AMERICAN CONSULTING ENGINEERS COUNCIL'S

AFFILIATE

HEAVY MOVABLE STRUCTURES, INC.

4TH BIENNIAL SYMPOSIUM

NOVEMBER 10TH - 12TH, 1992

SHERATON DESIGN CENTER
FT. LAUDERDALE, FLORIDA

SESSION
WORKSHOP NOTES

#35 Author: I. Wayne Wallace
J & M Turner, Inc.
"*Field Bolt Tension Measurements*".

Disclaimer
It is the policy of the Corporation to provide a mean *for information interchange*. It DOES NOT propagate, recommend or endorse any of the information interchanged as it relates to design principles, processes, or products presented at the Symposium and/or contained herein. All Data are the author's and NOT the Corporation's. Application of information interchanged is the responsibility of the user to validate and verify its integrity prior to use.

FIELD BOLT TENSION MEASUREMENTS
AIRCRAFT ASSEMBLY SITES
AND
INTERSTATE BRIDGE

I. W. Wallace
President
Applied Bolting Technology/
Canfab Steel
HMS/MB Symposium
November 1992

ABSTRACT

The Research Council Specification requires that bolts be tensioned during installation to a level higher than 70% of their minimum specified ultimate tensile strength. Thus 80 kips and 64 kips are the minimum expected tensions for 1 1/8" diameter and 1" diameter ASTM A490 bolts respectively. Until recently, no reliable field bolt tension testing method was available to check the "as installed" level of bolt tension. Raymond Engineering has developed the Ultrasonic Extensometer for this purpose, based on the measurement of "release stretch", or "length change", on releasing the bolt tension. This paper reports on the extensometer "release stretch" tests of 54 bolts on three different project sites. Bolt tensions deduced from these release stretches are reported and compared to the specified minimums. Of the 54 bolts, 45 bolts had been tensioned with Direct Tension Indicators (DTI's) and 9 bolts had been tensioned by turn-of-nut and torque wrench inspection. The results show that the bolts tensioned with DTI's exhibited mean preloads above the specified minimum, while those without DTI's exhibited a wide scatter in tensions and a mean well below specified minimum.

BACKGROUND

This report documents the field measurements of tensions in various randomly selected 1 1/8" A 490 bolts in roof truss connections of an aircraft assembly building in Northwestern USA, and various 1" A490 bolts in a bridge "pin-and-hanger" repair connection bracket on a major interstate bridge in Pennsylvania. This testing was done because the owners' inspection data showed some DTI's to be slightly low in load resistance at a specified gap according to tests done in conformance with ASTM F959. The manufacturer of the DTI's, J. & M. Turner, produced laboratory retest data from field samples which showed acceptable DTI results. This product testing controversy caused the owners and their consultants to question the adequacy and consistency of bolt tensions produced by the DTI's. The field testing was initiated in an attempt to answer the questions about the adequacy of bolt tensions produced by the suspect DTI's.

45 bolts were inspected which had been installed with the use of DTI's, and 9 bolts were inspected which had been installed by means of turn-of-nut, without DTI's. Of the 45 bolts which had been installed with DTI's, 32 DTI's had been installed under the turned element, an acceptable procedure according to J. & M. Turner, and 14 DTI's had been installed under the bolt head. The latter orientation of the DTI is more usually found, but both positions of the DTI are acceptable.

Anecdotal evidence from the aircraft assembly building sites had it that the bolt installers were taking too much time (20 to 30 seconds or more vs 10 seconds maximum specified by the Research Council) to compress the DTI's, due primarily to poor bolt management practices on the site. Rusty bolts caused by exposure to rain, etc., will increase the nut factor (torque resistance per unit of tension achieved) of the bolt assembly and result in tightening times of this magnitude or longer. Poor quality wrenches or inadequate air supply to them will also cause this problem. Complaints from the erector of broken bolts and destroyed wrenches preceded the decision to go to the site to measure tensions.

Figure 1 shows four photographs of trusses and connections, both on the ground and erected, from the aircraft assembly building sites. No photographic prints of the interstate bridge site are included with this paper, although the oral presentation will include slides. Figure 2 shows a sketch of the bridge connections tested.

TEST METHOD

The ultrasonic method of measuring bolt tensions has been documented by Notch ("Bolt Preload Measurements Using Ultrasonic Methods", Engineering Journal, AISC, 2nd Quarter 1985). The method is based on the measurement of ultrasonic sound transit time from transducer face to the end of the bolt. Because the bolts had already been installed, the initial (stretched) bolt length is measured, then the unstretched bolt length is measured after release of the nut, and the difference is the "release stretch". Once the "release stretch" is known, that bolt can be removed from the steelwork and, with the same transducer in place, pulled to the same stretch in a calibrated tensioning device. The load then can be read which would correspond to the preload which was in the bolt when it was in the hole in the stretched condition.

A Raymond ultrasonic bolt gage model 934-01 was used, complete with Epson hand held computer and appropriate transducer. Software installed on this Epson controller was version 3.0 1990 and included the Bolt Gage Program, the Bolt Program, the Tensile Program, and the Setup Program. The equipment was calibrated before use with the calibration bars provided with it. The equipment was run on a trial bolt in an office prior to going up on the steelwork.

The method used included grinding smooth the bolt heads and shanks so that a consistent initial 'length' was obtained - the stressed length. The nut was then released and the unstressed length was obtained, recorded on the Epson as a negative stretch.

An example of the individual bolt type was then removed from the steelwork and pulled to the minimum preload tension of 80,000 lbs. and 64,000 lbs, and the Raymond Tensile program was used to store the "stiffness", or load per unit of extension, for that bolt. The bolts' stiffnesses were obtained by pulling them in a portable Biach tension tester connected to a Volumetric Digital Load Analyser reading in kips.

The Epson unit printed the results of the negative stretches from each bolt, correlating each to a tension from the calibrated tension test. Temperature measurements were made on each bolt as the ultrasonic transducer was placed, and a consistent effort was made to obtain consistent tensioned and untensioned 'lengths'. Length measurements were repeated until three readings were the same to the nearest +/-.002".

The "release stretches" measured in this manner, times the measured bolt stiffnesses, equals the apparent preload in the bolts. This is illustrated in Figure 3.

Note:The 1" diameter bolts from the bridge were retained by the bridge owner, and therefore could not be calibrated by pulling them as described above. To get an idea of their adequacy, the Raymond Bolt Program was used to calculate an approximate extension necessary to reach 64 kips. This program is built into the Epson unit, and depends on Young's modulus, threads in the grip, steel type, nut dimensions, etc., but it should be emphasized that it is approximate and not as accurate as calibrating an example bolt.

TEST RESULTS

Figures 4, 5, and 6 are from the aircraft manufacturing plant tests, and Figure 7 is from the Pennsylvania bridge tests.

Figure 4 shows the results of tensions measured in 21 1 1/8" bolts from three connections, all bolts having been installed with DTI's. Of these 21 measurements, two of the initial tests did not produce solutions on the bolt gage due to setup problems. One bolt was mistakenly grouped with other bolts of different length, and consequently meaningful readings could not be obtained. Of the remaining 18 bolts, the mean tension found was 85.75 kips and the standard deviation was 9.3 kips. Only one bolt was found to be significantly undertensioned by 15%, and this was the bolt on which the DTI had not been compressed anywhere near the specified .005" gap.

