



**1. Scope**

This Technical Information Note deals with the use of high tensile fasteners on tower cranes and their supporting structures.

**2. Introduction**

High tensile fasteners are used to connect tower crane components to each other and to supporting structures such as bases and ties. The correct specification, installation and maintenance of high tensile fasteners will minimise the risk of failure and potential collapse of the tower crane.

The failure of any high tensile fasteners should be investigated to establish the cause of failure before replacing and returning the crane to service. Temporary replacement of failed fasteners may be required to secure the crane structure whilst investigations are carried out.

**3. Specification**

Replacement high tensile bolts, nuts and washers for tower crane components should be sourced from the tower crane manufacturer or from a quality assured supplier to the original manufacturer's specification. High tensile fasteners for connecting tower cranes to supporting structures should be specified by the supporting structure designer together with the preferred method of tightening and the preload or torque value.

It is important that all high tensile fasteners are of the correct strength grade and have rolled threads, rather than machined threads. Washers should be through hardened to ensure that they do not permanently deform under load and reduce bolt pre-load.

*NOTE: Large diameter fasteners, particularly those manufactured in small batches may only be available with machined threads.*

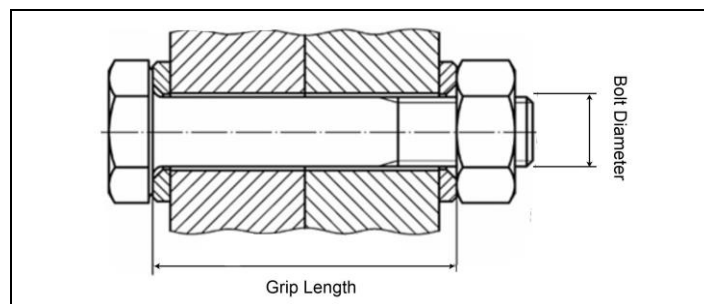
**Fasteners should not be replaced with higher grade fasteners without the approval of the crane manufacturer or supporting structure designer. Use of higher grade fasteners without approval may lead to unforeseen issues.**

Care should also be taken to guard against hydrogen embrittlement (see **Annex 1**).

**4. Design considerations**

Where high tensile fasteners, such as bolts and Macalloy bars, are subjected to cyclic loading it is essential that they are pre-tensioned to specified design stresses. They should also have a sufficiently high ratio of bolt grip length to diameter (> 5) to ensure that bedding in of the joint will not result in significant loss of pre-load. (see **Figure 1**)

During the design process consideration should be given to specifying larger diameter bolts of a lower grade to reduce the likelihood of issues with hydrogen embrittlement. The use of tension indicating devices should also be considered.





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**5. Standards for Bolts/Bolting Assemblies**

Preloaded and non-preloaded bolting assemblies for thread sizes M12-M36 are covered by harmonised standards BS EN 14399-1 and BS EN 15048-1 respectively and should be supplied complete with CE marking. Engineering bolts/studs like those used for connecting tower crane masts with larger thread sizes will not be covered by these harmonised standards but the mechanical properties and chemical composition for all thread sizes should be in accordance with BS EN ISO 898-1 for bolts. Accompanying nuts should be to BS EN ISO 898-2 and as shown in **Table 1**.

<b>Head Marking</b>	<b>Bolt Grade and Material</b>	<b>Bolt Mechanical Properties</b>		<b>Corresponding Minimum Nut Grade</b>	<b>Min. Proof stress (MPa)</b>
		<b>Min. Proof stress (MPa)</b>	<b>Min. Tensile Strength (MPa)</b>		
	Grade 8.8 Medium carbon steel, quenched and tempered	600	830	Grade 8	800
	Grade 10.9 Alloy steel, quenched and tempered	830	1040	Grade 10	1000
	Grade 12.9 Alloy steel, quenched and tempered	970	1220	Grade 12	1200

**Table 1 - Bolt and Nut Grades and Properties**

**6. Installation**

High tensile bolt connections should be assembled in accordance with the crane manufacturer's or supporting structure designer's instructions. Particular attention should be paid to ensure that:

