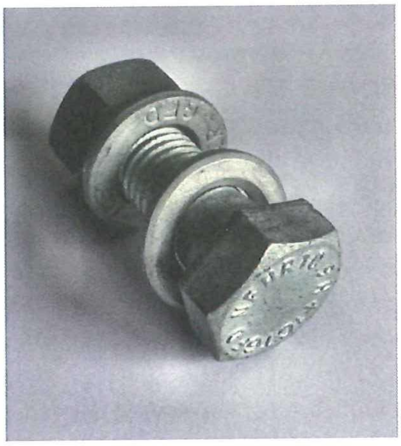
Stevin report 6-17-1

Evaluation the tightening procedures of preloaded bolt assemblies according to prEN 1090-2

“Technical requirements for steel structures” for reaching 95% reliability as prescribed in EN 1990



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Foreword

This document is an updated version of document N 232 of WG2 of CEN TC 135 which was issued in January 2012 and which was accepted by CEN TC 135 WG2.

The reason for this update is the fact that in the CEN TC 135 document N 798, which has now been sent to CEN in preparation for the 2nd Enquiry, the earlier by WG2 accepted last paragraph of clause 8.5.1 is replaced by an earlier text which was declined by WG2.

The text in document N 289, dated 2016-05-16, which was accepted by CEN/TC 135/WG 2, is:

> *"The potential loss of preloading force from its initial value due to several factors, e.g. relaxation, creep of surface coatings (see Annex G.4 and Table 16) is generally considered in the combined method specified in 8.5.4 except for thick surface coatings."*

In document N 798, dated 2016-07-11, sent to CEN for enquiry, the text as written in document N 289 is replaced by the following text earlier declined by WG 2:

> *"The potential loss of preloading force from its initial value due to several factors, e.g. relaxation, creep of surface coatings (see Annex F.4 and Table 17), is generally considered in the tightening methods specified below except for thick surface coatings."*

This replacement is in full conflict with the conclusions in document N 232 of WG2 of CEN TC 135 which was issued in January 2012 and which was accepted by CEN TC 135 WG2, resulting in the text as stated in document N289.

This is the reason for making this updated version of document N 232 of WG2 of CEN TC 135 with the aim to overcome the opposition against the originally accepted text by adding a more nuanced view to the tightening procedures, but still satisfying the 95% reliability demands asked for by EN 1990 "Basis of structural design" to all structural components, including preloaded bolt assemblies. With the text as given in document N 798 a number of tightening procedures for preloaded bolt assemblies do not always satisfy this demand.

Another reason for this update is the fact that the references in document N 232 (January 2012) are based on the present EN 1090-2:2008+A1:2011. As this code is in the final stage of revision, the references in this new version of document N 232 are now based on the latest version of prEN 1090-2 presented as CEN TC 135/WG2 document N 798.

A small number of later insight corrections with minimal influence on the conclusions are also made in this version.

Table of Content

1 General

This evaluation is based on the description of the methods for tightening of preloaded bolt assemblies as given in EN 1090-2. The execution of the four mentioned tightening methods are evaluated with respect to the reliability of the their ability to fulfill the nominal minimum preload force $F_{p,c} = 0{,}70\, f_{ub} A_s$ as demanded in EN 1993-1-8.

The value of $F_{p,c} = 0{,}70\, f_{ub} A_s$ is accepted in clause 8.5.1. of EN 1090-2. This value has to be reached with a 95% reliability as asked for in clause 4.2 of EN 1990. To prove the reliability of the preloading process a Gaussian distribution is used as mentioned in clause 4.1.2 (4) of EN 1990. The designer can trust on a durable in situ value of the bolt preload with a 95% reliability of that value which he uses in his design calculations.

Based on the assumption that the plates in the connections are fully snug tight clamped in the first step of the tightening procedure, in this paper the reliability is evaluated that the required preload $F_{p,c} = 0{,}70\, f_{ub} A_s$ is reached in the second step of the tightening procedure independent on which one of the four tightening methods is used.

Clause 8.5 of EN 1090-2 gives the four tightening methods allowed in EN 1090-2 for the preloading of bolt assemblies.

1. The torque method
2. The combined method
3. The HRC method
4. The direct tension indicator (DTI) method

For all four methods, the preloading of the bolts has to be executed in two steps. The first step is needed to be sure that the package of steel plates is fully clamped together before the final preloading of the bolts starts.

In the second step the bolt assemblies shall be tensioned to a level of at least the required preload $F_{p,c} = 0{,}70\, f_{ub} A_s$ asked for by the design with a reliability of at least 95%, but the bolts should not be elongated too close to failure. This means that the second step asks for a much higher level of accuracy and control than the first step. The steps for each tightening method are explained in clause 8.5.2 to 8.5.6 of EN 1090-2. See chapter 5 of this document.

For this evaluation the "rotation-bolt force curve" is used as described in EN 14399-2 "High-strength structural bolt assemblies for preloading" clause 10.1. See figure-2 in Annex C of this document.

This curve is numerically specified in tables 8 and 9 of EN 14399-3 and tables in 6 and 7 of EN 14399-4 for the characteristic or nominal minimum value line for the "rotation-bolt force curve" of EN 14399-2 for HR and HV bolt assemblies by the rotation of the nut relative to the bolt shank.

In clause 7.2 of both EN 14399-3 and EN 14399-4 the characteristic maximum value of this curve is defined as $F_{bi\,max} \geq 0{,}9\, f_{ub}\ A_s$, caused by the combination of tension and shear stresses.

This means that the resulting preloads, with a 95% reliability for the lowest values and a 95% reliability for the highest values of the statistical deviation shall be between $0{,}70\, f_{ub} A_s$ and $0{,}90\, f_{ub} A_s$

The results of this evaluation are summarized in the rotation-bolt force figures in Annex D of this document. For these figures 10.9 HV and 10.9 HR bolt assemblies with $2\,d \leq t \leq 6\,d$ dimensions are used.

NOTE : No human inaccuracies are taken into account in this evaluation.

NOTE : The statistical influence of the torque tools on site on the result are taken into account for the Torque method. For the accuracies of the test apparatus used during the fabrication of the bolt-sets are supposed to be included in the V_k values mentioned in the concerning codes (EN 14399-3 and EN 14399-4).

2 Conclusions

2.1 Reliability of the tightening methods.

Clause 8.5.1 of EN 1090-2 determines that "unless otherwise specified the nominal minimum preloading force $F_{p,c}$ shall be taken as $0{,}7\,f_{ub}A_s$". This value agrees with the nominal value to be used as the preload for bolts in the design calculations according to EN 1993-1-8 clause 3.6.

EN 1990 prescribes in clause 4.2 that this nominal minimum preload $F_{p,c} = 0{,}7\,f_{ub}A_s$, shall be available in situ with a reliability of 95% according to a Normal distribution.

The resulting values of the reliability of the preloads executed according to the four preloading methods mentioned in EN 1090-2 with Vk ≤ 0,06 as specified in the EN 14399 series are determined in chapter 5 of this document as:

1. The Torque method	reliability	< 95 % [1)]	5.2.2
2. The Combined method:	reliability	100 %	5.3.2
3. The HRC method:	reliability	= 95 %	5.4.3
4. The direct tension indicator (DTI) method:	reliability	< 95 % [2)]	5.5.2

1) The reliability will become 95% provided that the factor 1,10 in the second step described in clause 8.5.3 EN 1090-2:2017 will be corrected to 1.12.

2) The reliability will become 95% provided that the restriction "No more than 10 % of the indicators in a connection bolt group shall exhibit full compression of the indicator" will return in EN 1090-2:2017.

However, the Torque, HRC and DTI method should provide the characteristic preload $F_{p,c} = 0{,}7\,f_{ub}A_s$ with 95% reliability just at the moment of finishing the second step. They don't have any reserve capacity for the later emerging relaxation of the bolt-sets, or eventually emerging creep due to creep out of the surface coatings between the contact faces. For that reason these three preloading methods are not suitable for all applications because there are no practical on site procedures available for a reliable retightening of the preloaded bolts.

2.2 Retightening preload during tests.

To allow the use of these four tightening methods for slip resistant connections, the tests to determine the slip factors for the different surface application (e.g. for corrosion protection or friction improving) systems have to be executed without any retightening of the bolts to reach original preload as reached after the second tightening step. The slip factors as mentioned in Table 18 of EN 1090-2, or as a result of similar tests, which satisfy this requirement.

If slip factors are determined by tests using retightening after the second step, this fact and the amount of retightening shall be mentioned in the specification for the executing of the in situ preloading of the bolts, including a practical instruction after what time and how to retighten the bolts in practice on site after the second step.

As for tension resistant connections the design code EN 1993-1-8 determines the characteristic preload $F_{p,c} \geq 0,7\ f_{ub}A_s$ with 95% reliability available during life time, the Combined method only is available for preloading the bolts without afterwards retightening.

When using the other tightening methods, retightened may only be used if a reliable, well tested, retightening method is specified.

