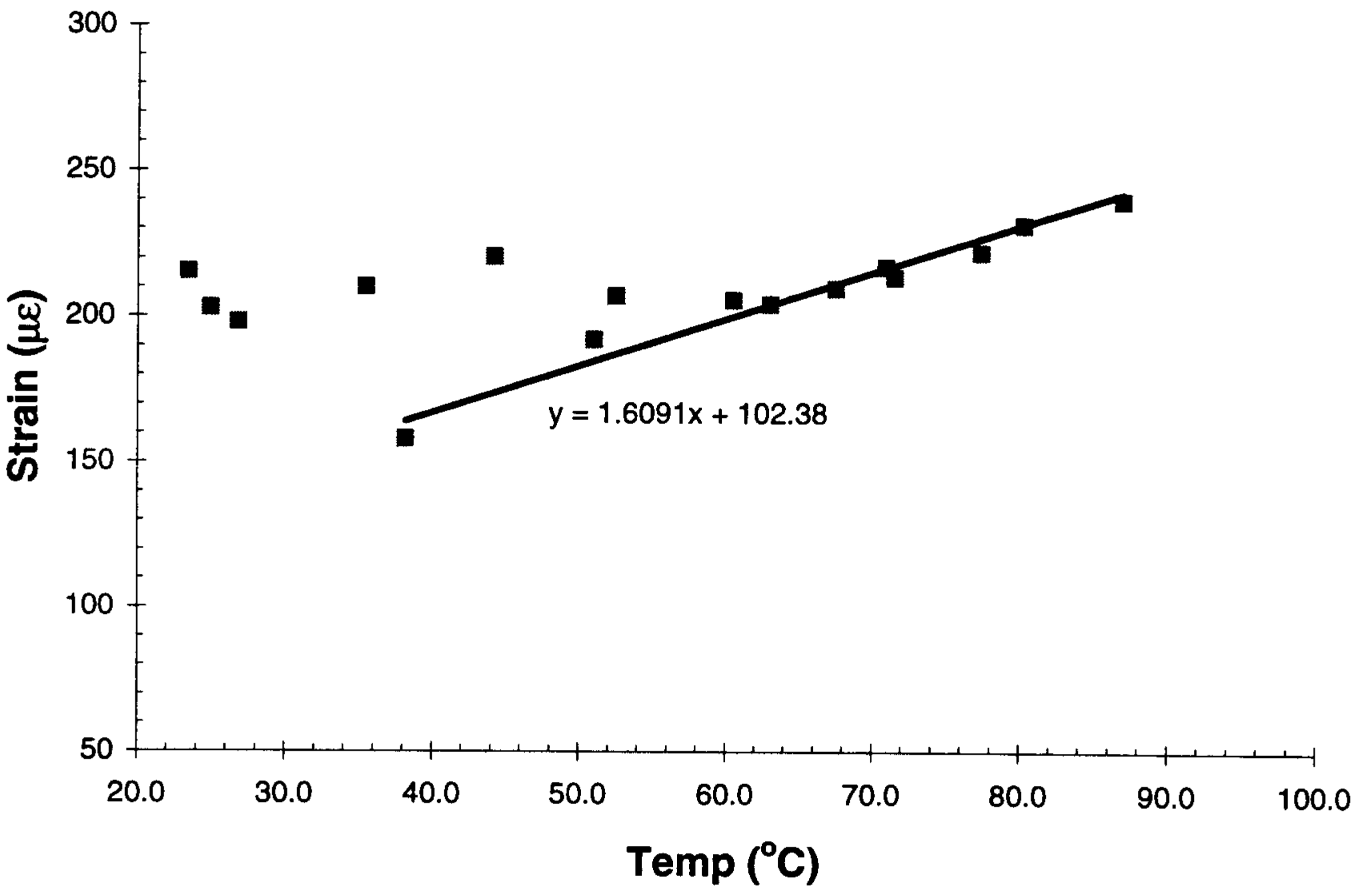



Figure 51: Strain vs Temperature
Orlando Sign, Long Bolt w/ Flat Washers, Tensioned, 5/7/99

# DISCUSSION

Tension in the bolts of seven highway signs were monitored over a period of a year, from May 1998 to the present. Seven bolts were equipped with conventional flat washers, while the other seven were installed with Belleville spring washers. However, it was impossible to achieve a continuous record of measurements for each of the 14 bolts monitored. Most of the strain gages had to be replaced at one point or another after being damaged accidentally by the weather, flooding, grass mowers, or other causes. Therefore it is somewhat difficult to show definite long term trends in the behavior of the bolts. However, there were clear differences between the two sets of specimens. They are summarized below.