- Components are fitted in the correct sequence, location, and orientation;
- There are 2 to 3 full threads extending beyond the nut;
- Components are lubricated before installation, as specified by the crane manufacturer or supporting structure designer; **NOTE:** Correct lubrication is essential if the required pre-load is to be achieved.
- Bolted connections are tightened in accordance with the method and sequence specified by the manufacturer or supporting structure designer. Where applicable the instructions should advise how a crane should be loaded when the joint is tightened. For example when replacing slew ring bolts, this may require the crane to be placed in balance with a load on the hook or the jib slewed to a certain position. Failure to follow the manufacturer's instructions could result in the bolted connection being incorrectly pre-loaded, with very short service life before failure;
- The tightening torque is applied to the nut rather than the bolt head, unless the manufacturer or supporting structure designer specifies otherwise. Tightening a bolt at the head can give rise to variability in bolt pre-loading due to variable friction between the bolt head and bearing surface and/or contact of the bolt shank with the hole;
- It is good practice to mark the nut and structure to give a visual indication of that the bolt has been torqued (see **Figure 2**);
- On completion, the components are protected against corrosion and plastic caps, if specified by the manufacturer or supporting structure designer, fitted over threads and nuts to exclude water from the threads.



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Any equipment used to tighten high tensile bolt connections (e.g. torque wrench or hydraulic tensioning device) should be maintained and calibrated in accordance with the manufacturer's instructions and stored in a secure location when not in use. Where the accuracy of the device relies on springs, the adjuster should be set to the lowest setting to avoid damage to springs during storage. The equipment should be marked with a unique identification mark and a copy of the current calibration certificate for the device should be held on file.

**NOTE:** *If torque or tensioning equipment is damaged, overloaded or there is any doubt about its accuracy, it should be re-calibrated before re-use.*

It is essential that fasteners are not over stressed during crane erection and commissioning as this may lead to stretching and loosening. This may be the result of issues such as:

- Use of incorrect components;
- Assembly of components in the incorrect correct order;
- Incorrect counterweight mass and position;
- Overloading during limit calibration.

**7. Maintenance**

**a. *Post Installation re-tensioning of bolt connections***

Following installation all high tensile bolt connections should be re-tensioned within the period specified by the crane manufacturer or support structure designer. This period is typically 3 to 6 weeks following installation. Re-tensioning is required because following installation and entering into service, high tensile connections may bed in and the pre-load in the bolt reduce.

**NOTE:** *Movement between the nut and structure mark shown in **Figure 2** should not be relied upon as an accurate indication of pre-load.*

**b. *Regular inspection and examination of bolt connections***

High tensile connections should be regularly inspected by a competent person to check that pre-load on the bolts has not been reduced. Loss of pre-load can result in movement of the joint under load and reduce the bolt's fatigue life. The frequency of inspection should be in accordance with the manufacturer's instructions. During this inspection, particular attention should be paid to checking that:

- There is no visual movement at joints as a load is taken off and on the crane;
- There are no rust stains, indicating movement at the joint; and
- Nuts have not worked loose or bolts have stretched.

A competent person should undertake an investigation if a high tensile joint is found to have come loose in service or bolts and/or nuts are stretched or broken. The investigation should:

- Examine the joint faces to check that they are flat, free of distortion, corrosion, damage and wear;
- Check that the components had been correctly assembled in accordance with the manufacturer's instructions; and
- Confirm whether the person who first assembled the joint tightened the connection in the correct sequence and to the correct pre-load or torque.

Bolts should only be retightened or replaced once the cause of loosening or failure has been established.

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***Regular inspection and examination of bolt connections (continued)***

Supplementary tests should be undertaken if, during inspection or thorough examination of the crane, the competent person completing the examination has any concerns regarding the integrity of the high tensile joint connections. The supplementary tests may include:

- Physical checks that the bolts are to the correct preload or torque;  
*NOTE: Use of the hammer or ping test where the nut is struck with a small hammer will not give an indication of preload. It will only indicate that a bolt is loose and has lost all preload.*
- Disassembly of the joint to allow the connection components and joint faces to be more closely examined; and
- Non-destructive testing (NDT) of all or a sample number of the components. NDT should be specifically requested where bolts have been subject to continuous or intermittent immersion in water on crane foundations or used on travelling rails.

The competent person may also decide that the frequency of thorough examinations should be increased until the crane is dismantled, at which time all high tensile bolt components should be examined in detail and any suspect components disposed of so that they cannot re-enter service.