2.3 Rotation- bolt force curve.

The combined method is based on an elongation of the bolt shank by a controlled rotation of the nut relative to the bolt shank. The preload values reached by this preloading method are all close to the maximal preload force in the "rotation-bolt force curve" as required in the EN 14399-2 with the θ_1 and θ_2 values mentioned in EN 14399-3 and EN 14399-4 (See Annex C of this document)

2.4 Reliability Torque method

For the torque method, the required K2 class HR or HV bolt assembles according to the 2005 EN 14399-3 or EN 14399-4 did not fully fulfill the reliability of 95 % under the conditions as mentioned in EN 1090-2008+A1:2011.

To overcome the discrepancy between EN 1090-2, the present EN 14399: 2015 series "High-strength structural bolting assemblies for preloading" changes their variation factor V_k from $V_k = 0,10$ to $V_k = 0,06$ as mentioned in prEN 1090-2.

The Torque method this $V_k = 0,06$ has to be combined with the accuracy of the needed torque tool specified as ± 4% in clause 8.5.1 EN 1090-2.

Therefore, the multiplication factor of 1,10, mentioned in clause 8.5.10 b) in EN 1090-2 to determine the mean value to $F_{p,c} = 1,10 \,.\, 0,7\, f_{ub}A_s \Rightarrow F_{p,c} = 0,77\, f_{ub}A_s$, shall at least be changed to a factor of 1,12 leading to $F_{p,c} = 1,12 \,.\, 0,7\, f_{ub}A_s \Rightarrow F_{p,c} = 0,784\, f_{ub}A_s$ to fulfill a reliability of 95,1% for the torque method (See Annex Table D.1.2 and Fig. D.1 and D.2).

2.5 Reliability Combined method

By using the combined method the reliability to reach $0,70\, f_{ub}A_s$ is 100%. Moreover, the expected preload is close to, or even over, the characteristic value of $0,90\, f_{ub}A_s$ of the bolt assembly. This additional preload, above the demanded $0,70\, f_{ub}A_s$, gives an minimal extra over capacity for losses due to relaxation and eventually creep in layers of surface coatings on the contact faces in the connections even to resist to cyclic tension loads acting on the connections (See Annex D , Figure D.4)

Therefore is the Combined method is allowed for all slip and tension resistant preloaded connections, with the restriction that eventual creep due to thick surface coatings shall be proved by tests.

2.6 Reliability HRC method.

The second step in the HRC method for HRC bolt assemblies produces nearly the same results as with the torque method. EN 14399-10: 2015 specifies now for HRC bolt assemblies the same $V_k \leq 0{,}06$ as for the class K2 bolt assemblies according to EN 14399-3 and EN 14399-4. As the turning off of the splice end determines the perforce in the bolt assembly. The accuracy of the torque tool does therefore not need to be combined with the $V_k \leq 0{,}06$ of the bolt assembly. (See Annex D Table D.2.1 and Fig. D.5)

Annex D Table D.2.1 indicates that the bottom value of Vk ≤ 0,06 leads to a reliability value of just 93,5%.

However, as in clause 8.4 of EN 14399-10 it is specified that the "individual value of $F_{p,c}$ mentioned as Fri ≥ 0,7 fub × As" shall be realized, the assumption may be made that the HRC method meets the 95% reliability.

At the moment no calibrated controls are available to check the preloads reached by the first step. No torque correction is possible The special torque needs not to be calibrated, so the torque moment is not known at spline shear off.

Correction or pre-loading shall therefore be done by an accepted tested method.

2.7 Reliability DTI method.

In prEN 1090-2:2017 for the execution of the second step in the DTI method reference is made to Annex B (Informative) of prEN 14399-9:2015.

The fact is that by this reference a 95% reliability execution for a structural component is referred from a normative Annex in the for safety of steel structures responsible EN1090-2 to a informative Annex B belonging to the interested EN 14399-9 product code, more or less besides the control of EN10902 and EN 1990 series.

The prEN 14399-9 is a typical product standard describing the production fabrication control tests for the washers according laboratory demands, which are not usable in practice on site. values.

The demand for a 95% reliability is normatively formulated in the relevant clauses in EN 1990. To reach this demand Annex B (Informative) of prEN 14399-9:2015 tells the users of the DTI method that they shall flatten the tension load indicators to a gap, depending of the placing, smaller than 0,40 or 0,25 mm (see Table 9 of EN14399-9) with the indication how many of the gaps shall be smaller than the above mentioned

Table 9 — Thickness of the feeler gauge

Dimensions in millimetres

Direct tension indicator positions	Designation H8 and H10 Thickness of feeler gauge
Under bolt head, when nut is rotated (Figure 7a)	0,40
Under nut, when bolt is rotated (Figure 8a)	
Under nut, when nut is rotated (Figure 7b)	0,25
Under bolt head, when bolt is rotated (Figure 8b)	

Table 10 — Feeler gauge requirements

Number of indicator protrusions	Minimum number of feeler gauge refusals
4	3
5	3
6	4
7	4
8	5
9	5

NOTE: There is not any restriction how far to close them and it is also allowed to close all the gaps of all the DTI's.

The prEN 14399-9 requires for production control:

Samples of direct tension indicators shall be tested by the manufacturer after the final production process including the surface finish of the washers, if any. The minimum number of direct tension indicators tested per manufacturing lot shall be eight and all samples shall pass the test.

Table 4 — Indicator compression loads at appropriate gap (see Table 9)

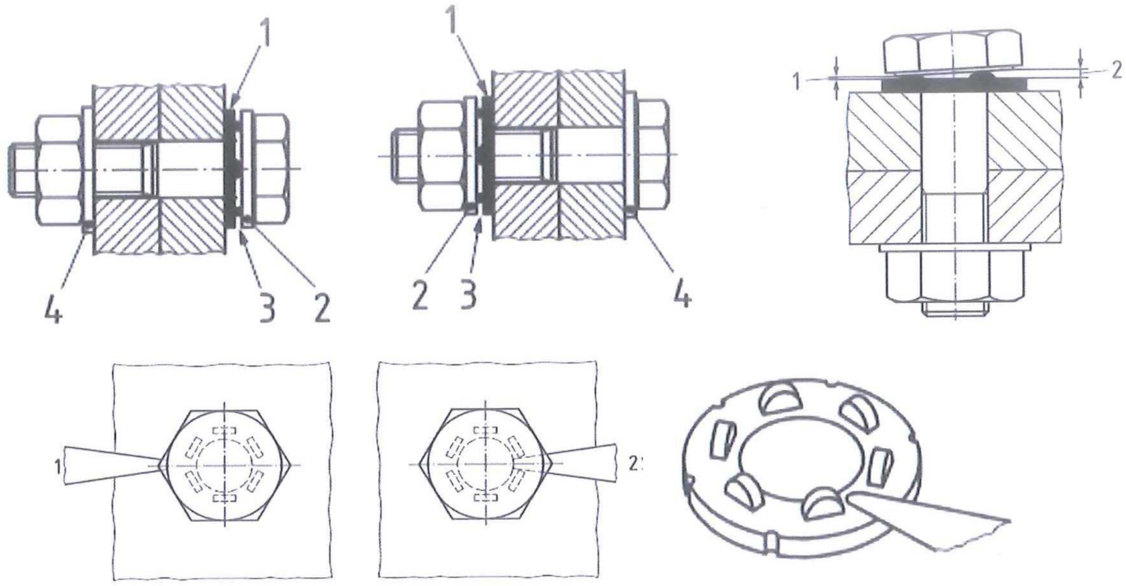
Load in kN

Nominal size d (nominal thread diameter of associated bolt)	Compression load			
	Designation H8		Designation H10	
	min.	max.	min.	max.
M12	47	56	59	71
M16	88	106	110	132
M20	137	164	172	206
M22	170	204	212	254
M24	198	238	247	296
M27	257	308	321	385
M30	314	377	393	472
M36	458	550	572	688

NOTE These minimum values are equal to $0.7 f_{ub} \times A_s$ in accordance with EN 1993-1-8.

These tests are made in the factory by well skilled laborers in a laboratory with a single bolt in a machined massive steel block with no other bolts to influence the measurements.
The protrusions shall be pressed to the level given in table 9 of EN 14399-9, that means exactly at the values of 0,40 or 0,25 mm depending on the position of the DTI's .
Table 4 of EN 14399-9 indicates that the resulting preload in the bolt shall be between 0,7 $f_{ub}A_s$ and 0,84 $f_{ub.}$

With these factory test values for the gaps the results of this factory test fulfils the 95% reliability asked for by EN 1990. This is inside the same final spread in preload forces reached with the second step of the Torque method by a well controlled process.
The assumption of the final step in the DTI method is that the in Table 4 mentioned compressive loads are surely reached as more than half the amount of the direct tension indicators are just pressed below the gap width indicated in table 9.



However on site a great part of the direct tension indicators will to be pressed far below the 0,40 or 0,25 mm widths used for the production tests by low skilled workers under bad site circumstances, as they have to meet the number of no-go gaps according to Table 10.
Total flattening of all direct tension indicators can be done easily and quickly by uncontrolled over powered tools as this approach saves time and costs for controls.