Figure 5 shows the results of tensions measured in 9 1 1/8" bolts from two connections, all bolts having been installed by means of turn-of-nut and inspected and approved by torque. Of the 9 bolts, the mean tension found was 52.9 kips, and the standard deviation was 24.5 kips. Only two bolts were found to have tension over 80 kips.

Figure 6 shows the results of tensions measured in 10 1 1/8" bolts from three connections, all bolts having been installed with DTI's, and all three connections having not been properly snugged. Despite the lack of snugging, 6 of these bolts had been inspected and passed by the usual means of judging the DTI gap. Of these 6 bolts, one bolt was found undertensioned probably due to the lack of snugging. Of these 6 bolts, the mean tension was 86.7 kips, still okay. The remaining 4 bolts had been previously inspected and rejected because the DTI gap was too large, and the ultrasonic tension measurements confirmed that the tensions were all below 96 kips, the highest allowed in ASTM F959 for the DTI.

Figure 7 shows the results of tensions measured in 14 1" bolts on the bridge. 12 out of 14 bolts were found to be probably tensioned at or above the minimum, and two were (22% and 68%) significantly below the minimum, despite the complete crushing of the DTI's in both cases. One of these two bolts could not be removed from the steelwork, exhibiting completely ruined threads. It is assumed that this would have occurred during installation. Even including this very low bolt, the mean stretch of all 14 bolts was 3% over the approximate calculated minimum.

DISCUSSION OF RESULTS

Determining bolt tensions by means of ultrasonic length change measurement is a relatively new technology as it applies to structural steel bolting. The accuracy of the "release stretch" measurement is to less than .001" and more than .0001". The Raymond bolt gage has made it possible to get excellent repeatability of measurements to less than .001", and this is sufficient to give the skilled operator a high degree of confidence in the measurements taken.

By these measurements, the bolts tensioned with DTI's are adequately preloaded, with an overall (38 bolts) mean of 106% of minimum. This mean preload level is lower than previous research has shown to be the case, especially when the DTI is placed under the bolt head. A mean preload of about 110% would be preferable. J. & M. Turner is interested in why this has occurred, and reportedly will be initiating an internal research program to check the influence of high nut factor bolts combined with marginal output impact wrenches to see if the adequate but somewhat lower than expected level of preloading found on these bolts can be repeated. If necessary, the preload necessary to compress the DTI (the load/gap relationship) can be raised somewhat to compensate for this result.

When tensioned with DTI's under the turned element as these 1-

1/8" bolts were, the overall (24 bolt) standard deviation is 10.5 kips. This is consistent with previous research which shows a wider distribution of tensions when the DTI is used in this manner than when it is used under the (unturned) head of the bolt.

The bolt tensions checked on the turn-of-nut bolts are, although from a small sample, predictably variable and, on average, far too low. This has been observed in previous tests done by others. The difficulty of deciding when "snug" has been achieved (complete joint compacting), and the high friction factor of bolts in the condition observed, both likely conspire to defeat the best efforts of the installers to achieve the correct result.

The 1" bolts tested from the bridge are satisfactory in total, although one of them is inexplicably and dramatically too low (68%). Since there was no apparent reason for this based on testing of the DTI itself, it is speculated that some dramatic error in snugging procedure has resulted in relieving of the preload even though the DTI has been flattened.

DATA MEASURED

SITE 1
AIRCRAFT ASSEMBLY BUILDING
DTI Connection 1 - 7 bolts

Minimum release stretch	.0156"	(80,000 lb.)
Calibrated bolt stiffness	5,072,780 lbs./in	
Bolt 11	-------	(no solution on release)
Bolt 12	.0203"	104,100 lb.
Bolt 13	.0167"	86,200 lb.
Bolt 14	too short (mistakenly included)	
Bolt 15	.0131"	67,700 lb.*
Bolt 16	-------	(no solution on release)
Bolt 17	.0154"	79,000 lb.

*purposely selected with a DTI gap larger than allowed.

SITE 1
AIRCRAFT ASSEMBLY BUILDING
DTI Connection 2 - 7 bolts

Minimum release stretch	.0105"	(80,000 lb.)
Calibrated bolt stiffness	7,254,000 lbs./in	
Bolt 21	.0110"	84,600 lb.
Bolt 22	.0122"	93,700 lb.
Bolt 23	.0109"	83,000 lb.
Bolt 24	.0145"	110,500 lb.
Bolt 25	.0110"	84,600 lb.
Bolt 26	.0101"	77,000 lb.
Bolt 27	.0114"	86,900 lb.

SITE 1
AIRCRAFT ASSEMBLY BUILDING
DTI Connection 3 - 7 bolts

Minimum release stretch	.0187"	(80,000 lb.)
Calibrated bolt stiffness	4,151,390 lbs./in	
Bolt 31	.0210"	89,900 lb.
Bolt 32	.0191"	81,700 lb.
Bolt 33	.0194"	83,000 lb.
Bolt 34	.0196"	83,900 lb.
Bolt 35	.0193"	82,600 lb.

Bolt 36	.0195"	83,400 lb.
Bolt 37	.0191"	81,700 lb.

SITE 1
AIRCRAFT ASSEMBLY BUILDING
Turn-of-Nut Connection 5 - 7 bolts

Minimum release stretch	.0151"	(80,000 lb.)
Calibrated bolt stiffness	4,986,900	lbs./in
Bolt 51	.0125"	66,200 lb.
Bolt 52	.0171"	90,600 lb.
Bolt 53	.0094"	49,800 lb.
Bolt 54	.0068"	36,000 lb.
Bolt 55	.0120"	63,600 lb.
Bolt 56	.0168"	89,000 lb.
Bolt 57	.0038"	20,100 lb.

SITE 1
AIRCRAFT ASSEMBLY BUILDING
Turn-of-Nut Connection 6 - 2 bolts

Minimum release stretch	.0110"	(80,000 lb.)
Calibrated bolt stiffness	6,864,000	lbs./in
Bolt 61	.0044"	32,000 lb.
Bolt 62	.0040"	29,100 lb.

SITE 2
AIRCRAFT ASSEMBLY BUILDING
DTI Connection 7 - 6 bolts

Minimum release stretch	.0140"	(80,000 lb.)
Calibrated bolt stiffness	5,724,860	lbs./in
Bolt 71	.0106"	60,570 lb.
Bolt 72	.0158"	90,300 lb.
Bolt 73	.0166"	94,900 lb.
Bolt 74	.0182"	104,000 lb.
Bolt 75	.0141"	80,600 lb.
Bolt 76	.0157"	89,700 lb.

