Instruction Manual for Installing Anchor Bolts, Anchor Rods, & Studs

with

DIRECT TENSION INDICATORS

(ASTM F2437)

INCH SERIES EDITION

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INTRODUCTION

Foundation bolts, anchor bolts, and anchor rods are well established as economical devices used to provide fixity between structural steel framing and foundation elements. Anchor rods are also used to on cantilever signal, sign, and light support structures.

When North American design and construction practices are followed, the *Specification for Structural Steel Buildings,* Approved by the American Institute of Steel Construction Committee on Specifications, sets the basic rules for their use. (AISC-360) For applications in bridges the AASHTO provisions of the *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals* apply.

Suitable anchorage provides safety during steel erection operations, provides resistance to design loads such as uplift, and provides resistance to nuisance fatigue cracks and fatigue failures.

The most common anchor rods and bolts used in modern practice are covered under ASTM F1554 *Standard Specification for Anchor Bolts, Steel, 36, 55, and 105-ksi Yield Strength.* ASTM F1554 includes provisions for three strength classes of anchoring material, two thread classes, and requirements for classification of anchors as 'weldable'. Anchors produced to this standard are available in nominal sizes from 1/4in up to 4in diameter. The most common specification for studs is ASTM A193 *Standard Specification for Alloy Steel and Stainless Steel Bolting for High Temperature or High Pressure Service.*

This manual is written for engineers, inspectors, and bolt installers to assist in installation of anchor bolts and anchor rods or studs using DTIs. This will ensure that anchors have been tensioned to the values required when used in pretensioned connections or connections subject to load reversal and fatigue. These instructions are also valid when DTIs are specified for use with anchors, bolts, and studs in other connections as a device to ensure that all anchors have actually been tensioned above a specified minimum tensions values, and when required, below specified maximum values.

INTRODUCTION (Continued)

TurnaSure LLC has years of anchor bolting experience and provides a range of consultation activity including seminars, site visits, tool recommendations, specification commentary and training programs. In addition TurnaSure LLC prepares instructional DVDs, published technical reports and articles for publication in trade journals. For additional information or to be placed on our mailing list, please contact us at the address shown on the inside cover or visit our website www.turnasure.com.

PRETENSIONING OF ANCHOR RODS/ANCHOR BOLTS

Designers are often confronted with applications where the performance of the structure will be compromised by excessive elongation of the anchor bolts/anchor rods under tensile loads, and pretension is required to mitigate these effects. Examples of applications in which pretensioned anchors may be required in include moment-resisting column bases with significant tensile forces in the anchors, structures that cantilever from concrete foundations, or where load reversal might result in progressive loosening of anchors.

Similarly, cantilevered signal, sign, and light supports are subject to truck-induced wind gusts, wind-induced vibration, vortex shedding vibration, harmonic 'galloping', and fatigue cracking. The most fatigue prone portions of these elements are the connections.

As reported in NCHRP Report 469 Fatigue-Resistant Design of Cantilevered Signal, Sign, and Light Supports, *"Whenever practical, anchor rods should be installed in the fully tightened condition. Although no benefit is recommended when designing fully tightened anchor rods for infinite life, it should be noted that the fully tightened condition precludes the possibility of anchor rod nuts becoming loose under service-load conditions. As a result, the fully tightened condition is inherently better with respect to the fatigue performance of the anchor rods."*

DIRECT TENSION INDICATORS (DTIs)

Direct Tension Indicators (DTIs) are simple and accurate devices for ensuring that anchors, bolts, and studs have been installed above the specified minimum tension values, and in the case of anchors, additionally ensuring that they have been installed to a preload less than a specified maximum tension.

Readers who have installed anchors, bolts, and studs using "torque/tension" values will notice that this manual does not relate torque to tension. Torque, or twisting force, is not a reliable measure of tension. DTIs measure tension regardless of applied torque.

A DTI is a steel, washer-shaped device with protrusions, "bumps," pressed out on one face, manufactured according to the provisions of ASTM F2437. The fact that it resembles a washer is incidental. It is, in fact, a precision made mechanical load cell, a device for tensioning which is covered by an ASTM Standard.