***c. Taking crane out of service when bolt connection problems occur***

The crane should be taken out of service if there are concerns regarding the integrity of the high tensile bolt connections, such as where it is suspected that a high tensile connection may have come loose or the pre-load may have been lost. If high tensile bolt connections are insufficiently pre-loaded, or the pre-loading is partially or fully lost the bolted connection can be subjected to considerably higher levels of cyclic strain (extension and relaxation) with a significant risk that the connection will fail with catastrophic consequences, as a result of fatigue.



**Figure 2 – Marking on Initial Installation**

***NOTE: Movement between the nut and structure mark should not be relied upon as an accurate indication of pre-load.***



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### The Use of High Tensile Fasteners on Tower Cranes

#### Annex 1 - Hydrogen Embrittlement in High Tensile Fasteners

##### 1. Introduction

Over the years there have been a number of tower crane high tensile fastener failures caused by a phenomenon called Hydrogen Embrittlement (HE). These are particularly problematic in that fasteners affected by HE may fail without warning, sometimes shortly after installation.

As some of the factors influencing the probability of HE occurring involve manufacturing quality it may be an issue with non-standard sized fasteners produced in small batches for connecting tower cranes to supporting structures, rather than the standard high tensile fasteners supplied by the tower crane manufacturer.

The process of HE is not fully understood and the following recommendations should be used as guidance rather than a definitive set of requirements.

##### 2. What is Hydrogen Embrittlement?

HE is a process in which the ductility and toughness of the steel are degraded due to the diffusion of hydrogen atoms into the metal. Several metals are affected by HE but this TIN applies only to carbon and low alloy steels which are used in fasteners. A small amount of hydrogen (a few mg per kg of steel) is sufficient to embrittle the steel. The hydrogen atoms responsible for the embrittlement can originate from several sources including primary steel manufacture, incorrect heat treatment (quenching and tempering) during fastener manufacturing, electroplating, welding, cathodic protection and corrosion.

There are two forms of HE affecting high tensile fasteners:

- **Internal Hydrogen Embrittlement (IHE)**

IHE can occur when atomic hydrogen is absorbed into the fastener before exposure to an externally applied stress, for example, as a result of improper heat treatment. When tension is applied to the fastener, the hydrogen tends to migrate to points of high stress concentration (under the head/first engaged thread). The pressure created by the hydrogen produces and/or extends a pre-existing crack which grows under subsequent stress cycles until the bolt breaks. This can happen quite quickly and within a few days after tensioning the bolts.

- **Environmental Hydrogen Embrittlement (EHE)**

EHE is generally caused by hydrogen introduced into the steel from the environment after being placed in service. In this case, the hydrogen can come from the by-products of general corrosion and stress corrosion represents a particular condition where cracks are induced and propagated under the combined effects of stress and corrosion environments.

The consequence of both types of HE is the risk of brittle failure of what is otherwise ductile steel. The failure occurs when embrittled steel containing more than a critical quantity of hydrogen is loaded in tension (as in most bolted connections) and the resulting energy released can propel the bolt heads several metres. In some cases a metal component can fracture almost instantaneously under a static stress much less than the yield strength of the steel as with IHE and in some cases this can happen long after the stress has been applied as with EHE, which is sometimes referred to as hydrogen induced delayed cracking.





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General View



Close-up of Fracture Surface

**Figure A.1 - Fracture due to Internal Hydrogen Embrittlement (Grade 10.9 Bolt)**

**3. Main Factors that Influence HE**

A number of factors influence HE but those most relevant here are tensile strength, hardness and corrosion.

**a. Tensile strength and hardness**

The sensitivity of steel to HE depends largely on its tensile strength, the susceptibility to HE increasing as strength increases. As hardness is broadly related to tensile strength, hardness is often used as a guide to assess the steel's susceptibility to HE. Also, higher than expected hardness can be a result of improper heat treatment during fastener manufacturing and it is imperative that reliable and representative test results complying with the relevant standards are provided prior to installation of the fasteners. It is also important that the hardness of the bolt's surface and core does not vary by more than the values specified in BS EN ISO 898-1 Table 3.