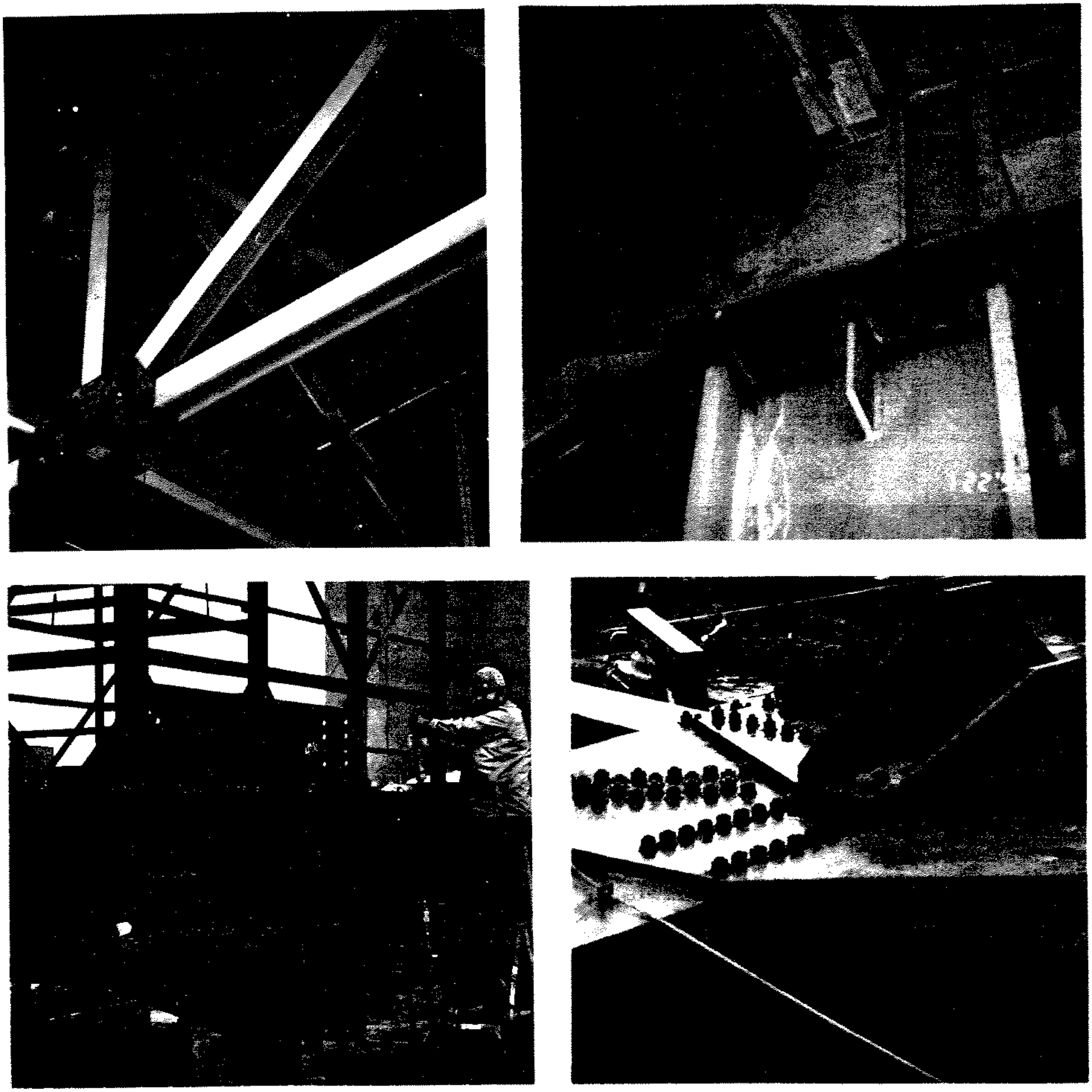
SITE 2
AIRCRAFT ASSEMBLY BUILDING
DTI Connection 7,8 - 4 bolts
DTI's not compressed properly

Field Bolt Tension Measurements (cont)

Bolt 77	.0067"	38,300 lb.
Bolt 78	.0010"	5,700 lb.
Minimum release stretch	.0150"	(80,000 lb.)
Calibrated bolt stiffness	5,185,340 lbs./in	
Bolt 81	.0161"	85,900 lb.
Bolt 82	.0101"	53,900 lb.

SITE 3
HIGHWAY BRIDGE
DTI Connections 1" bolts

BOLT NO.	DESCRIPTION	STICKOUT	RELEASE STRETCH MEASURED	THEOR MIN	%
BR1	1" 490, 5 3/8" LG.	1/2"	.0115"	.0119"	97
BR2	1" 490, 5 3/8" LG.	1/2"	.0135"	.0119"	113
BR3	1" 490, 5 3/8" LG.	1/2"	.0133"	.0119"	112
BR4	1" 490, 5 3/8" LG.	1/2"	.0128"	.0119"	108
BR5	1" 490, 6 " LG.	1/2"	.0144"	.0139"	104
BR6	1" 490, 6 " LG.	1/2"	.0162"	.0139"	117
BR11	1" 490, 6 " LG.	1/2" (overtyped)	.0157"	.0141"	111 -
BR12	1" 490, 6 " LG.	3/8"	.0179"	.0141"	127
BR13	1" 490, 5 3/4" LG.	1/2"	.0086"	.0126"	68
BR14	1" 490, 5 3/4" LG.	5/8"	.0160"	.0122"	131
BBR11	1" 490, 6 " LG.	1/2"	.0156"	.0141"	111
BBR12	1" 490, 6 " LG.	3/8"	.0151"	.0145"	104
BBR13	1" 490, 5 3/4" LG.	5/8"	.0153"	.0125"	122
BBR14	1" 490, 5 3/4" LG.	5/8"	.0028"	.0125"	22