When a DTI is installed on an anchor rod, anchor bolt, or stud with the "bumps" placed against a hardened surface such as a hardened washer or the underside of a bolt head there are noticeable gaps between the "bumps." As the nut is turned and the anchor or stud tensioned, the "bumps" flatten. When the "bumps" are flattened so that the gaps have been reduced to a dimension less than that associated with the minimum specified tension, the anchor or stud has been properly tensioned and required clamping force is present.

The size of the residual gap following tightening also provides assurance that the anchor or stud is installed to a tension less than the maximum specified, when a maximum is specified. A DTI does not make it more difficult to tension an anchor or stud, it merely shows that the fasteners have been properly tensioned. (See Figure 1)

DIRECT TENSION INDICATORS (Continued)

Direct Tension Indicators are supplied either "plain finish," that is without a coating, mechanically galvanized to ASTM B695 Class 55, or with a corrosion-inhibiting 'black oxide' finish. Other coatings may be available upon inquiry.

Most often DTIs are installed against an ASTM F436 through-hardened washer. To assure that the DTI is properly installed, "load-gap" charts are available from TurnaSure to show the relationship between the residual gap and the load for a given lot of DTIs. Designers may thereby choose a specific tension for their application or simply have the DTIs installed and tightened to the minimum tension specified in ASTM F2437, which specifies acceptable tension at a designated gap of 0.010in.

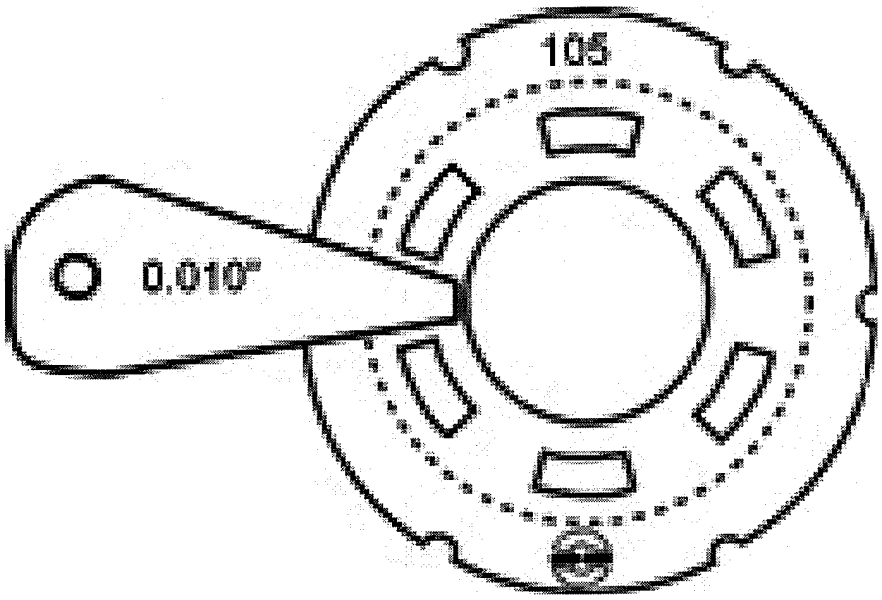

Figure 1

When inserted the feeler gage must be pointed at the center of the anchor bolt and be at the center of the space. "Notches" in the O.D. of the DTI assist in feeler gage inspection. See Figure 1.

DIRECT TENSION INDICATORS (Continued)

Depending upon the specific application and the applicable requirements for tension in the fasteners, DTIs may be used to verify that the tension in the anchor or stud is above a specified minimum, or when necessary, both above a specified minimum and below a specified maximum.

When the requirements are that fasteners be above a specified tension, refusal of the applicable feeler gauge in more than half of the spaces between the DTI protrusions or 'bumps' assures that the minimum tension has been exceeded.

When the requirements are that fasteners be both above a specified minimum tension and below a specified maximum tension, two feeler gauges of different thicknesses are used to verify that the tension is between acceptable limits. One feeler gauge is used as a 'no-go' gauge to ensure that the minimum tension is exceeded and a second thinner feeler gauge is used as a 'go' gauge to ensure that the maximum tension is not exceeded.

Selection of suitable 'go' and no-go' gauges, when required, may be determined by reviewing the optional "Load-Gap Curve" for the DTI production lot to be used. See Figure 2 below.