This means that the direct tension indicators shall pass these test values for fabrication in the second step of tightening considerable. The result will be that the preloads in the DTI bolt assemblies will be higher than during the factory tests and that bolt sets are most certainly overturned by trying to close all the caps.
Uncontrolled overloading and overturning is not acceptable for the Torque, Combined and HRC methods, so these can also not be accepted for the DTI method for meeting the 95% reliability.

As this concerns the reliability requirement asked for by the EN 1990 series design codes, restrictions are needed in the execution code EN 1090-2 and not in the product standard EN 14399-9.

The deleted restriction from the earlier version of EN 1090-2 that "No more than 10 % of the indicators in a connection bolt group shall exhibit full compression of the indicator." This requirement shall be placed again in the clauses 8.5.6 and 12.5.2.7 to draw attention to this restriction and to make checking possible.

2.8 The control on the second step of preloading

2.7.1 The preload reached by the torque method may be controlled by checking the individual bolt assemblies again using a torque moment lower than the in clause 12.5.2.5 specified value for reaching 0,70 $f_{ub}A_s$, assuming that no extra torque is needed to start (for an eventual correction) the rotation. This stick-slip effect may be avoided by first turning the nut backwards over a small angle, with a later replace.

The resulting retightening preload value remains still below the 0,70 $f_{ub}A_s$, so this retightening method is not adequate for tension resistant connections.

For the second step the Torque method requires adjustable torque wrenches with 4% accuracy, at least weekly checked and in case of pneumatic wrenches every time the hose length is changed.

2.7.2 For the Combined method the amount of the rotation of the nut relative to the shank can be 100% visually controlled by checking the markings between the nut and the bolt.

For inspection reports, marked photo's can be made before and after the second step.

If doubt, some nuts may be turned some degrees further to prove the resistant.

For the second step of the Combined method any type of wrench may be used.

2.7.3 The real preload in the HRC bolt assemblies cannot be checked after the spline-end is sheared off. The torque moment at the moment of the shear off is not known, unless *k*-class K2 bolts are used.

For the HRC method special shear wrenches need to be used. These wenches need no calibration.

2.7.4 The reached preload in a DTI bolt assembly depends on the correct measuring of the gap with a precision of tenths of millimeters using feelers by construction workers on site. Maybe they may not reach the same accuracy as the production controllers.

No flattening data are available to measure the pressing to reach the first step of the tightening method. The protrusions shall lightly be flattened.

The preload once reached by the DTI method may be controlled by checking the individual bolt assemblies again by measuring the remaining gaps between the washers and the plate.

The bolt assemblies are sensitive for accidental overload pressing all the protrusions flat.

For the second step of the DTI method each type of wrench may be used.

To be added to clauses 8.5.6 and 12.5.2.7 of EN 1090-2 (see clause 2.6 of this document):

´No more than 10 % of the indicators in a connection bolt group shall exhibit full compression near the indicator´.

3 Type of bolt assemblies to be used for preloading.

According to clause 5.6.4 of EN 1090-2 high strength structural bolt assemblies for preloading include system HR, system HV and HRC bolts. The deliveries shall satisfy the requirements of the harmonized standard EN 14399-1 (CE-marking) and the appropriate European Standards as listed in next table 7 of EN 1090-2.

Table 7 of EN 1090-2: Product standards for high strength structural bolting assemblies for preloading.

Bolts and nuts	Washers
EN 14399-3 EN 14399-4 EN 14399-7 EN 14399-8 EN 14399-10	EN 14399-5 EN 14399-6

NOTE: For an overview of the EN 14399-1/10 series, see Annex B of this document

EN 14399-2 gives the suitable tests for preloading, including technical requirements such as the relations for the "rotation-bolt force curve" in figure 2 of EN 14399-2 and Annex C and D of this document.

The bolts assemblies to be used in combination with the Torque, Combined and DTI method are the Hexagon HR and HV bolts as described in EN 14399-3 and EN 14399-4. They shall be delivered in sealed boxes complying with one of the three K-classes with the following information written on the boxes as mentioned in table 1 of EN 14399-1:

Table 1 — k-class and k-factor

k-class	k-factor
K0	—
K1	$0{,}10 \le k_i \le 0{,}16$
K2	$0{,}10 \le k_m \le 0{,}23$ $V_k \le 0{,}06$

Table 19 of EN 1090-2 describes which K-classes of bolt assemblies shall be used for the four allowed tightening methods:

Table 2 — Information related to tightening methods for the required preload $F_{p,C} = 0{,}7\, f_{ub}\, A_s$

Tightening method according to EN 1090-2	Minimum information to be supplied	k-class
Torque method	k_m = _ _ _ 1st step: Torque = _ _ _ Nm 2nd step: Torque = _ _ _ Nm	K2
Combined method	1st step: Torque = _ _ _ Nm 2nd step: Further rotation	K1[a]
HRC method	–	K0 for HRD nuts K2 for HR nuts
Direct tension indicator method	–	K0[b]

[a] K2 can also be used.
[b] K1 or K2 could also be used, but declared as K0.

According to clause 8.2.2 EN 1090-2 at least one thread pitch shall protrude out of the nut, and at least four full threads (in addition to the thread run out) shall remain clear between the bearing surface of the nut and the unthreaded part of the shank.

The lengths of the threaded parts on the bolt shanks of the HR bolts are larger than those lengths on the HV bolts. That means that the choice for the lengths of the HV bolts to fulfill the requirement in clause 8.2. during installation is more critical in order to meet the actual clamp lengths of the connection.

HR bolt assemblies make it easier to fulfill this requirement and may save labor costs.

4 Determination distribution range preload values reached by the second step.

The minimum nominal value $F_{p.C}$ to be reached, according to the reliability approach given in Annex B of the EN 1990, shall be at least the nominal value of the preload $F_{p.C}$ to be used in structural design calculations. This nominal minimum preload is defined in clause 8.5.1 of EN 1090-2 as:

"Unless otherwise specified the nominal minimum preloading force $F_{p,C}$ shall be taken as $F_{p,C} = 0,7\, f_{ub} A_s$ where f_{ub} is the nominal ultimate strength of the bolt material and A_s is the stress area of the bolt."

This value correspond to the nominal minimum values used for the structural design calculations as mentioned in clause 3.9.1(2) of EN 1993-1-8.

The maximum nominal value of yielding due to tightening of the bolt assemblies shall be equal to the maximum individual tension value of each bolt force. The specific HS and HV bolt standards EN 14399-3 and EN 14399-4 reduce the nominal minimum top preload in the bolt assembly to $F_{bi.max} = 0,90\, f_{ub} A_s$ due to the combination of tension and shear during tightening.

Therefore the criterions to the target ranges for the final preload by a torque or load indicated methods) are restricted to:

$$0,7\, f_{ub} A_s \leq F_{bi.max} \leq 0,9\, f_{ub} A_s.$$

For the Combined method the second step top should be restricted to a maximum rotation of $\Delta\Theta_2$ to be sure that the preload is well above $0,7\, f_{ub} A_s$ and close to $0,9\, f_{ub} A_s$, but not in the decreasing part of the yield curve behind the top value.

(See Annex C and figure D.4 of this document)

5 Tightening methods.

5.1 General.

For all methods the tightening will be executed in two steps. The first step is to close the package of the steel plates that have to be clamped together in order to be sure that no gaps between the plates are left before starting the second step for tightening the bolts to the final preload. Between the first and second step the packages shall be inspected to be sure that the plate packages are fully clamped together to prevent that already finally tightened bolts are unloaded by the tightening of later bolts closing the left open gaps.

5.2 Tightening procedure using the Torque method

5.2.1 First step of the tightening procedure using the Torque method

The determination of the preload in the bolt assembly using the Torque method is based on the relation between the value of the torque moment on the nut and the effecting preload in the shank of the bolt. The so called "relation coefficient" is influenced by the friction between the nut and the threat of the bolt and the friction between the nut and the direct bearing plain washer.

EN 1090-2 gives for example the formula for a relation in clause 8.5.2 as: $M_{r.2} = k_m d \,.\, F_{p.c}$

with:
- $M_{r.2}$ torque on the nut
- k_m factor determining the relation between torque moment and preload
- d diameter of the bolt
- $F_{p.c}$ preload in the bolt assembly

Bolt assemblies with the K-class qualification K2 shall be used for the Torque method.
These bolts assembly series are tested by the producer for the relation between the torque moment and the preload in the bolt assembly. These bolt assemblies shall be delivered in sealed boxes mentioning the factor k_m and the standard deviation V_k for the factor k_m based on the fabrication production control tests.

For the class K2 bolt assemblies the following values apply according EN 14399-3 and 4(version 2015):

$$0{,}10 \le k_m \le 0{,}23 \quad \text{and} \quad V_k \le 0{,}06$$

The values on the packages of K2 bolt assemblies are only valid when the torque rotates the nut. In cases where the head of the bolt is rotated a separate testing according to Annex H of EN 1090-2 is needed to determine the k_m factor.