TYPICAL CONNECTIONS
TESTED

FIGURE -1

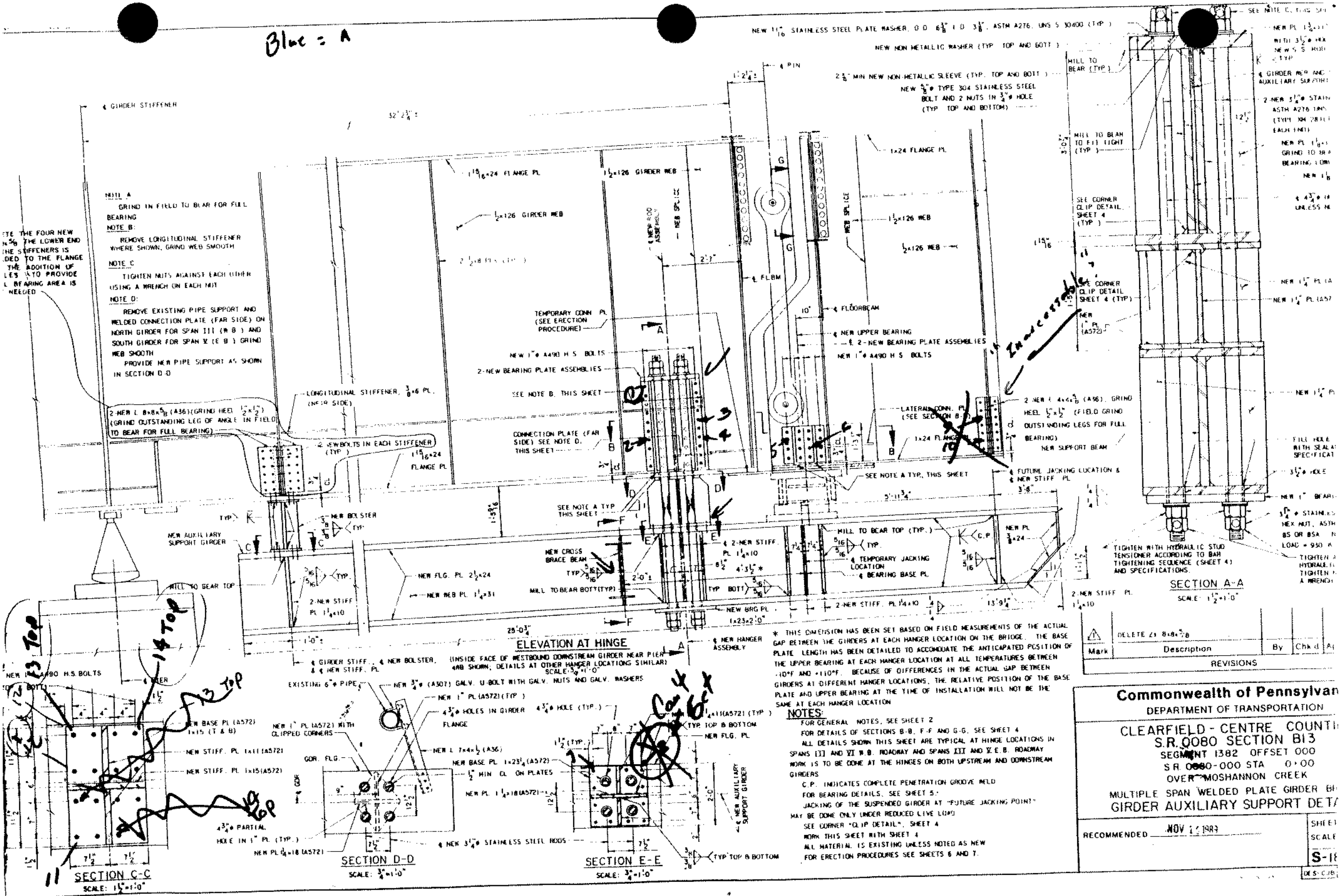
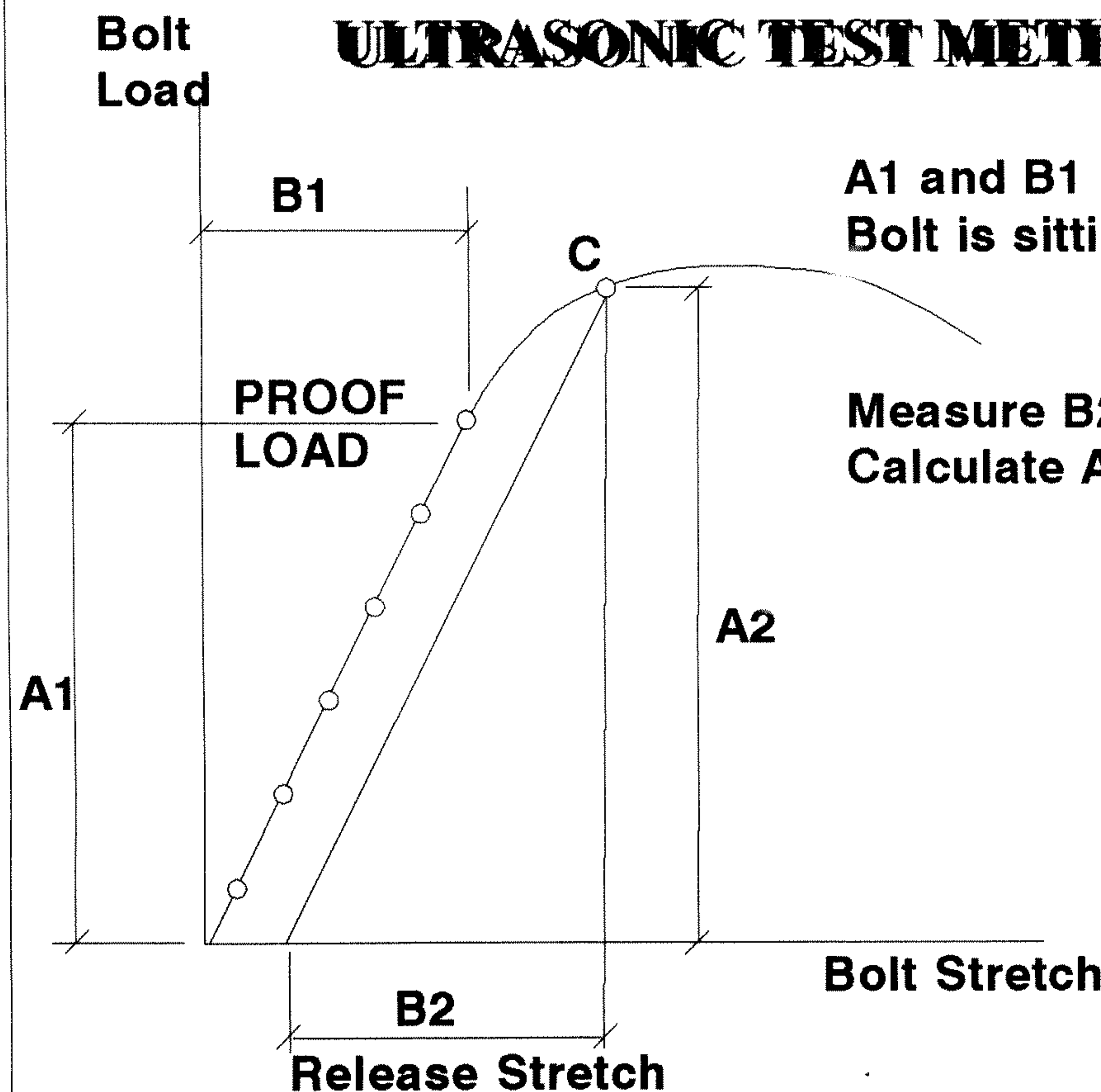

Blue = A
NOTE A
GRIND IN FIELD TO BEAR FOR FULL BEARING
NOTE B:
REMOVE LONGITUDINAL STIFFENER WHERE SHOWN, GRIND WEB SMOOTH
NOTE C
TIGHTEN NUTS AGAINST EACH OTHER USING A WRENCH ON EACH NUT
NOTE D:
REMOVE EXISTING PIPE SUPPORT AND WELDED CONNECTION PLATE (FAR SIDE) ON NORTH GIRDER FOR SPAN III (W.B.) AND SOUTH GIRDER FOR SPAN V (E.B.) GRIND WEB SMOOTH
PROVIDE NEW PIPE SUPPORT AS SHOWN IN SECTION D-D
ELEVATION AT HINGE
SECTION A-A
SECTION C-C
SECTION D-D
SECTION E-E
* THIS DIMENSION HAS BEEN SET BASED ON FIELD MEASUREMENTS OF THE ACTUAL GAP BETWEEN THE GIRDERS AT EACH HANGER LOCATION ON THE BRIDGE. THE BASE PLATE LENGTH HAS BEEN DETAILED TO ACCOMODATE THE ANTICAPATED POSITION OF THE UPPER BEARING AT EACH HANGER LOCATION AT ALL TEMPERATURES BETWEEN -10°F AND +110°F. BECAUSE OF DIFFERENCES IN THE ACTUAL GAP BETWEEN GIRDERS AT DIFFERENT HANGER LOCATIONS, THE RELATIVE POSITION OF THE BASE PLATE AND UPPER BEARING AT THE TIME OF INSTALLATION WILL NOT BE THE SAME AT EACH HANGER LOCATION
NOTES:
FOR GENERAL NOTES, SEE SHEET 2
FOR DETAILS OF SECTIONS B-B, F-F AND G-G, SEE SHEET 4
ALL DETAILS SHOWN THIS SHEET ARE TYPICAL AT HINGE LOCATIONS IN SPANS III AND VI W.B. ROADWAY AND SPANS III AND V E.B. ROADWAY
WORK IS TO BE DONE AT THE HINGES ON BOTH UPSTREAM AND DOWNSTREAM GIRDERS
C.P. INDICATES COMPLETE PENETRATION GROOVE WELD
FOR BEARING DETAILS, SEE SHEET 5
JACKING OF THE SUSPENDED GIRDER AT "FUTURE JACKING POINT" MAY BE DONE ONLY UNDER REDUCED LIVE LOAD
SEE CORNER "CLIP DETAIL", SHEET 4
WORK THIS SHEET WITH SHEET 4
ALL MATERIAL IS EXISTING UNLESS NOTED AS NEW
FOR ERECTION PROCEDURES SEE SHEETS 6 AND 7.
REVISIONS
Commonwealth of Pennsylvan
DEPARTMENT OF TRANSPORTATION
CLEARFIELD - CENTRE COUNTI
S.R. 0080 SECTION B13
SEGMENT 1382 OFFSET 000
S.R. 0080-000 STA 0+00
OVER MOSHANNON CREEK
MULTIPLE SPAN WELDED PLATE GIRDER B
GIRDER AUXILIARY SUPPORT DETA
RECOMMENDED NOV 1 1983