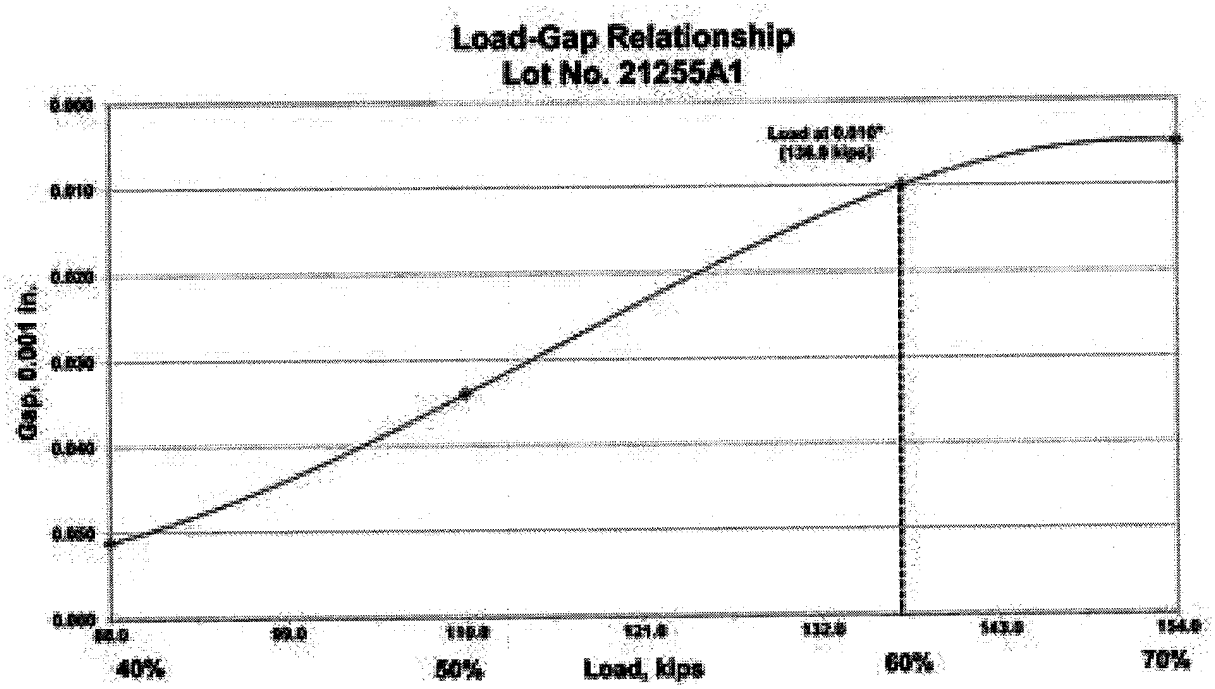

Figure 2

DIRECT TENSION INDICATORS (Continued)

The Load-Gap Curve for a given lot of DTIs allows the user and/or installer to choose a target tension for each application. In some cases the designer may wish to target a tension equal to 40% of the yield strength of the anchor or stud, and in other applications the designer may wish to target 60% of yield or some other value. ASTM F2437 requires that Grade 55 and Grade 105 DTIs be tested at a 0.010in gap and the mean compression load at the test gap corresponds with 60% of yield for the anchors or studs on which the DTIs are most frequently used. (See Table 1 below for ASTM F2437 test loads) Other target tensions and sizes are available upon request.

TABLE 1 Acceptable Range of Compression Load

DTI Nominal Diameter (in.)	Mean Compression Load Range in Pounds (lbs)	
	GRADE 55	GRADE 105
½	4450 to 4900	8500 to 9400
9/16	5700 to 6300	10 900 to 12 050
5/8	7050 to 7800	13 500 to 15 000
¾	10 500 to 11 600	20 000 to 22 150
7/8	14 500 to 16 000	27 650 to 30 550
1	19 000 to 21 000	36 250 to 40 100
1⅛	23 950 to 26 450	47 300 to 52 300
1¼	30 400 to 33 600	59 850 to 66 150
1⅜	38 550 to 42 600	73 800 to 81 600
1½	44 050 to 48 700	89 300 to 98 700
1⅝	55 800 to 61 700	106 200 to 117 400
1¾	59 550 to 65 850	124 600 to 137 750
1⅞	75 550 to 83 500	144 500 to 159 700
2	78 650 to 86 950	165 800 to 183 300
2¼	102 050 to 112 750	212 900 to 235 350
2½	125 400 to 138 600	240 550 to 265 850

REUSE OF DIRECT TENSION INDICATORS ON ANCHOR BOLTS, STUDS, & ANCHOR RODS

The reuse of DTIs is not recognized by TurnaSure as a viable and accurate means to assure that required clamp force has been generated in bolted connections. DTIs, like other fasteners, plastically deform during use. Thus, reuse of such fasteners cannot be assumed to be sound engineering practice.