***Bolts with Spring Washers***

<u>Long term behavior</u>

The bolts equipped with spring washers appeared to have a better, more predictable behavior. They were able to maintain the tensions within the acceptable range for five out of seven signs.

The Orlando sign is the only sign that was never damaged, and therefore was never re-torqued. It is the only sign for which we have a single continuous record of measurements. Throughout the initial 10 month monitoring period, tension readings were all within the acceptable range. Only at the end of the monitoring, during the spring of 1999, the readings went below the allowable range, probably because of a defective gage.

The Indian River and Brevard (2) bolts with spring washers were able to hold the tension within the acceptable range for approximately 200 days after they were torqued. Lamentably, both bolts had to be re-installed in February 1999. Since then, the tension readings kept within the acceptable range.

The Tampa bolt with spring washers was able to hold the tension within the acceptable range for 112 days after it was first installed. Lamentably, the left wire was cut on October 1998 and the bolt was not re-installed until February 1, 1999. On February 8, 1999, the initial readings were too low so the bolt was re-torqued using a new spring washer stack. After an initial peak, the tension readings have kept within the acceptable range to date.

The Brevard (1) bolt with spring washers were able to hold the tensions in the acceptable range for approximately 85 days, after the initial installation. However, the bolt had to be re-installed on November 20, 1998 and the tension readings were initially slightly above the upper limit of 3600 lb and then stayed in the allowable range The temperature readings for this particular series seemed to follow the trend of the bolt tensions.

The Martin and Sebastian bolts with spring washers had several problems with their strain gages throughout the testing program, so no definite trend could be observed.

The results of the monitoring of the bolts showed that the spring washers can maintain the tension in the bolts for extended periods of time. The Orlando sign is a prime example. The bolt has never been re-torqued since it was installed on May 16, 1998 and yet, the tension was maintained within the acceptable range for most of the experiment. It should be noted that the Orlando sign is in a high-traffic area and this fact supports the ability of the spring washers to maintain tensions more efficiently than regular flat washers do.

The Indian River results also show that the spring washers can maintain the tension in a bolt even if the bolt is not properly aligned. From June 17, 1998 to January 18, 1999, the left gage registered negative strains, as a result of a big eccentricity in the bolt. Nevertheless, the spring washers were able to maintain the tension for a majority of the time.

Finally, and very importantly, the connection with spring washers displayed outstanding behavior during a car accident, as described above in the section on the results of the Sebastian Inlet bolt.

*Galvanized vs. stainless washers*

At each sign location, three bolts were assigned galvanized washers, and one bolt was assigned stainless washers. To date, no significant differences were observed between the two types of washers, in term of behavior, degradation and rust. Rust was observed in both cases. However it seems to be more related to the fact that the washers come prepackaged in a plastic wrap that traps the humidity. In all cases, the rust appeared on the edges of the washers.

*Installation procedure*

The tension in the bolts depends on the deflection of the spring washers. Consequently, the investigators have proposed an installation procedure based on measuring the deflection with filler gages. The procedure is described with details in the Phase I report [1]. Over the course of the study, a total of 21 installations of instrumented bolts with spring washers were performed with this method. Table 18 summarizes the results of these installations. For each of the seven signs, the different installations are listed, with the corresponding dates and the values of the tension measurements for the two readings following each installation. We are including the second reading in the table, because we observed that sometimes, although the first readings indicated a value outside of the allowable tension range, after a short initial period of adjustment, the second and subsequent readings fell between the range.

It can be seen that out of 21 cases, 81% (or 17 cases) were successful installations, and only 19% (or 4 cases) were unsuccessful. Successful means that the tension in the bolt was in the allowable range. This is a fairly high rate of success, specially compared to the 32% rate of success for the traditional torquing method, as described in the next section. However, we feel that the method could be improved upon by designing a special instrument to measure the deflections. Also, it was observed that lubrication of the connection prior to installation improves the chances of success.

| Sign | Reading # Date | 1 (lb.) | 2 (lb.) |
|---|---|---|---|
| *Tampa* | 5/18/98 | 2178 | 1806 |
| | 6/10/98 | 1877 | 1883 |
| | 2/1/99 | 2755 | |
| | 2/8/99 | 4093 | 3024 |
| *Orlando* | 5/16/98 | 3382 | 3651 |
| *Brevard (2)* | 5/16/98 | 2787 | 3299 |
| | 2/12/99 | 3333 | 2960 |
| *Brevard (1)* | 7/14/98 | 3697 | 2956 |
| | 11/20/98 | 3880 | 3836 |
| *Sebastian Inlet* | 5/15/98 | 2671 | 2505 |
| | 11/11/98 | 3148 | -298 |
| | 12/4/98 | 2654 | |
| | 1/22/99 | 2400 | |
| | 1/29/99 | 3039 | |
| | 2/5/99 | 2846 | 2555 |
| *Indian River* | 5/15/98 | 2018 | 1787 |
| | 6/17/98 | 3434 | 2684 |
| | 2/5/99 | 3341 | 2869 |
| *Martin County* | 5/15/98 | 3068 | 3491 |
| | 11/11/98 | 3530 | |
| | 12/4/98 | 2678 | 4109 |