FIG. 2

ULTRASONIC TEST METHOD



A1 and B1 measured in Biach
Bolt is sitting at pt C in steel

Measure B2 using bolt gage
Calculate A2 = (B2/B1) x A1

FIGURE 3

BOLT TENSIONS
SITE 1 : USING DTI'S
AIRCRAFT ASSEMBLY BUILDING

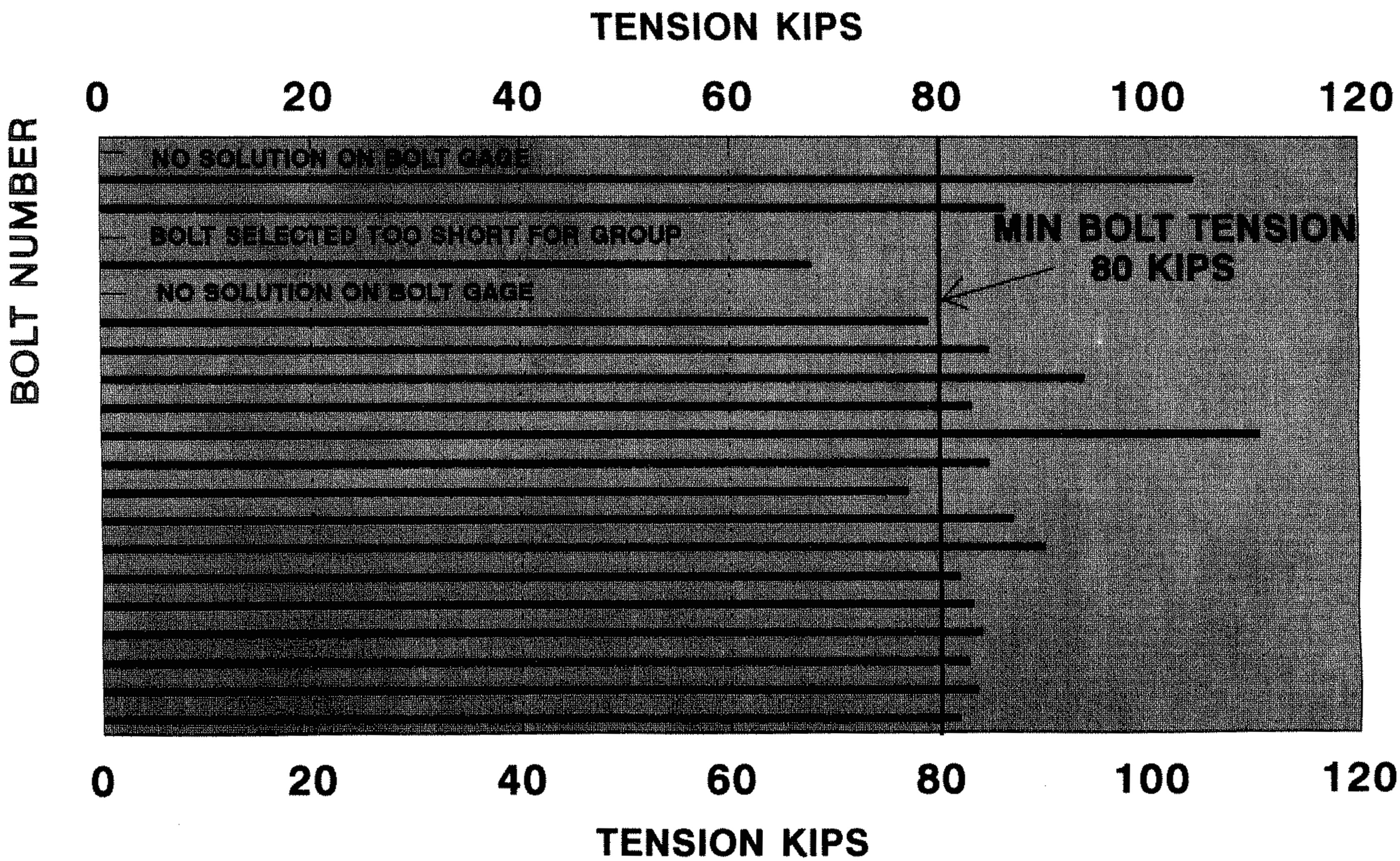
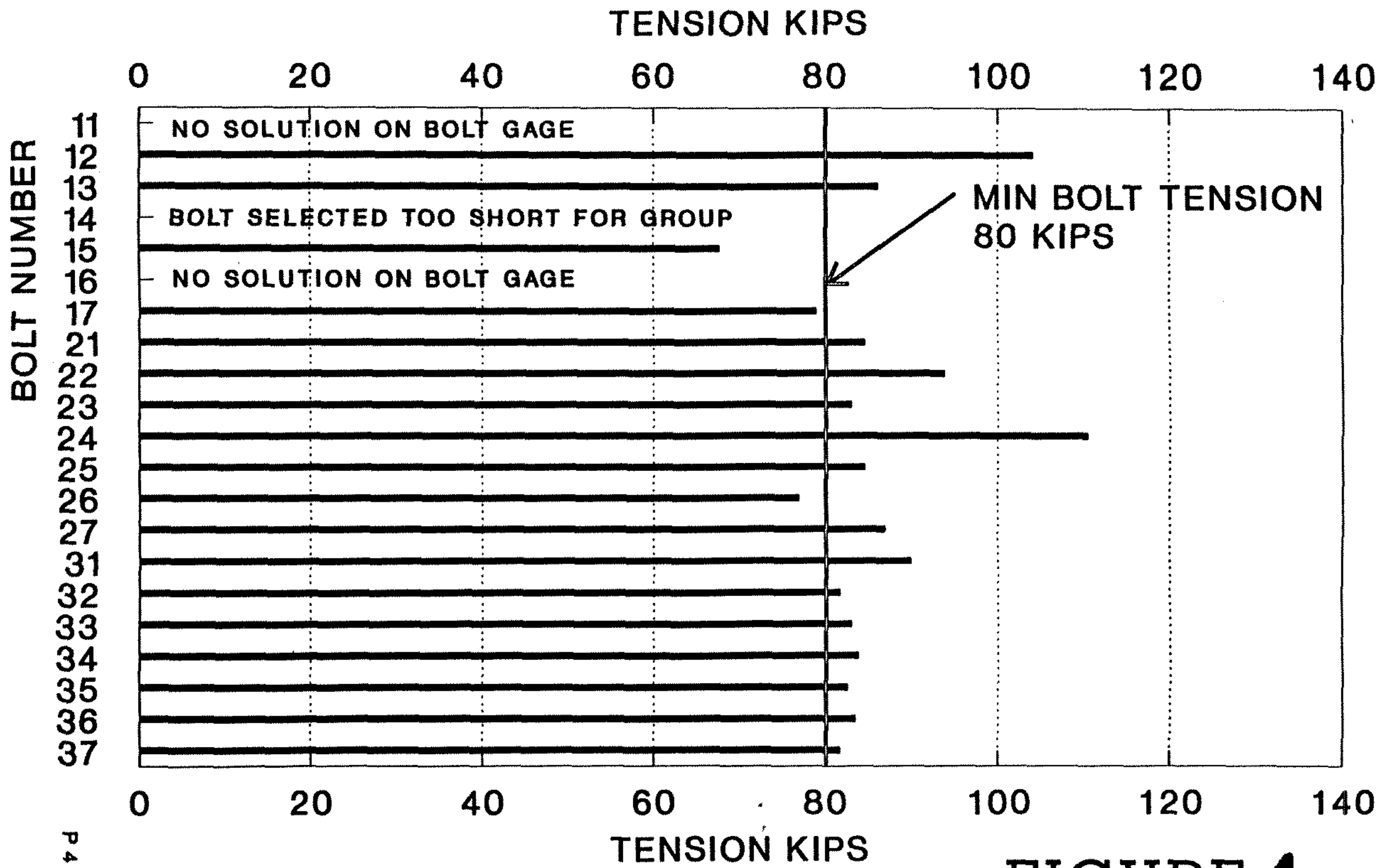