DTIs which have been installed on tightened bolts can be verified for proper bolt load in a Compression Load Analyzer following removal of the bolting assembly from the connection. Any further flattening of the residual gap of a used DTI will require that a load equal to or greater than the previously installed load be induced. The above noted test is best left for cases of arbitration, should one arise.

ANCHOR AND STUD TENSIONING USING DTIs

DTI Placement within Assembly

ASSEMBLY
The specific configuration of a fastener assembly with a DTI can vary from application to application. The two fundamental requirements for proper DTI function are as follows:

(1) The DTI must be adequately supported under the side with the 'pockets'. This may be accomplished by placing the DTI over washers or plates with normal sized holes, that is, 1/16in larger than the anchor size. Adequate support of the DTI may also be accomplished by placing the bottom of the DTI against the heavy hex nut or, if applicable, a bolt head.
(2) The protrusions or 'bumps' on the DTI must be placed against a hardened surface such as against an F436 washer, against a hardened nut or a bolt head. (Figure 3 below depicts a common assembly configuration.)

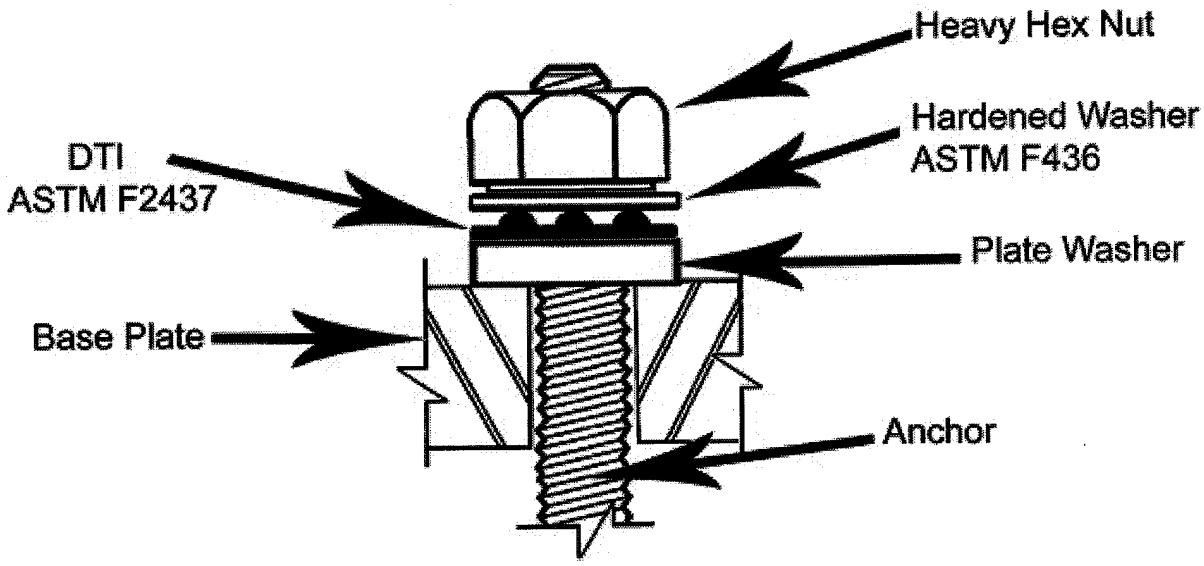

Figure 3

ANCHOR AND STUD TENSIONING USING DTIs (Continued)

Figure 3 depicts an optional plate washer (or extra thick flat washer) as would be used to cover an oversized hole in a base plate. If the hole in the base plate for the anchor is 'normal size' (i.e. 1/16in over the nominal size of the anchor) then such a washer is not necessary. Similarly, if the design calls for a hardened washer to be placed on the base plate under the DTI as shown in Figure 3, the inside diameter of the hardened washer should be 1/16in larger than the anchor size. TurnaSure LLC can help in the procurement of suitable hardened washers for use in anchor assemblies.