First step in the tightening of the bolt assemblies:

In the first step of the Torque method, the bolt assemblies shall be preloaded to an average value of 75 % of $F_{p.c} = 0{,}75 \,.\, 0{,}7\, f_{ub}A_s = 0{,}525\, f_{ub}A_s$, according to clause 8.5.3 of EN 1090-2.

For the first step to $F_{p,1} = 0{,}525\, f_{ub}A_s$, torque wrenches with an accuracy of 10% shall be used.
In combination with a 6% friction variation in V_k, this may lead to a range of $(10^2+6^2)^{0,5}$ = +/- 11,66%.
According to clause 4.2 of EN 1990 the range of values is determined by ± 1,65 x 11,66 = 19,2%, resulting, that after the first step, the preload in the bolt assembly will be in the range of 0,42 $f_{ub}A_s$ and 0,63 $f_{ub}A_s$. These values are not really critical.
In case that the plate packages in the connection are not fully packed, additional measurements to correct this shall be performed and the first step in the tightening shall start again. The bolt assemblies may be used again.

5.2.2 Second step of the tightening procedure using the Torque method.

To reach a 95% reliable value of $F_{p,C} \geq 0{,}7\, f_{ub}A_s$ clause 8.5.3 of EN 1090-2 defines now a target value for the preload 10% above the nominal minimum preloading force of $F_{p,C} = 0{,}7\, f_{ub}A_s$ leading to $F_{p,C} = 0{,}77\, f_{ub}A_s$, with the argument that this corresponds with a an increase of 1,65 . V_k = 1,65 . 0,06 = 0,10, leading to the in clause 8.5.3 mentioned factor of 1,10 on the second step Torque moment. The value V_k = 0,06 is given in the bolt codes EN 14399-3:2015 and EN 14399-4:2015

However the "Second step" step is more critical than the first step and shall be evaluated considering other influences on the results too.

During execution

EN 1090-2: the required accuracy of the torque wrench in the second step is ± 0,04, which means statistically that V_{tool} = 0,04/1,65 = 0,024.
The combination bolt assembly + torque becomes so $V_{k+\text{torque}} = (0{,}06^2+0{,}024^2)^{0{,}5} = 0{,}0646$

In Annex D.1 and D.2 of this document the calculations are given for the torque method with variations in the bolt friction in combination with the torque wrench variation via $V_{k+torque}$. The additional influence of the torque tool on the statistical reliability needs for an elevation of the multiply factor on the second step torque from 1,10 to 1,12. (See also Figures D.1 to D.3. in Annex D of this document.

Annex D.1.1 gives in his Table the result for values mentioned/allowed in the EN 1090-2 with

Column 2: the former V_k = 0,10 and target/mean value 0,77 $f_{ub}A_s$ leading to:

- a 95% reliable preload reached at 0,639 $f_{ub}A_s$, leading to a 81,2 % reliability for the nominal load of 0,70 $f_{ub}A_s$.. Not acceptable.
- a 5% top value reached at 0,901 $f_{ub}A_s$ leading to an 0,001 exceeding of the minimum nominal strength of the bolt assembly. Acceptable?? (uncontrolled elongation of some bolts)

Column 3: the present V_k = 0,06 and target/mean value 0,77 $f_{ub}A_s$ leading to:

- a 95% reliable preload of 0,688 $f_{ub}A_s$, leading to a 92 % reliability for the nominal load of 0,70 $f_{ub}A_s$. Not acceptable.
- a 5% top value of 0,852 $f_{ub}A_s$ leading to no exceeding of the minimum nominal strength of the bolt assembly.

Both combinations do not fulfill the requirement of clause 8.5.1 EN 1090-2 for a 95% reliability at 0,70 $f_{ub}A_s$. The V_k = 0,10 is now corrected to V_k = 0,06 in the EN 14399-3 and 14399-4. 2015.

Annex D.1.2 gives the result for alternative values

Column 2 : V_k = 0,06 and target/mean value 0,784 $f_{ub}A_s$ (factor 1,12) leading to:

- a 95,1% reliable preload reached at 0,700 $f_{ub}A_s$, leading to a 99 % reliability for the nominal load of 0,70 $f_{ub}A_s$. Exact sufficient to reach 0,70 $f_{ub}A_s$.
- a 5% top value reached at 0,868 $f_{ub}A_s$ with no exceeding the 0,90 $f_{ub}A_s$

Column 3: V_k = 0,06 and target/mean value 0,80 $f_{ub}A_s$ leading to:

- a 95% reliable preload reached at 0,715$f_{ub}A_s$, leading to a 95,1 % reliability for the nominal load of 0,70 $f_{ub}A_s$. Acceptable.
- a 95% top value reached at 0,885 $f_{ub}A_s$ leading to a 0,2 % exceeding of the minimum nominal strength of the bolt assembly.
  Acceptable, but very close to 0,90.

The last two combination fulfill the requirement of clause 8.5.1 EN 1090-2 for a 95% reliable value of 0,70 $f_{ub}A_s$. without exceeding the value 0,90 $f_{ub}A_s$ to prevent overturning of the bolt assembly.

The conclusion is that an adjustment of the factor 1,10 to at 1,12 of in clause 8.5.1 is the best solution to guaranty a reliable 95% preloading in the second step to $F_{p,C}$ = 0,7 $f_{ub}A_s$.

5.3 Tightening procedure using the Combined method.

5.3.1 First step of the tightening procedure using the Combined method.

For the combined method, K2 or K1 bolt assemblies according to EN 14399-3 and -4 may be used. For the K2 bolt assemblies a torque moment shall be used determined by the k_2 factor with the relation factor between torque moment and resulting pre-load mentioned by the producer of the bolt systems. For the K1 bolt assemblies with factors $0{,}10 \le k_i \le 0{,}16$ the fixed of value of k_i = 0,125 may be used, leading to the torque values for the first step given in Table 20 of EN 1090-2

The first step of the Combined method is the same as for the Torque method, preloading up to 0,525 $f_{ub}A_s$ by turning the nut with a certain torque value.

Clause 8.5.4 a) allows as simplification the factor k_i = 0,125 for the first step of the Combined method. So $M_{r,1}$ = 0,125 d $F_{p,C}$ or for the first step $M_{r,1}$ = 0,125 d 0,75 $F_{p,C}$ = 0,094 d $F_{p,C}$.

In Annex D3 of this document the maximum and minimum expected values are statistically determined for this simplification. This simplification may lead to a statistical bottom value for the preload 0,40 $f_{ub}A_s$ and a top value for the preload 0,67 $f_{ub}A_s$.
And an ultimate value of 0,37 $f_{ub}A_s$ for the bottom value and 0,72 $f_{ub}A_s$ as maximum

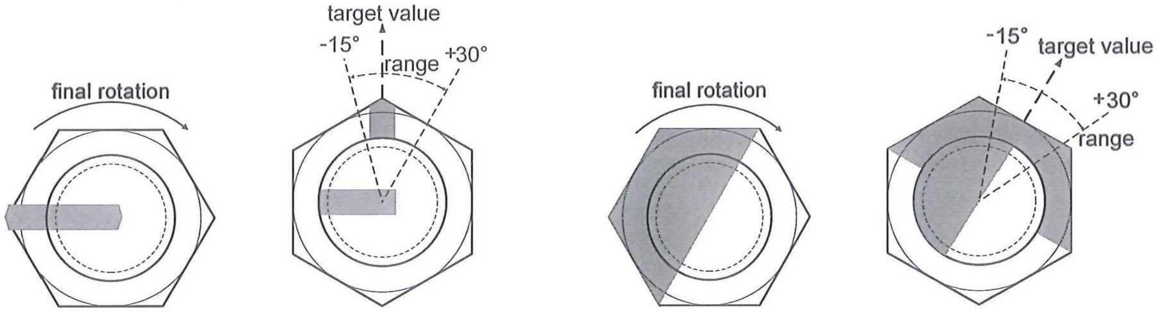
Because these values are situated on the steep part of the rotation-bolt force curve with E=210.000 N/mm^2, this will create very small differences in the horizontal displacements.(Δ in figure D.4 in this document) The maximum difference is 0,72 - 0,37 = 0,35 $f_{ub}A_s$. Which means a stress difference of 350 N/mm^2 for a 10.9 bolt grade.

When the plates in the connection are not firmly closed during this first step, the alignment of the plates in the connection, the used tools and the k-factor of the used bolt assemblies shall be checked (Annex H of EN 1090-2). The connection shall be corrected and the first step shall be repeated.

5.3.2 Second step of the tightening procedure using the Combined method.

The second step of the Combined method consists of a rotation of the nut by a prescribed and controlled angle which is dependent on the bolt shank length such that the bolt elongates and reaches the required preload. The angle is given in table 21 of EN 1090-2.

Before starting the second step of preloading, the position of the nut shall be marked relative to the shank of the bolt by paint, or another marking material, to make the control of the final turn of the nut relative to the bolt shank possible. The bolt will yield by this elongation and therefore shall not be used again in case of rejection.