FIGURE 4

From Ultrasonic Measurements Jan 1992

BOLT TENSIONS
SITE 1 : USING DTI'S



From Ultrasonic Measurements Jan 1992

FIGURE 4

BOLT TENSIONS
SITE 1 : NO DTI'S

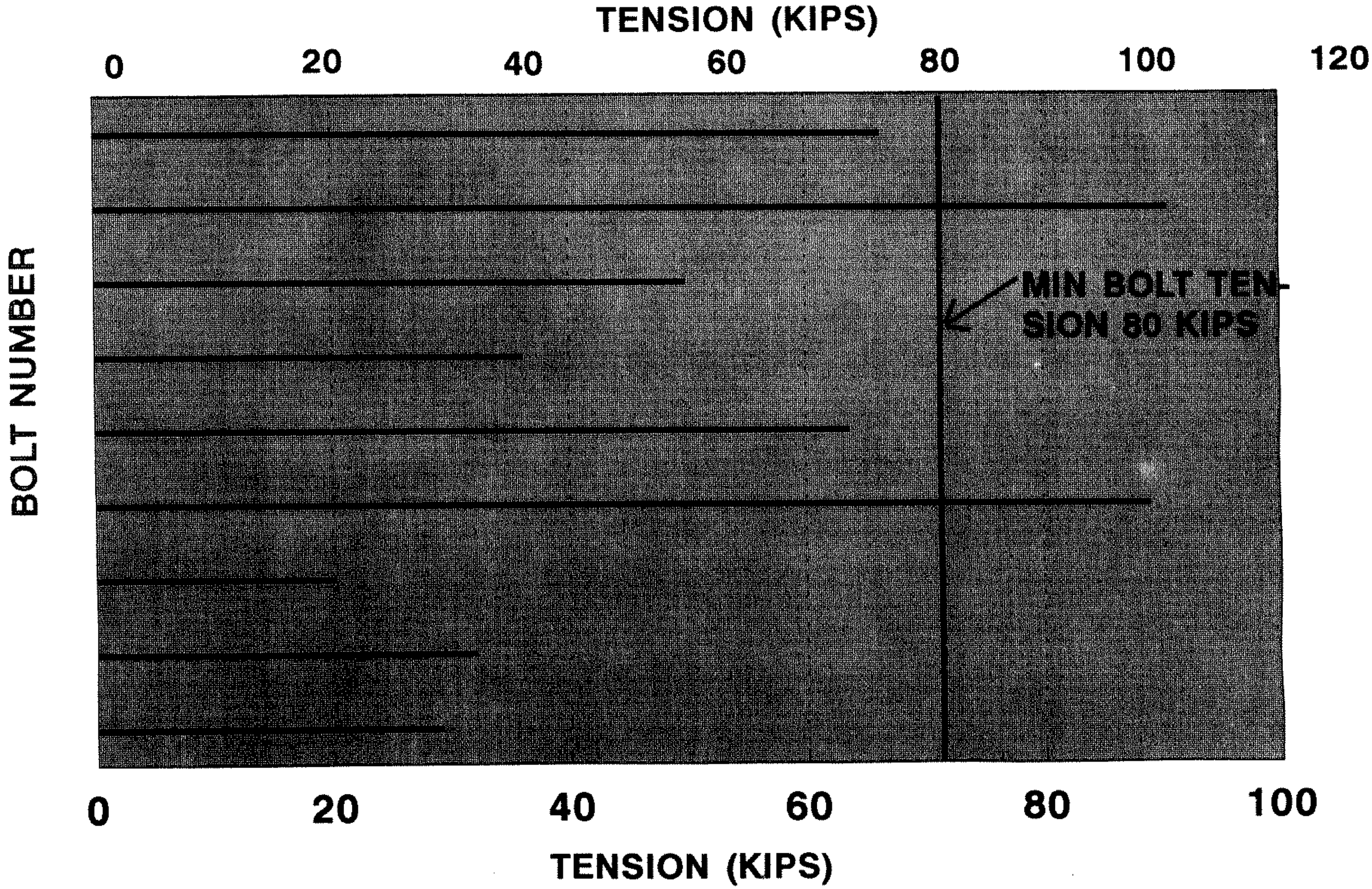
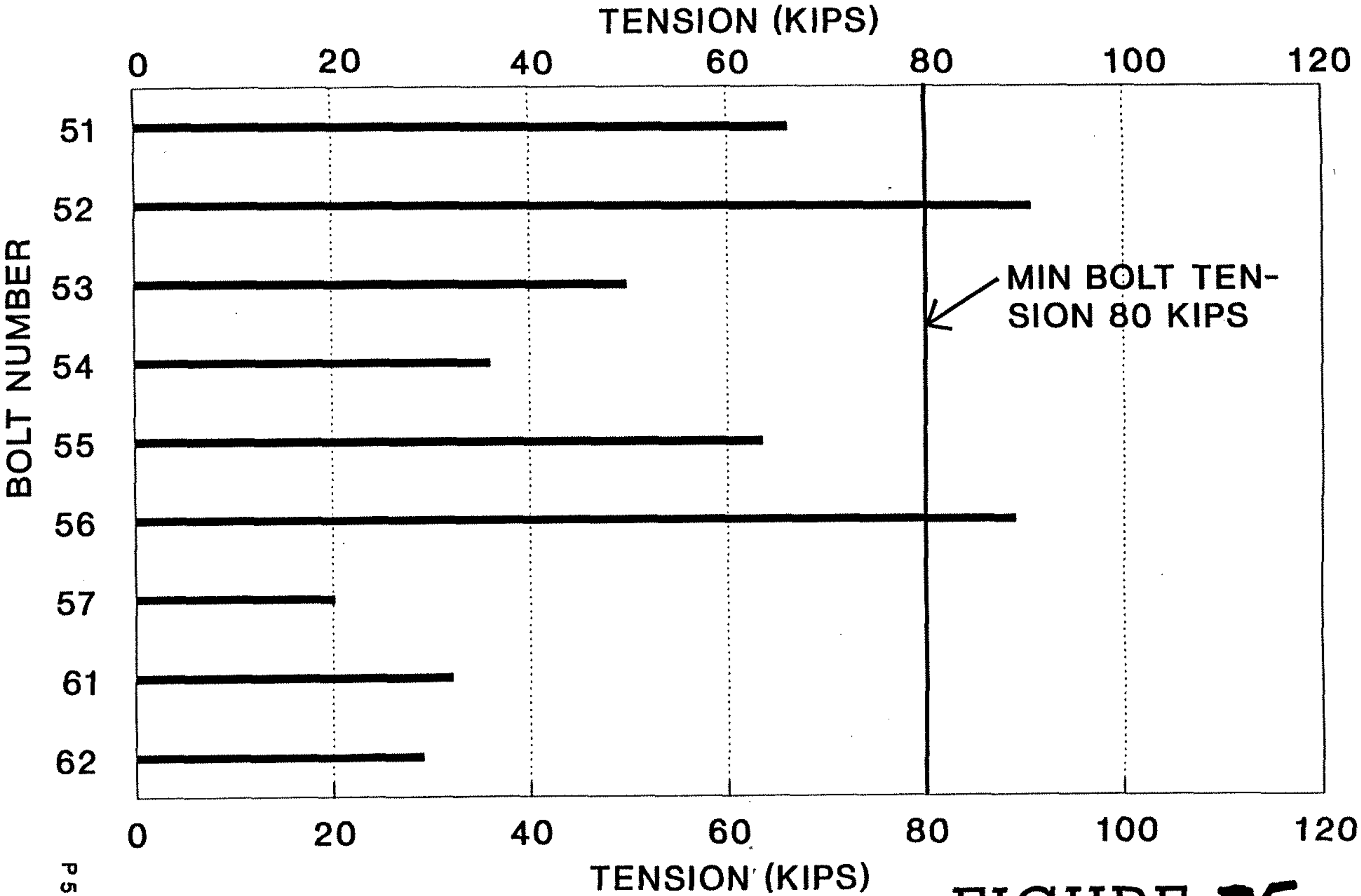