Figure 4 depicts a 'before' and 'after' installation in a typical stud application in which both minimum and maximum tension criteria apply. Note that most stud applications, and many anchor applications, require that tightening (regardless of method) be performed in a specific sequence and following patterns specified by the designer. See 'Sequence of Tightening' section below for guidance, but always defer to the sequence specified by the designer or controlling specification.

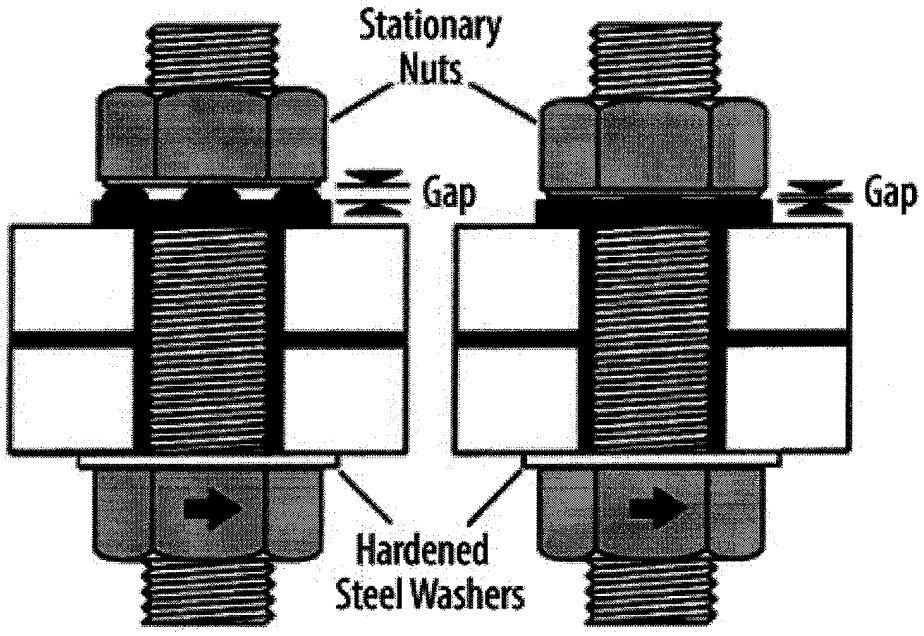

Figure 4

SEQUENCE OF TIGHTENING

It is recommended that tightening operations be undertaken in a sequential manner and that tensioning of anchors or studs be performed in at least two, and preferably three or more steps as necessary.

The first step in tightening should be installation of the fasteners and all components of the connection such that they are assembled and drawn together into firm contact. In applications involving leveling nuts, shims, or similar fixing devices, firm contact should be verified following leveling and fixing operations.

The 2nd and subsequent steps in tightening involve incremental increases in anchor or stud tension based upon application of increasingly higher torque and subsequent confirmation via DTI residual gaps that uniform loading of the anchors or studs is being achieved. **Uniform loading should never be presumed to be the result of the same torque being applied to each anchor or stud**. Uniform loading is evidenced by comparable flattening of the DTI protrusions.

In applications with circular anchor or stud patterns, tightening should progress in a 'star pattern' similar to that depicted in Figure 5 below.

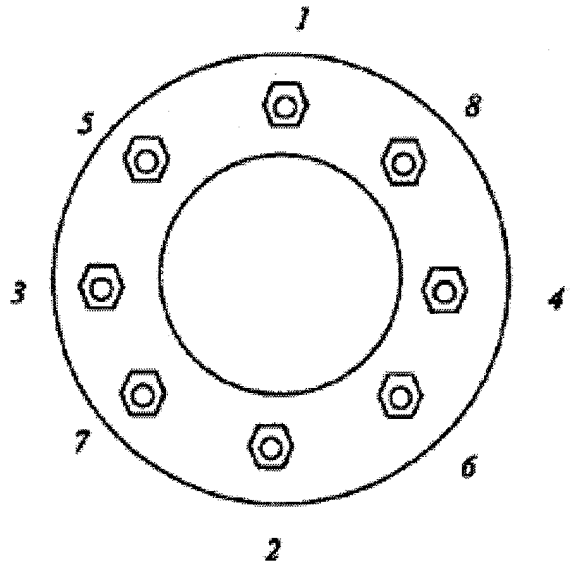

Figure 5

SEQUENCE OF TIGHTENING (Continued)