NOTE: Examples of marking before the second step. The solution on the right side is reached by shielding half the bolt shank and nut by a cap and sprayed with a thin layer of paint. This method has preference because of the easy way of marking and clear control.
The reached preload has a 100% reliability and the bolts can easy be controlled visually on whether the preloading is reached. For a documented control, pictures can be made before and after the second step.

According to clause 12.5.2.5 of EN 1090-2 the markings indicating the angle of rotation shall be inspected after the second step using the following requirements:

a) if the rotation angle is more than 15° below the specified value, this rotation angle shall be corrected;
b) if the rotation angle is more than 30° over the specified angle, or the bolt or the nut has failed and the bolt assembly shall be replaced by a new one.

According to EN 14399-3 (HV) and EN 14399-4 (HR) the minimum angles ($\Delta\Theta_1$) by which the nut or bolt has to be turned, starting from a preload of 0,7 $f_{ub}A_s$, to reach the maximum pre-tension $F_{bi.max}$ on the rotation-bolt force curve are as indicated in table 8 EN 14399-3 or 6 (HV) EN 14399-4. This curve is equal for the HV and HR blts.
The minimum angle ($\Delta\Theta_2$) by which the nut or bolt has to be turned starting from a preload of 0,7 0,7 $f_{ub}A_s$ until F_{bi} has dropped again to, or even below 0,7 $f_{ub}A_s$ are specified in table 9 of EN 14399-3(HR) or table 7 of EN 1090-4 (HV). For the HR bolts the $\Delta\Theta_2$ values are 30° higher than for the HV bolts. (See figure 2 in Annex C of this document)

Annex C of this document gives the figures and definitions for $\Delta\Theta_{1t}$ and $\Delta\Theta_{2t}$ as mentioned in EN 1090-2 together with the curve for the "Rotation-bolt force curve" in EN 14399-3 and EN 14399-4. The values of the rotation angles used for the second step of the Combined method compared to the values in tables 6 and 7 for the system HV bolts in EN 14399-4 are:

Grip length Σt	Second step Combined Method min.	target	max.	$\Delta\Theta_1$ min.	$\Delta\Theta_2$ min.
$\Sigma t < 2d$	45°	**60°**	90°	**90°**	180°
$2d \le \Sigma t < 6d$	75°	**90°**	120°	**120°**	210°
$6d \le \Sigma t \le 10d$	105°	**120°**	150°	**150°**	240°

The values of the rotation angles used for the second step of the Combined method compared to the values in tables 8 and 9 for the system HR bolts in EN 14399-3:

Grip length Σt	Second step Combined Method min.	target	max.	$\Delta\Theta_1$ min.	$\Delta\Theta_2$ min.
$\Sigma t < 2d$	45°	**60°**	90°	**90°**	210°
$2d \le \Sigma t < 6d$	75°	**90°**	120°	**120°**	240°
$6d \le \Sigma t \le 10d$	105°	**120°**	150°	**150°**	270°

The horizontal displacement of $\Delta\Theta_1$ and $\Delta\Theta_2$ starts at 0,7 $f_{ub}A_s$. The second step of the combined method starts earlier at the average value of 0,525 $f_{ub}A_s$, resulting in a slightly lower end position

Table 21 — Combined method: additional rotation (8.8 and 10.9 bolts)

Total nominal thickness "t" of parts to be connected (including all packs and washers) d = bolt diameter	Further rotation to be applied, during the second step of tightening: Degrees	Part turn
$t < 2d$	60	1/6
$2d \le t < 6d$	90	1/4
$6d \le t \le 10d$	120	1/3
NOTE Where the surface under the bolt head or nut (allowing for taper washers, if used) is not perpendicular to the bolt axis, the required angle of rotation should be determined by testing		

value between the first step and $\Delta\Theta_1$ or $\Delta\Theta_2$.

The above Tables show:

1. The target value of the second step to reach the preload is for all grip lengths of the bolt assemblies more than 30° below the $\Delta\Theta_1$.
2. The minimum value of the second step to reach the preload is for all grip lengths more than 45° below the $\Delta\Theta_1$.

3. The maximum value of the second step to reach the preload is for all grip lengths less than $\Delta\Theta_1$.
4. The average value of the second step to reach the preload is for all grip lengths system HV bolts more than 90° below the minimum nominal value of $\Delta\Theta_2$.
5. The minimum value of the second step to reach the preload is for all grip lengths system HR bolts more than 120° below the minimal nominal value of $\Delta\Theta_2$, for HR bolts 120°.

After the second step, with the rotation close to $\Delta\Theta_1$ on top of the nominal "Rotation-bolt force curve", the preload is at least close to minimum nominal top value of the bolt assembly strength. However, as the real strength of the bolt assembly will be higher than the nominal strength, so the preload may even be higher than the nominal value of 0.90 $f_{ub}A_s$. (See annex D.4 of this document)

A great extra advantage of the Combined method is the structural use of the individual extra strength of the bolt assemblies above the nominal value as required and mentioned in the EN 14399 codes.
So the Combined method reached the value of $F_{p,c} \geq 0,7\, f_{ub}A_s$ amply in the second step and has therefore a reliability of 100%.

The ability to visually control the rotation of each nut also fully guaranties that enough thread was available on the bolt shank before elongating the bolt assembly to the required preload.

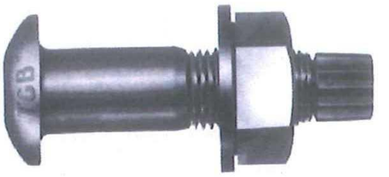
The combined method is the only tightening method using the real strength of the individual bolt assemblies. The second step is quick and easy to execute and the amount of yield is reliable and allows all over control, even by non-specialist supervisors. (photographs before and after the second step)

5.4 Tightening procedure using the HRC method.

5.4.1 Tightening applying the HRC method.

The HRC bolt assembly is not a widely used type for preloaded bolts in Europe. The EN1090-2 gives the following description in art 8.5.5.:

"The HRC bolts shall be tightened using a specific shear wrench equipped with two co-axial sockets which react by torque one against the other. The outer socket which engages the nut rotates clockwise. The inner socket which engages the spline end of the bolt rotates anticlockwise."

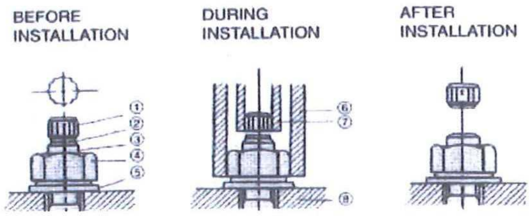


NOTE 1 *The shear wrench operates as follows:*

- *during the tightening operation of an assembly, the socket in rotation is the one that finds the least resistance to it;*
- *from the outset and right up to the last tightening step, the outer socket on the nut rotates clockwise while the inner socket holds the spline-end without rotating, the result being that the bolt assembly is progressively tightened by the increasing torque applied to the nut;*
- *at the last tightening step, i.e. when the tensional resistance plateau of the break-neck section is attained, the inner socket rotates anticlockwise while the outer socket on nut provides the reaction without rotating;*
- *the bolt assembly installation is complete when the spline-end shears off at the break-neck section.*

The specified preload requirement is in fact a Torque method, controlled by the HRC bolt itself by means of the nominal values for the geometrical and torsion mechanical properties together with the lubrication conditions. The tightening equipment does not need calibration.
The lubrication condition (aging) may influence the reliability in reaching the minimal preload.

In order to ensure that the preloads in the fully installed bolt assemblies in the connections meet the specified minimum preload requirement, the bolt installation process should also comprise two tightening steps, both using the same torque wrench.



5.4.2 First step of the tightening procedure using the HCR method.

The first tightening step is achieved at the latest when the torque wrench outer socket stops turning. This first step shall be completed for all bolts in the connection prior to beginning with the second step.

NOTE 2 Clause 8.5.5 EN 1090-2:
Guidance of the equipment manufacturer may give additional information on how to identify if pre-tightening has occurred, e.g. sound of torque wrench is changing, or if other methods of pre-tightening are suitable.

The two expected preload values by this methods in the first and in the second step are not quantified and may depend on the stiffness of the connections. Before starting the second step, the closure of the steel plate package has to be checked. If not fully closed, the bolt assemblies shall be removed and the plate package shall be corrected.

5.4.3 Second step of the tightening procedure using the HCR method.

The second tightening step is achieved when the spline-end of the bolt shears off at the break-neck.

If the assembly conditions are such that it is not possible to use the torque wrench on the HRC bolt assembly, e.g. for lack of space, tightening shall be carried out using a procedure in accordance with the Torque method, see EN 1090-2 clause 8.5.3 of EN 1090-2 with the aid of the k-class K2 information or using a direct tension indicator, see clause 8.5.6. and clause 12.5.2.6 of EN 1090-2.

For the second step, visual inspection shall be carried out on 100 % of the bolt assemblies. Fully tightened bolt assemblies are identified as those with the spline end sheared off. A bolt assembly for which the spline end remains is considered to be under-tightened.

If tightening of HRC bolt assemblies is completed using the torque method according the EN 1090-2 clause 12.5.2.4 or clause 12.5.2.7 as appropriate.