FIGURE 5

From Ultrasonic Measurements Jan 92

BOLT TENSIONS
SITE 1 : NO DTI'S

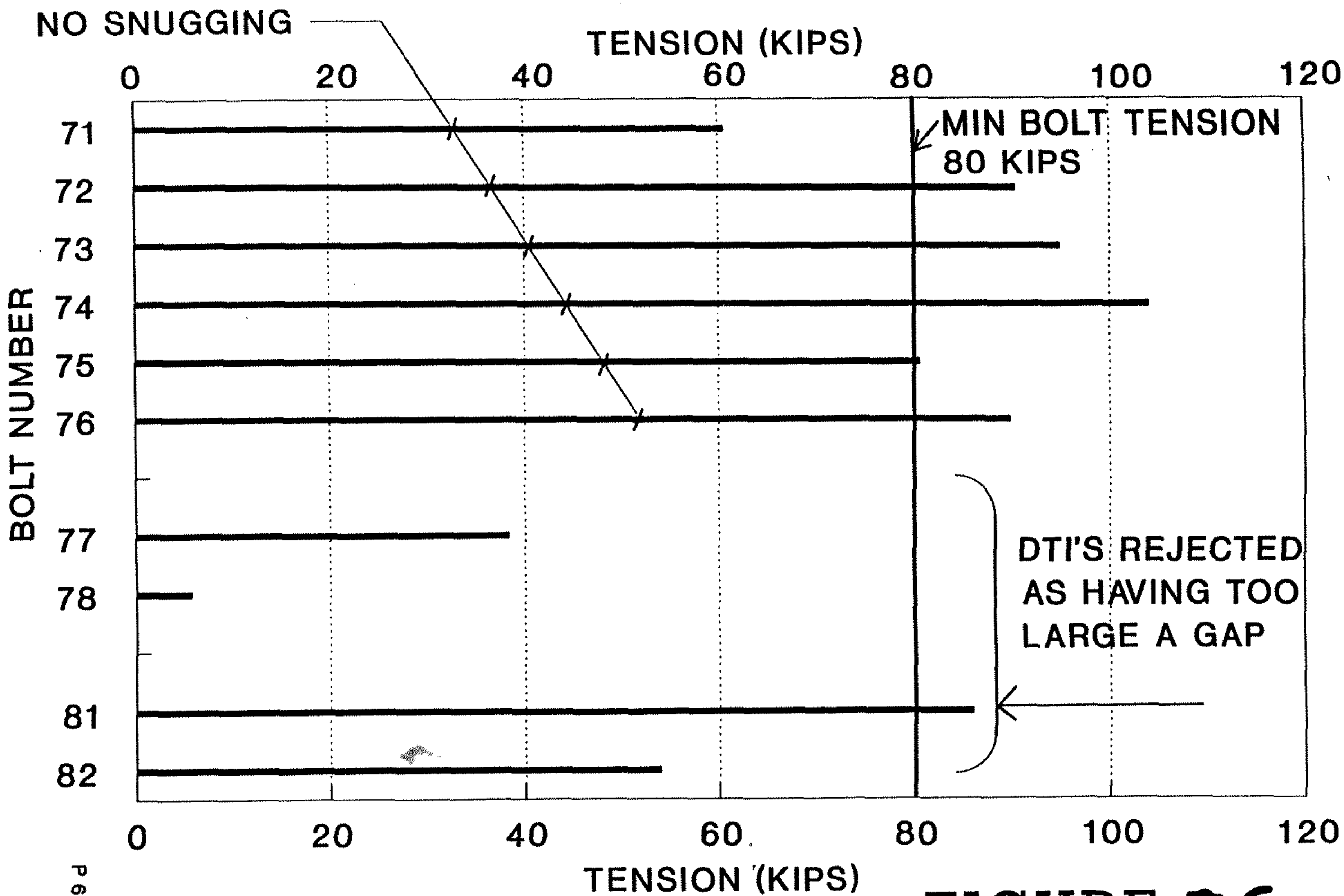


P 5

From Ultrasonic Measurements Jan 92

FIGURE [redacted]5

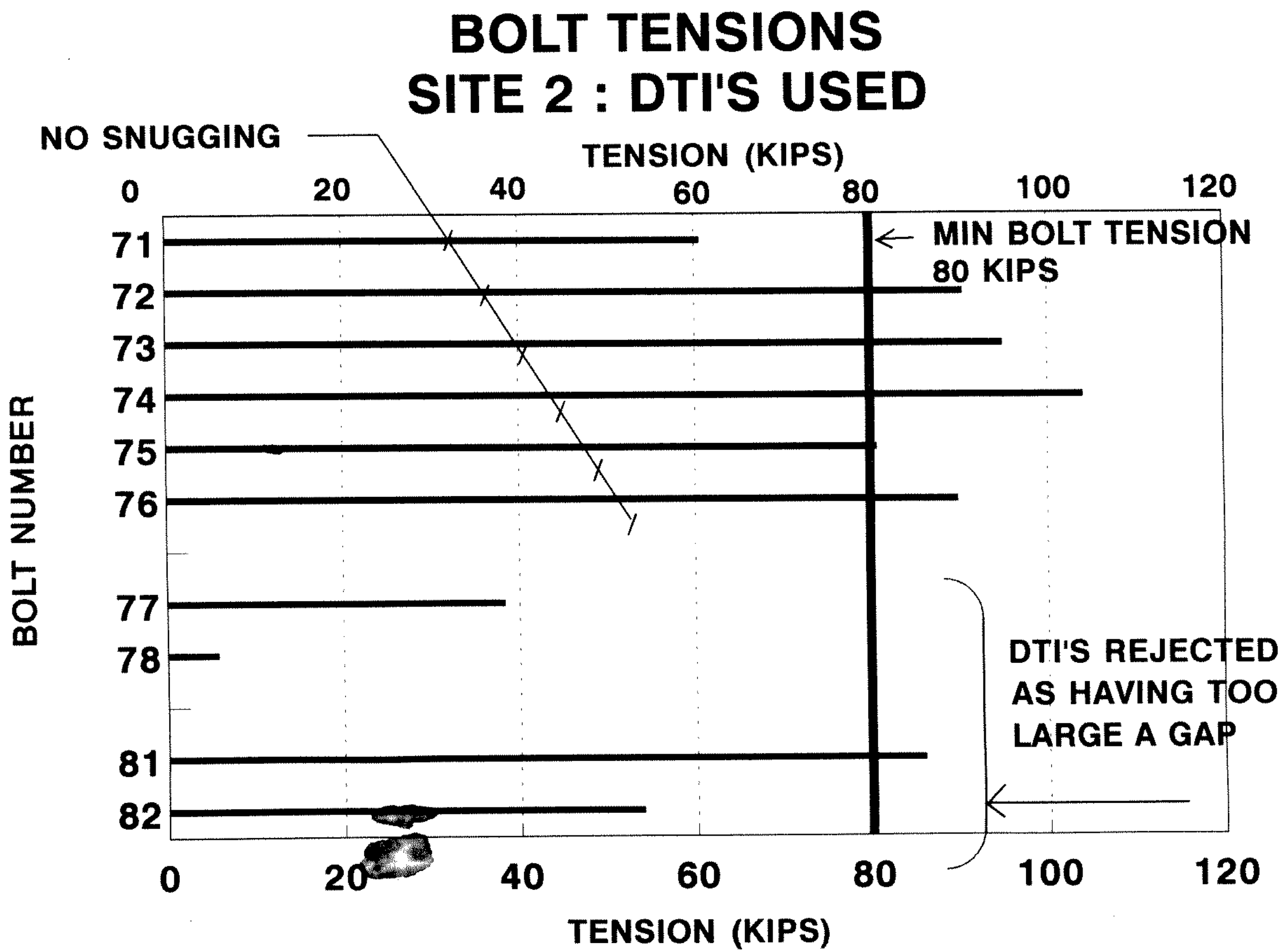
BOLT TENSIONS