Tightening is completed when all of the DTIs have been sufficiently flattened below the specified gap to ensure that minimum required tension has been achieved, and if required, that maximum tension has not been exceeded. A typical anchor rod application is depicted below in Figure 6. Similar configurations may be used to fasten vibratory equipment or framing subject to uplift forces.

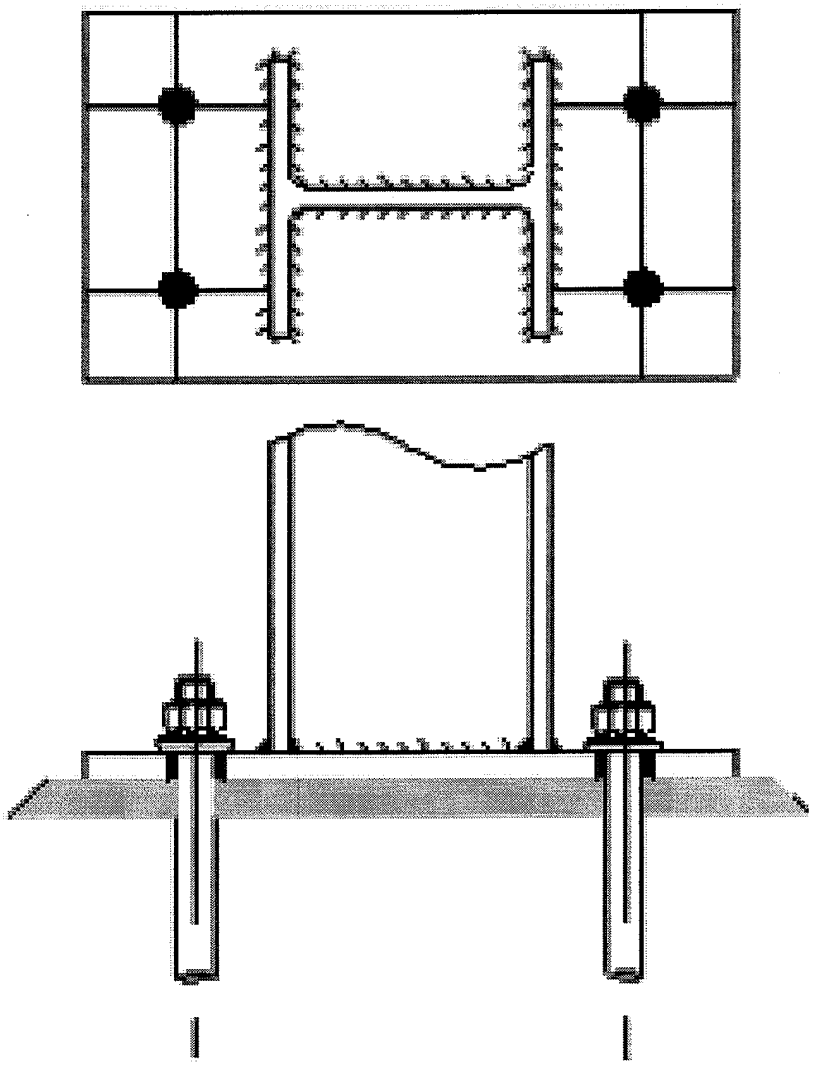

Figure 6

Note: TurnaSure 'curved protrusion' DTIs (Figure 7) do not necessarily benefit from hardened washers placed between the hardened nut and the DTI. DTIs with the older design "straight-sided" protrusions as depicted in Figures 8 and 9 below would still require a hardened (ASTM F436) washer between the turned element and the DTI.