Remarks to these descriptions in EN 1090-2:

1. The procedure for preloading for the first step to close the plate package before shearing off of the spline-ends is not clearly defined in NOTE 2 clause 8.5.5 EN 1090-2 of the description. For example, the sound of the equipment may depend on the stiffness of the structure around the bolt assembly as well. Up to now it is not defined between which values of $f_{ub}A_s$ the tightening of the first step will lead to.
2. If spline-ends of bolts are sheared off before the plate package is fully packed, the bolts shall be removed and replaced by new ones, to reach a firm closure of the plate package.
3. According to EN 14399-9 table 9, during production the bolt assemblies shall be calibrated such as to arrive at the preload value ≥ 0,7 $f_{ub}A_s$ with 95% reliability by reaching a mean value ≥ 0,77 $f_{ub}A_s$, and a $V_{ft} \leq 0{,}06$.
4. The life time for a corrosion protection on the sheared off surfaces of the bolts may be critical for the durability of the structure under all-weather circumstances. Grinding of these surfaces before painting does not seem to be a realistic solution.

EN 14399-10

Table 12 — Limiting values of bolt force at the fracture of the spline-end

Thread d	Nominal stress area of standard test mandrel A_s mm²	F_r min 0,7 × f_{ub} × A_s [a] N	F_r mean min 0,77 × f_{ub} × A_s [a] N
M12	84,3	59 010	64 911
M16	157	109 900	120 890
M20	245	171 500	188 650
M22	303	212 100	233 310
M24	353	247 100	271 810
M27	459	321 300	353 430
M30	561	392 700	431 970
M36	817	571 900	629 090

[a] f_{ub} is the nominal tensile strength of the bolt ($R_{m,\ nom}$).

5.5 Tightening applying the Direct Tension Indicator (DTI) Method.

5.5.1 General

Annex J, describing the use of the compressible washer-type direct tension indicators, is removed from EN 1090-2. For the execution of this method for preloading bolt assemblies reference is made to EN 14399-9.

With this adaption, the requirement in clause 12.5.2.5 the present EN 1090-2 that no more than 10% of the direct tension indicators should ot be pressed totally flat disappeared, as earlier described in clause 2.6 of this document.

This requirement has to be returned in the EN 1090-2:2017 to fulfill the 5% reliability demand of EN 1990 to satisfy the confidence of the structural designers.

The system consists of an extra washer with protrusions, to be placed between the plate surface and one of the flat washers of the bolt assembly. The thickness and the number of protrusion on the DTI washers depend on the size and the material grade (8.8 or 10.9) of the bolt assemblies used. The tightening starts with a gap between the DTI washer and the bolt assembly plain washer. The amount of flattening of the protrusions indicates the preload in the bolts during tightening. As they yield, the protrusions do not spring back when the load decreases.

The great difference between the DTI and the other three methods is the way of measuring the preload during tightening. The DTI method measures the preload on an indirect and unknown non-linear way by the amount of flattening of the protrusion with external feelers in both steps.

The Torque and HRC method are direct and constant measuring the preload by the moment needed to turn the nut in both steps, the Combined method measured the first step by the moment and the second step by the deference in the markings between the nut and the shank.

The criterion for the realization of the tightening by the DTI method as described in EN 1090-2 with a a reference to EN 14339-9 and is based on the deformation of the protrusions as an indication for the reached preload on the bolts. As the total width of this gap for a M20 - 10.9 bolt is about 1.5 mm, the deformation should be measured in tenths of mm.

According to clause 12.5.2.7 EN 1090-2 No more than 10 % of the indicators in a connection bolt group should exhibit full compression of the indicator.
This sentence is deleted in the last proposals for the EN 1090-2 revised, but shall be brought back to prohibit that all the protrusions shall be totally flattened with the risk of overturning the bolts.

At the end of the second step the compressed cap should be < 0,25 mm. The total flattening has to be between 1,25 and 1,5 mm. With a pitch of 2,5 mm for an M20 bolt the total needed rotation should be between 180° and 216°, so a final target angle of 36°.

5.5.2 First step of the tightening procedure using the DTI method.

The first step of this method it is essential to fully close the gaps in the steel plate package. Otherwise, the first finally tightened bolts in step 2 are prone to being unloaded by a further compression of the package during the final tightening of subsequent bolt assemblies.

This point of not fully closing the gaps may not easily be reached during execution because of the small dimensions of these protrusions. No preload force for the first step is prescribed by EN 1090-2 and there is no required flattening-preload curve available in EN 14399-9. The firm closure of the plates in the connection shall be reached by a go around partially flattening of the DTI washers, measuring the remained gaps in order to have sufficient gap left over for the second step reaching the preload.

This needs concentration and skilled workmanship.

5.5.3 Second step of the tightening procedure using the DTI method.

In the second step the protrusions shall be deformed till their final positions . When the DTI is placed on the side where the bolt assembly is tightened by turning either the nut or bolt head, the final gap should be less than 0,25 mm. When the DTI is placed on the opposite side the final gap should be less than 0,40 mm

After the tightening, the height of the gaps shall be checked for all bolt assemblies using a feeler gauge with a thickness of 0,25 or 0,40 mm as a “no go” inspection tool. The feeler gauge shall be placed between the protrusions and pointed to the centre of the bolt. At least half of the number of the passages between the protrusions shall be too narrow for the feeler.

No more than 10% of the washers with protrusions in the bolt assemblies should be fully pressed. (see clause 2.7 of this document)

According to EN 14399-9, the DTI washers shall be calibrated during the fabrication production control on the preload values being between 0,7 $f_{ub}A_s$ and 0,84 $f_{ub}A_s$, with 0,77 $f_{ub}A_s$ as average.

These values are reached when the gap between the washers is reduced to the values given in his Table 10. It should be recognized that these results are reached by well skilled and well trained operators under laboratory circumstances. In practice the bolt assemblies should be installed by construction workers on site under all-weather circumstances, with the task to measure with an accuracy of tenths of millimeters.

The DTI method satisfies just $F_{p,c}$ = 0,7 $f_{ub}A_s$ with the 95% reliability as asked for in EN 1990 Annex B, without any overload to compensate later occurring relaxation and eventual creep by corrosion protection

6 Applications for the four mentioned preload methods.

The Torque, HRC and DTI methods are just able to reach the preload of Fp.c = 0,7 $f_{ub}A_s$ with the required 95% reliability, with no extra capacity for the not to be avoided relaxation of the bolt assemblies just after the loading or the potential loss of preload due to creep in case that thick surface coatings on the contact areas in the connection are present.

Due to the controlled turn of the nut of the bolt assembly, the preload realized by using the Combined method will reach a value of the preload of at least close to 0,9 $f_{ub}A_s$ with a reliability for l Fp.c = 0,7 $f_{ub}A_s$ of 100%. In reality this preload will be mostly higher than 0,9 $f_{ub}A_s$ caused by the individual actual strength of the bolt material for which the value of f_{ub} is the 2,3% undercut value in the log-normal statistical distribution.

Preloaded connections where the bots are loaded in pure tension and / or in combination with shear loads are very sensible for too low preload. The designer relies in his calculations on at least Fp.c = 0,7 $f_{ub}A_s$.

When the preloads in the bolts are too low, the clamped plates in the connection may come loose from each other with the danger of corrosion for static connections.

For connections with the bolts loaded in cyclic tension gaps between the clamped plates lead to stress cycles in the bolts greater than expected which shall decrease the fatigue life of the structure severely

As the fabricator doesn't know the functions of the connections, the preloading of these connections shall always be done by the Combined method to avoid accidents.

A review of the tests, carried out by the Stevin II Laboratory of the Delft University of Technology, is used as basis for the slip factors mentioned in Table 17 prEN1090-2. These tests were executed after preloading of the bolts without any correction loss of preload due to relaxation or creep. In these values for the slip factors the relaxation in the bolts and creep in the mentioned surface coating is included. (published in the ECCS Technical Committee 10 Report 37, Slip Factors of Connections with H.S.F.G. Bolts)

So, all four preload methods are allowed for executing pure slip resistant preloaded bolted connections, subject to the requirement that the tests to determine the slip factor are executed starting with the preload in the bolt assemblies in first instance without any correction to it prior to testing.

Annex A

Part 8.5 of the CEN/TC 135/ WG2 Document N 292

8.5 Tightening of preloaded bolts

8.5.1 General

Unless otherwise specified, the nominal minimum preloading force $F_{p,C}$ shall be taken as:

$F_{p,C} = 0{,}7\, f_{ub}\, A_s$

where f_{ub} is the nominal ultimate strength of the bolt material and A_s is the stress area of the bolt as defined in EN 1993-1-8 and specified in Table ~~20~~18.

This level of preload shall be used for all slip resistant preloaded connections and for all other preloaded connections unless a lower level of preload is specified. In the latter case, the bolt assemblies, the tightening method, the tightening parameters and the inspection requirements shall also be specified.

NOTE Preload can be used for slip resistance, for seismic connections, for fatigue resistance, for execution purposes, or as a quality measure (e.g. for durability).