**b. Corrosion**

Corrosion is a primary source of hydrogen for HE of fasteners. Inappropriate protective coating type/thickness, damage to the corrosion protection or any areas where water can pond or be trapped creating local spots with prolonged periods of wetness/submersion will lead to atmospheric corrosion, hydrogen generation and therefore a greater risk of HE. In addition, where dirt accumulates, this would be expected to restrict oxygen access potentially increasing the risk of hydrogen generation and consequently HE.

To reduce the risk of HE, bolts of Grade 10.9 and above should not be coated with an electroplated finish. Where fasteners are to be installed for a long period of time the advice of the crane manufacturer or supporting structure designer should be sought.

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**4. Recommendations to Reduce the Probability of Failure Due to Hydrogen Embrittlement**

The likelihood of in service failure by HE whether caused by the manufacturing process or environmental conditions of high tensile fasteners which meet the product standards and have adequate corrosion protection is considered low but the consequences of failure could be catastrophic. Fasteners that suffer corrosion will be susceptible to HE. The following guidance should be used for reducing the risk of HE with high tensile fasteners:

- Where high tensile fasteners of Grade 10.9 and above are specified, the specification should be vetted and the designer of the connections challenged to ascertain if lower grade fasteners could be used. In most cases, this may not be viable but should be checked and the use of lower grade fasteners instigated wherever possible.
- The detail around the fastener connections should be checked and if possible modified to avoid any areas where excessive water or dirt could accumulate, causing locally persistently wet conditions which will accelerate the corrosion process.
- The corrosion protection system applied to the fasteners should be appropriate for the exposure environment and service life.
- Where high tensile studs used for connecting tower crane masts to the supporting structure show evidence of corrosion of steel on the shanks or threads they should be removed from service. Studs should also be replaced after the maximum number of uses stated in the crane manufacturer’s recommendations.
- As an additional precaution to check for IHE, preload/tension a few test bolts in a protected steel connection for 7 days. This should be done prior to the intended installation to prove if any damaging atomic hydrogen had been absorbed into the bolts during manufacture where a brittle type of fracture would be expected to occur within 7 days of tensioning.
- High tensile fasteners of Grade 10.9 and above are usually provided with a type 3.1 Inspection Certificate from the supplier/manufacturer to BS EN 10204 confirming compliance with the purchase order including test results and mill certificates. Some users have experienced instances where such certification showed conformity with subsequent independent testing resulting in non-conformance. Therefore, in addition to the normal test records provided by the supplier, an independent comparative testing regime is recommended to validate the properties of fasteners of Grade 10.9 and above, before they are installed. Site teams should make allowance for this testing in their programmes and note that additional bolts/studs will need to be purchased to enable this. All bolts should be stamped with identification marking to allow full traceability back to cast codes and raw materials used. Testing should be carried out on finished bolts by a suitably qualified laboratory with UKAS accreditation for the relevant tests



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- A recommended testing regime is included in **Table A.1** below. Project specifications requiring more onerous testing shall take precedence over this testing regime. Should any bolt fail to meet specification then the batch lot should be quarantined pending additional testing and investigation to verify if other bolts are affected.

Test	Test Method	Frequency	Acceptance Criteria
Tensile Strength (Rm, MPa) Yield Stress (Rp0.2, MPa) Elongation after fracture (A, %) Reduction of area (Z, %)	BS EN ISO 6892-1	2 representative samples for each thread size from each manufacturing source for every 400 bolts purchased	BS EN ISO 898-1 Table 3
Vickers Hardness (HV) at a distance equal to one diameter from bolt end at surface, mid radius and core positions.	BS EN ISO 6507-1	2 representative samples for each thread size from each manufacturing source for every 400 bolts purchased	BS EN ISO 898-1 Table 3
Impact Strength - Charpy V-notch at -20°C (J)	BS EN ISO 148-1	1 representative sample for each thread size from each manufacturing source	BS EN ISO 898-1 Table 3
Chemical Composition	Relevant International Standard	1 representative sample for each thread size from each manufacturing source	BS EN ISO 898-1 Table 2
Microstructure Examination	Qualified Metallurgist	1 representative sample for each thread size from each manufacturing source	Min. 90% martensite, homogeneous, free from banding

**NOTE:** All the above tests can be performed from 1 sample provided the length is  $\geq 500\text{mm}$

**Table A.1- Comparative Testing Regime – Property Grade 10.9/12.9 Engineering Bolts/Studs**