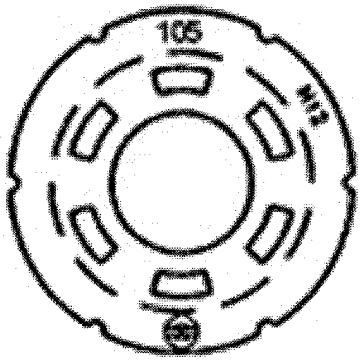

Figure 7

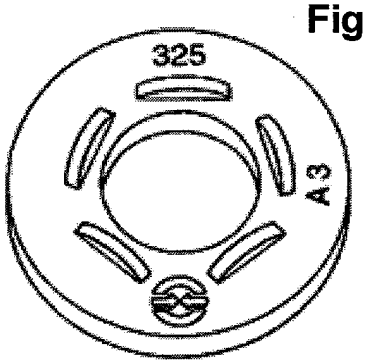

Figure 8

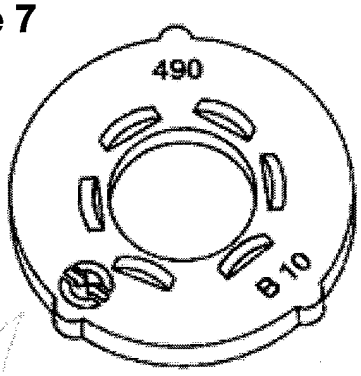

Figure 9

PROBLEMS COMMONLY ENCOUNTERED WHEN TENSIONING BOLTS

Dry or Rusty Fastener Threads or Nut Faces –Usually caused by poor storage conditions or passage of time between installation of anchors or studs bolts and start-up of final tensioning. Dry or rusty anchors, studs, bolts, nuts, or washers should not be permitted. Ideally all fasteners (and DTIs) should be kept in dry storage and their containers not opened until immediately before use. Rust significantly increases the amount of torque required to tension an anchor or stud. Ideally nuts should be wax dipped before use, particularly on large diameters or when Grade 105 tensions are targeted. Lubricant on the face of the nut is very desirable. If it is necessary to lubricate anchors or studs at the site at the time of installation Castrol Industrial STICK WAX Lubricant is recommended. It is available from many sources including TurnaSure LLC. **The necessity of adequate lubricant to achieve the desired level of pretension cannot be over-emphasized.**

Damaged Threads –Usually caused by inadequate protection of projecting anchors in foundation details.

Anchors Too Short –The anchors were set at the wrong elevation and there is not adequate projection to accommodate necessary connection components and also ensure full thread engagement with the nut. (The nut must be on far enough to have full thread engagement with the first fully-formed thread.)

Recommended Nuts –Nuts that are not through-hardened are susceptible to galling or stripping. Heavy Hex nuts manufactured to ASTM A563 DH are recommended when anchors and studs are to be tensioned.

Omission of Hardened Washers under the Turned Element – Although not always required, the use of hardened washers under the turned element significantly reduces the torque required to tension an anchor or stud and is recommended by TurnaSure LLC whether DTIs are used or not.

PROBLEMS COMMONLY ENCOUNTERED WHEN TIGHTENING BOLTS (Continued)

Oversized Holes and/or Oversized Washer IDs– An ASTM F436 hardened washer or suitable plate washer should be used to cover slotted or oversized holes. F436 washers in larger diameters may themselves have hole sizes larger than a standard hole. DTIs must be supported upon a surface with a normal size hole (nominal size +1/16in). TurnaSure can assist in the procurement of suitable hardened washers at customer's request.

TOOL SELECTION AND PERFORMANCE

Air driven impact wrenches as would be used for installing high-strength structural bolts are generally unsuitable for tightening anchors and studs. Hydraulic or electric wrenches of suitable capacity will likely be necessary. Manual wrenches with sufficient strength sockets and significant arm lengths (>6ft) have been used.

For recommendations on suitable wrenches, TurnaSure LLC recommends products provided and serviced by:

GWY Inc. http://gwyinc.com/

FASTORQ http://www.fastorq.com/

HYTORC http://www.hytorc.com/en

DTI IDENTIFICATION MARKINGS

TRADEMARK

The trademark of TurnaSure LLC is shown on the cover of this booklet. DTIs marked with it have been manufactured by TurnaSure LLC.

GRADE AND SIZE

Each DTI is marked with a series of numbers. "105" signifies the DTI is Grade 105 per ASTM F2437, for example. The nominal size may also be marked on DTIs to aide identification.

LOT NUMBER

For purposes of traceability DTIs are also be marked with a lot number.