Table 18: Tension in Bolts with Spring Washers

*Maintenance*

The maintenance procedure should be the same than for the traditional flat washer connections. It is emphasized that a better installation and latter performance will be achieved if the bolt and washers are initially lubricated. In addition, special care should be given to the filler gages used for installation. They should be conveniently oiled and kept without corrosion, to ensure proper measurement of the spring washer deflections. The bolts and stacks of washers should be replaced periodically in accordance with manufacturer prescriptions, and FDOT maintenance schedules [1].

***Bolt with Flat Washers***

*Long term behavior*

The tension readings in the bolts with flat washers generally were not within the acceptable range. In four out of seven cases, the tensions in the bolt decreased over time. In four out of seven cases, in spite of being installed with the proper torque according to FDOT specifications, the bolts remained under-tensioned. In one case the bolt was over-tensioned despite being torqued to the proper FDOT specifications.

The Orlando sign registered tensions below the lower bound with a decreasing trend since it was first installed in May 16,1998. The bolt has been re-torqued six times and four out of these five times, the bolt was under-tensioned. Despite using a new torque wrench, two out of the three times it was used, the bolt still remained under-tensioned. The left gage has almost always registered a negative strain since June 10, 1998. This resulted in a big eccentricity in the bolt. One possible cause for this result is that the different connection components are not properly aligned.

The Indian River bolt had only one tension reading within the acceptable range. In spite of being torqued to the proper torques according to FDOT specifications, the bolt still remained under-tensioned.

The Brevard (2) bolt also had only a few tension readings within the acceptable range. In spite of being torqued to the proper torques according to FDOT specifications, the bolt still remained under-tensioned.

The Tampa sign registered values in the allowable range with peaks above the range, and the tension readings fluctuated a lot.

The Martin sign was able to maintain the tension within the range for 101 days. After it was replaced on December 4, 1998, the tension fluctuated severely.

The Sebastian sign registered an increasing trend. The bolt was re-installed on November 11, 1998 and the tension readings were above the upper bound of 3600 lb. The bolt was again re-installed on December 4, 1998 and since then, the tension has only been in the acceptable range once.

The Brevard (1) sign has never been re-torqued since it was installed in July 14, 1998. The results have always been below the allowable values.

The results of monitoring the bolts show that the flat washers cannot maintain the tension over an extended period of time. The Brevard (1) sign is a clear indication of this trend. Another observation is that the tension fluctuated more with the flat washers than the spring washers.

*Installation procedure*

The results also show that the current installation technique is faulty. In four out of seven cases, the bolts remained under-tensioned in spite of being installed with the proper torque according to FDOT specifications. In one case the bolt was over-tensioned despite being torqued to the proper FDOT specifications.

In this case, the tension in the bolts depends on the magnitude of the torque applied. The method of installation is described with detail in the FDOT manual [2]. However, we were surprised to find that the different FDOT jurisdictions are not in agreement over the value of torque to be used. Table 1 in the first part of this report shows that one jurisdiction at least (Orlando) uses a value of torque of 36 ft-lb, different from the 43 ft-lb used by the other FDOT offices.

Over the course of the study, a total of 31 installations of instrumented bolts with flat washers were performed with the conventional method. Table 19 summarizes the results of these installations. For each of the seven signs, the different installations are listed, with the corresponding dates and the values of the tension measurements for the two readings following each installation. We are including the second reading in the table, because we observed that sometimes, although the first readings indicated a value outside of the allowable tension range, after a short initial period of adjustment, the second and subsequent readings will fall between the range.

It can be seen that out of 11 cases, only 32% (or 10 cases) were successful installations, and 68% (or 4 cases) were unsuccessful. Successful means that the tension in the bolt was in the allowable range. This is a fairly high rate of failure, specially compared to the 81% rate of success for the new torquing method, as described above. It was observed that lubrication of the connection prior to installation improves the chances of success. However, from our experience in the field with the FDOT crews, consistent lubrication of the connections does not seem a realistic option.