Table ~~20~~ 18 — Values of $F_{p,C}$ in [kN]

Property class	Bolt diameter in mm									
	12	14	16	18	20	22	24	27	30	36
8.8	47	65	88	108	137	170	198	257	314	458
10.9	59	81	110	134	172	212	247	321	393	572

Any of the four tightening methods given in 8.5.3 to 8.5.6~~Table 21 19~~ may be used unless restrictions on their use are specified. The *k*-class (as-delivered calibration condition) of the bolting assembly shall be in accordance with Table ~~21~~ 19 for the method used.

Table ~~21~~ 19 — *k*-classes for tightening methods

Tightening method	*k*-classes
Torque method (see 8.5.3)	K2
Combined method (see 8.5.4)	K2 or K1
HRC tightening method (see 8.5.5)	K0 with HRD nut only or K2
Direct tension indicator (DTI) method (see 8.5.6)	K2, K1 or K0

For the Torque and HRC tightening methods, the coefficient of variation~~standard deviation~~ for the bolt assemblies *k*-factor (V_k according to EN 14399-1) or for the bolt assembly *Fr*-factor (V_{Fr} according to EN 14399-10) shall be ≤ 0,06.

As an alternative, calibration to Annex ~~I~~ L may be used, except for the torque method unless this is permitted in the execution specification.

The as-delivered calibration is valid for tightening by rotation of the nut. If tightening is done by rotation of the bolt head, calibration shall be done according to Annex ~~I~~ L or by supplementary testing ~~from the fastener manufacturer~~ otherwise in accordance with EN 14399-2.

Burrs, loose material and excessive thickness of paint that would prevent solid seating of the connecting parts shall be removed before assembly.

Before commencement of preloading, the connected components shall be fitted together and the bolts in a bolt group shall be tightened in accordance with 8.3 but the residual gap shall be limited to 2 mm with the necessary corrective action on steel components.

Tightening shall be performed by rotation of the nut except where the access to the nut side of the assembly is inadequate. Special precautions, depending on the tightening method adopted, may have to be taken when bolts are tightened by rotation of the bolt head.

Both at the first step and at the final tightening step, tightening shall be carried out progressively from the most rigid part of the joint to the least rigid part. To achieve uniform preloading, more than one cycle of tightening may be necessary.

Torque wrenches used in all steps of the torque method shall be capable of an accuracy of ± 4 % according to EN ISO 6789. Each wrench shall be maintained in accordance with EN ISO 6789, and in case of pneumatic wrenches checked every time the hose length is changed. For torque wrenches used in the first step of the combined method, these requirements are modified to ± 10 % for the accuracy and yearly for the periodicity.

Checking shall be carried out after any incident occurring during use (significant impact, fall, overloading etc.) and affecting the wrench.

Other tightening methods (e.g. axial preloading by hydraulic devices or tensioning with ultrasonic control) shall be calibrated in accordance with the recommendations from the equipment manufacturer.

High strength bolts for preloading shall be used without alteration to the as-delivered lubrication unless DTI method or the procedure in Annex ~~J~~I is adopted.

If a bolt assembly has been tightened to the minimum preload and is later un-tightened, it shall be removed and the whole assembly shall be discarded.

NOTE 1 Bolt assemblies used for achieving initial fit up should not generally need to be tightened to the minimum preload or un-tightened, and would therefore still be usable in location in the final bolting up process.

NOTE 2 If the tightening process is delayed under uncontrolled exposure conditions the performance of the lubrication may be altered and should be checked.

The potential loss of preloading force from its initial value due to several factors, e.g. relaxation, creep of surface coatings (see Annex ~~G~~F.4 and Table ~~18~~17), is ~~generally~~ considered in the tightening methods specified below except for thick surface coatings. For thick surface coatings, the potential loss of preload may be evaluated using Annex ~~K~~J1. ~~For other tightening methods and in~~In the case of thick surface coatings it shall be specified if additional measures shall be taken to compensate for possible subsequent loss of preloading force.

8.5.2 Torque reference values

For the torque method and the combined method, the~~The~~ torque reference values $M_{r,i}$ to be used for a nominal minimum preloading force $F_{p,C}$ are determined for each type of bolt and nut combination used by one of the following options:

a) values based on k-class declared by the fastener manufacturer in accordance with the relevant parts of EN 14399:

1) $M_{r,2} = k_m \, d \, F_{p,C}$ with k_m for k-class K2.

2) $M_{r,1} =$ ~~k_m~~ 0,094 $d \, F_{p,C}$ ~~with k_m~~ for k-class K1.

b) values determined according to Annex ~~J~~I:

$M_{r,test} = M_m$ with M_m determined according to the procedure relevant to the tightening method to be used.

8.5.3 Torque method

The bolts shall be tightened using a torque wrench offering a suitable operating range. Hand or power operated wrenches may be used. Impact wrenches may be used for the first step of tightening for each bolt.

The tightening torque shall be applied continuously and smoothly.

Tightening by the torque method comprises at least the two following steps:

a) a first tightening step: the wrench shall be set to a torque value of about 0,75 $M_{r,i}$ with $M_{r,i} = M_{r,2}$ or $M_{r,test}$. This first step shall be completed for all bolts in one connection prior to commencement of the second step;

b) a second tightening step: the wrench shall be set to a torque value of 1,10 $M_{r,i}$ with $M_{r,i} = M_{r,2}$ or $M_{r,test}$.

NOTE The use of the 1,10 coefficient with $M_{r,2}$ is equivalent to $1/(1 - 1{,}65\ V_k)$ with V_k or $V_{Fr} = 0{,}06$ for k-class K2 in combination with the $V_{k,tools}$. See EN 14399-1 for the coefficient of variation factors V_k and V_{Fr} factors. $V_{k,tools}$ is the coefficient of variation associated with the calibration of tools used in the tightening methodology.

8.5.4 Combined method

Tightening by the combined method comprises two steps:

a) a first tightening step, using a torque wrench offering a suitable operating range. The wrench shall be set to a torque value of about 0,75 $M_{r,i}$ with $M_{r,i} = M_{r,2}$ or $M_{r,1}$ or $M_{r,test}$. This first step shall be completed for all bolts in one connection prior to commencement of the second step. When using $M_{r,1}$, for simplification $M_{r,1} = 0{,}1$~~3~~25 d $F_{p,C}$ as given in Table 20 may be used, unless otherwise specified;

Table ~~22~~ 20 — Torque moment in [Nm] for the first step in the combined method

Property class	Bolt diameter in mm									
	12	14	16	18	20	22	24	27	30	36
8.8	53~~55~~	85~~89~~	132~~137~~	182~~190~~	258~~267~~	351~~365~~	446~~463~~	652~~677~~	886~~918~~	1548~~1608~~
10.9	67~~69~~	106~~111~~	165~~172~~	227~~235~~	322~~335~~	439~~455~~	557~~578~~	815~~845~~	1107~~1150~~	1935~~2008~~

b) a second tightening step in which a specified part turn is applied to the turned part of the assembly. The position of the nut relative to the bolt threads shall be marked after the first step, using a marking crayon or marking paint, so that the final rotation of the nut relative to the thread in this second step can be easily determined. The second step shall be in accordance with the values of Table 21, unless otherwise specified.

Table ~~23~~ 21 — Additional rotation for the second step in the combined method (8.8 and 10.9 bolts)

Total nominal thickness "*t*" of parts to be connected (including all packs and washers)	Further rotation to be applied, during the second step of tightening	
d = bolt diameter	Degrees	Part turn
$t < 2d$	60	1/6
$2d \leq t < 6d$	90	1/4
$6d \leq t \leq 10d$	120	1/3
NOTE Where the surface under the bolt head or nut (allowing for taper washers, if used) is not perpendicular to the bolt axis, the required angle of rotation should be determined by testing		

8.5.5 HRC method

The HRC bolts shall be tightened using a specific shear wrench equipped with two co-axial sockets, which react by, torque one against the other. The outer socket, which engages the nut, rotates clockwise. The inner socket, which engages the spline end of the bolt, rotates anticlockwise.

NOTE 1 The shear wrench operates as follows:

— during the tightening operation of an assembly, the socket in rotation is the one that finds the least resistance to it;

— from the outset and right up to the last tightening step, the outer socket on the nut rotates clockwise while the inner socket holds the spline end without rotating, the result being that the bolt assembly is progressively tightened by the increasing torque applied to the nut;

— at the last tightening step, i.e. when the torsional resistance plateau of the break-neck section is attained, the inner socket rotates anticlockwise while the outer socket on nut provides the reaction without rotating;

— the bolt assembly installation is complete when the spline end shears off at the break-neck section.

The specified preload requirement is controlled by the HRC bolt itself by means of the geometrical and torsion mechanical characteristics together with the lubrication conditions. The equipment does not need calibration.

In order to ensure that the preloads in fully installed bolts in connections meet the specified minimum preload requirement, the bolt installation process generally comprises two tightening steps; both using the shear wrench.

The first tightening step is achieved at the latest when the shear wrench outer socket stops turning. If specified this first step is repeated as often as required. This first step shall be completed for all bolts in one connection prior to commencement of the second step.