SITE 2 : DTI'S USED



P6

From Ultrasonic Measurements Jan 92

FIGURE 6



From Ultrasonic Measurements Jan 92

FIGURE 6

I-80 MOSHANNON CREEK BRIDGE
1" A490 BOLT TENSIONS

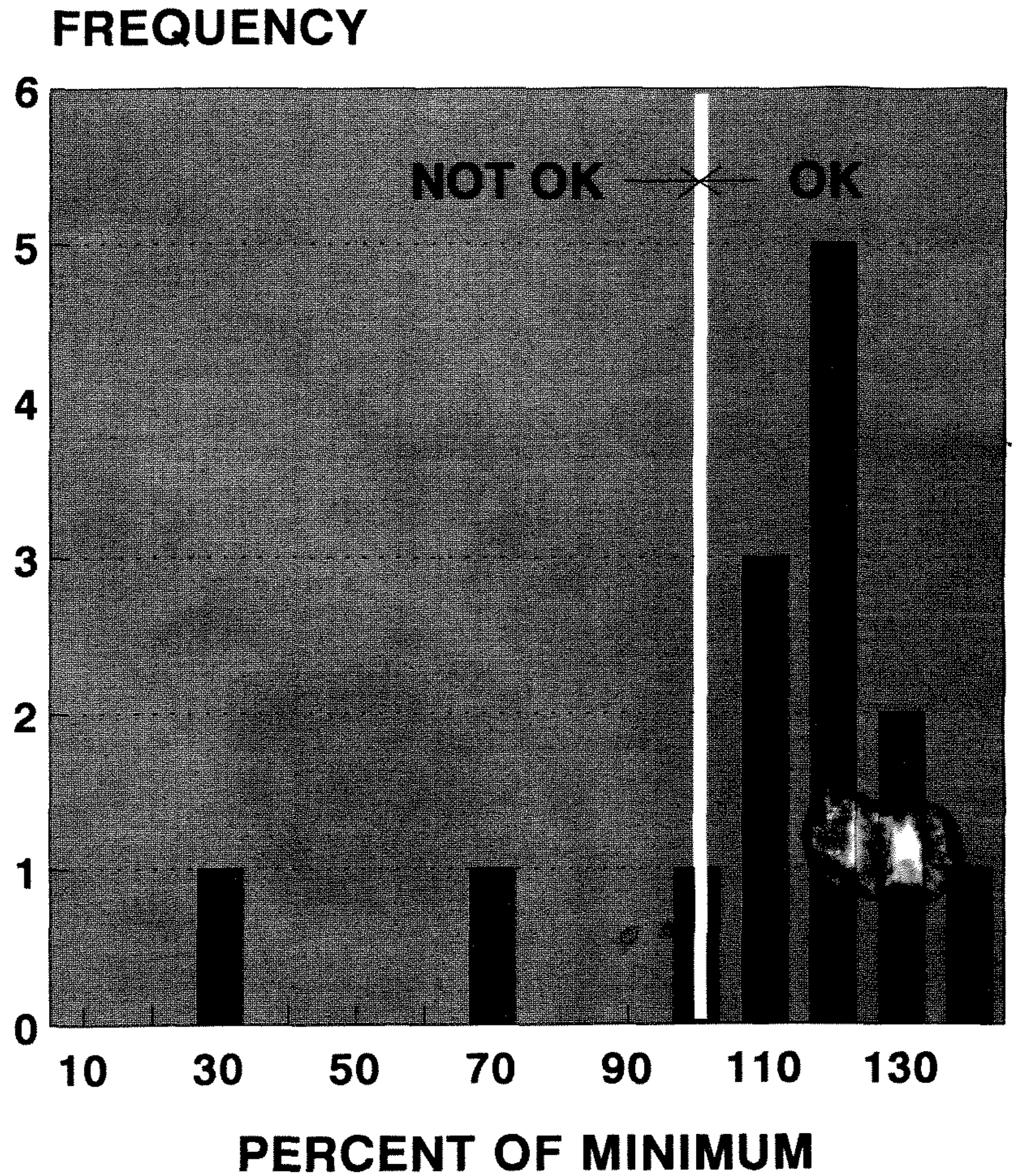


FIG. 7

FROM USONIC TESTS JUNE 1992