| Sign | Reading # Date | 1 (lb.) | 2 (lb.) |
|---|---|---|---|
| *Tampa* | 5/18/98 | 2915 | 3613 |
| | 6/10/98 | 4273 | 2959 |
| | 2/1/99 | 2414 | |
| | 2/8/99 | 2159 | 1787 |
| *Orlando* | 5/16/98 | 2601 | 9705 |
| | 6/10/98 | 2671 | 1992 |
| | 10/23/98 | 2140 | |
| | 11/4/98 | 1409 | 1243 |
| | 12/2/98 | 2404 | 1987 |
| | 2/1/99 | 2208 | |
| | 2/8/99 | 1705 | |
| | 2/15/99 | 1098 | |
| | 2/22/99 | 2674 | |
| *Brevard (2)* | 5/16/98 | 3523 | 5714 |
| | 6/1/98 | 6009 | |
| | 6/10/98 | 4177 | 1557 |
| | 11/13/98 | 3316 | 5291 |
| | 1/25/99 | 1165 | 777 |
| | 2/8/99 | 1547 | 1040 |
| *Brevard (1)* | 7/14/98 | 2651 | 2529 |
| *Sebastian Inlet* | 5/15/98 | 4215 | 3568 |
| | 12/4/98 | 3774 | 3780 |
| | 2/5/99 | 4300 | 3449 |
| *Indian River* | 5/15/98 | 2255 | 5810 |
| | 6/25/98 | 1672 | 1877 |
| | 11/6/98 | 6455 | |
| | 11/11/98 | 1239 | |
| | 12/9/98 | 970 | 672 |
| | 2/5/99 | 2199 | 2124 |
| *Martin County* | 5/15/98 | 3818 | 3267 |
| | 12/4/98 | 3476 | 4722 |

Table 19: Tension in Bolts with Flat Washers

# CONCLUSIONS AND RECOMMENDATIONS

## *Conclusions*

A new method is proposed to measure and maintain the tension in the bolts of break-away slip base connections. The method is fairly simple to implement, and it is based on the utilization of Belleville spring washers. For each different bolt diameter and associated load range, a combination of spring washers is recommended. The stacks of spring washers, which come pre-wrapped, are installed on the bolt just as any ordinary washers, and the bolts are torqued with any kind of torque wrench. According to the method, a block of filler gages measures the deflection of the stack of spring washers which is proportional to the tension in the bolt. For each desired value of tension, there is a corresponding value of deflection. The main advantage of this technique is that it eliminates the uncertainties associated with torque measurements, and it provides a more reliable way to estimate the tension of the bolt.

Seven signs were selected along Central and South Florida highways. At each sign, one of the posts was equipped with bolts with spring washers, while the other post remained connected with bolts with conventional flat washers. At each sign, one of the bolts with spring washers and one of the bolts with flat washers were instrumented with strain gages, and the variations of tension in these bolts were monitored over a period of several months.

The following conclusions were obtained based on the results of the field monitoring.

1. Over the long term, bolts installed with spring washers appear to maintain the tension in the bolt. No instances of consistent bolt loosening below the allowable range of tensions were observed, even in high traffic areas like Orlando.

2. On the contrary, several bolts installed with flat washers exhibited a downward trend in the bolt tension.

3. The proposed installation procedure based on measuring deflections of the spring washers appears to be more successful than the conventional method based on measuring the torque. 81% of the bolts installed with spring washers had their initial tension in the allowable range, as opposed to only 32% of the bolts installed with flat washers.

4. The effectiveness of the break-away connection with spring washers was demonstrated during a car accident. A car hit a sign post equipped with spring washers, near the Sebastian Inlet. The break-away functioned perfectly and the post separated from the base.

5. Over the monitoring period, no significant advantage was observed regarding the use of stainless washers. Minor corrosion was observed for both the stainless and galvanized washers, and it appears to be due to the fact that the plastic wrapping of the stack of washers traps some humidity. The solution could be to slash the wrapping after installation.

***Recommendations***

Based on the results of the field monitoring, which confirm the results of the laboratory tests from the phase I of the project, spring washers appear to be a good alternative to the use of conventional flat washers, for break-away connections. The accurate measurement of the deflection of the stack of spring washers remains a critical issue. Filler gages can be used with a reasonable rate of success, as shown during this testing program, although the investigators feel that the FDOT crews would be reluctant to use the method as is. As a compromise, the bolts could still be installed with spring washers, to ensure that no loosening occurs, but they could be torqued with the conventional method.

To take full advantage of the proposed solution for break-away connections, we strongly recommend that a special measurement device be developed to specifically measure the deflection of the stack of spring washers. Such a device would significantly improve the efficiency of the method.

# REFERENCES

1. FDOT, Ground Mounted Single And Multi-Pos Sign Inspection Manual, Florida Department of Transportation, November 1994.

2. Pinelli, Jean-Paul, Subramanian, Chelakara. *Final Report, Study of Break-Away Sign Connections, State Job No. 99700-3344-119, Contract No. BA521, WPI No. 0510777, March 18, 1998*