NOTE 2 Guidance of the equipment manufacturer may give additional information on how to identify if pretightening has occurred, e.g. sound of shear wrench changing, or if other methods of pretightening are suitable.

The second tightening step is achieved when the spline end of the bolt shears off at the break-neck.

If the assembly conditions are such that it is not possible to use the shear wrench on the HRC bolt assembly, e.g. for lack of space, tightening shall be carried out using a procedure in accordance with the torque control method (see 8.5.3) with the aid of the *k*-class K2 information or test according to Annex ~~H~~L, or using a direct tension indicator (see 8.5.6).

8.5.6 Direct tension indicator method

This subclause applies to compressible washers, such as direct tension indicators in accordance with EN 14399-9, which indicate at least the required minimum preload has been achieved, by monitoring the force in the bolt. It does not cover indicators that rely on torsion. It does not apply to direct measurement of bolt preload by use of hydraulic instruments.

The direct tension indicators and their associated washers shall be assembled as specified in EN 14399-9.

The first step of tightening to reach a uniform "snug-tight" condition of a fastener assembly shall be when initial deformation of the DTI protrusions begins. This first step shall be completed for all bolts in one connection prior to commencement of the second step.

The second step of tightening shall be as EN 14399-9. The gaps measured on the indicating washer may be averaged to establish the acceptability of the bolt assembly.

Annex B

Used codes:

EN1090-1:2009+A1:2011	-Execution of steel structures and aluminium structures Part 1: Requirements for conformity assessment of structural components
EN 1090-2+A1:2011	-Execution of steel structures and aluminium structures Part 2: Technical requirements for steel structures
EN 1990+A1+A1/C2:2011	- Basis of structural design

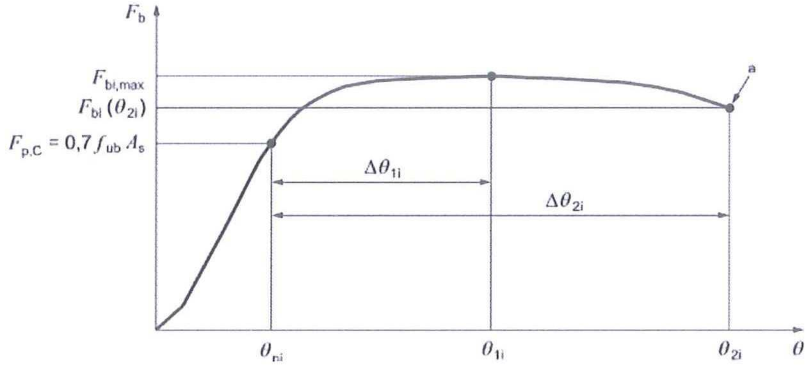
Overview EN 14399 codes:

EN 14399-1:2015*	-High-strength structural bolting assemblies for preloading General requirements
EN 14399-2:2015	- Suitability test for preloading
EN 14399-3:2015	- System HR – Hexagon bolt and nut assemblies
EN 14399-4:2015	- System HV – Hexagon bolt and nut assemblies
EN 14399-5:2015	- Plain washers
EN 14399-6:2015	- Plain chamfered washers
EN 14399-7:2008	- System HR - Countersunk head bolt and nut assemblies
EN 14399-8:2008	- System HV - Hexagon fit bolt and nut assemblies
EN 14399-9:2009	- System HR or HV - Direct tension indicators for bolt and nut assemblies
EN 14399-10:2009	- System HRC - Bolt and nut assemblies with calibrated preload

* Harmonized code. This series of EN 14399 codes are part of CE-marking.

Annex C

Results tightening methods related to the rotation-bolt force curves of EN 14399-2 "general", EN 14399-3 "HR bolts" and EN 14399-4 "HV bolts"

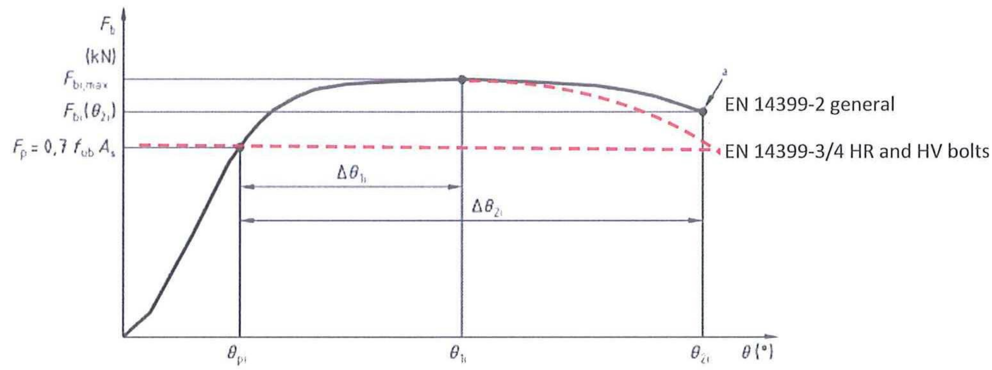


EN 14399-2 "General requirements" Figure 2.

In this figure of EN 14399-2 is

- $\Delta\Theta_1$ defined as the angle difference between $F_p = 0.7\ F_{ub}A_s$ and the rotation at the maximum bolt force $F_{bi,max}$ i.
- $\Delta\Theta_2$ is defined as the angle difference between $F_p = 0.7\ F_{ub}A_s$ and the rotation where the test is stopped.

Figure 2 EN 14399-2 corrected according to EN 14399-3 and EN 14399-4 used for the evaluation



NOTE: "a" on the end of the curve means end of the test, not the failure of the bolt.

EN 14399-3 and EN 14399-3 gives a more specific definition of the $\Delta\Theta_1$ and $\Delta\Theta_2$ value.
In these codes

- $\Delta\Theta_1$ is defined as the angle by which the nut (or bolt) has to be turned starting from a preload of $F_p = 0.7\ F_{ub}A_s$ until the maximum bolt force $F_{bi,max}$ is reached.
- $\Delta\Theta_2$ is defined as the angle by which the nut (op bolt) has to be turned starting from a preload of $F_p = 0.7\ F_{ub}A_s$ until F_{bi} has dropped again to $F_p = 0.7\ F_{ub}A_s$.

This evaluation makes use of the corrected line as the nominal or nominal rotation-bolt curve for the determination of the pre-loads in the bolt assemblies.

EN 14399-3 (HR)

7.3 Angle by which the nut (or bolt) has to be turned starting from a preload of 0,7 $f_{ub} \times A_s$ until $F_{bi\,max}$ is reached ($\Delta\Theta_1$)

The values indicated in Table 8 are for information only.

Table 8 — Values for $\Delta\Theta_1$

Clamp length Σt [a]	$\Delta\Theta_1$ min.
$\Sigma t < 2d$	90°
$2d \leq \Sigma t < 6d$	120°
$6d \leq \Sigma t \leq 10d$	150°
[a] Σt is the total thickness of the clamped parts including washer(s).	

7.4 Angle by which the nut (or bolt) has to be turned starting from a preload of 0,7 $f_{ub} \times A_s$ until F_{bi} has dropped again to 0,7 $f_{ub} \times A_s$ ($\Delta\Theta_2$)

The values for $\Delta\Theta_2$ specified in Table 9 apply.

Table 9 — Values for $\Delta\Theta_2$

Grip length Σt [a]	$\Delta\Theta_2$ min.
$\Sigma t < 2d$	210°
$2d \leq \Sigma t < 6d$	240°
$6d \leq \Sigma t \leq 10d$	270°
[a] Σt is the total thickness of the clamped parts including washer(s).	

EN 13499-4 (HV)

7.3 Angle by which the nut (or bolt) has to be turned starting from a preload of 0,7 $f_{ub} \times A_s$ until $F_{bi\,max}$ is reached ($\Delta\Theta_1$)

The values indicated in Table 6 are for information only.

Table 6 — Values for $\Delta\Theta_1$

Clamp length Σt [a]	$\Delta\Theta_1$ min.
$\Sigma t < 2d$	90°
$2d \leq \Sigma t < 6d$	120°
$6d \leq \Sigma t \leq 10d$	150°
[a] Σt is the total thickness of the clamped parts including washer(s).	

7.4 Angle by which the nut (or bolt) has to be turned starting from a preload of 0,7 $f_{ub} \times A_s$ until F_{bi} has dropped again to 0,7 $f_{ub} \times A_s$ ($\Delta\Theta_2$)

The values for $\Delta\Theta_2$ specified in Table 7 apply.

Table 7 — Values for $\Delta\Theta_2$

Grip length Σt [a]	$\Delta\Theta_2$ min.
$\Sigma t < 2d$	180°
$2d \leq \Sigma t < 6d$	210°
$6d \leq \Sigma t \leq 10d$	240°
[a] Σt is the total thickness of the clamped parts including washer(s).	

Annex: D.1.1

Determination reliability of the Torque method for tightening bolt assemblies.

Input old EN 14399 version Vk = 0,10 and 2015 version Vk = 006 mean value 0,77 $f_{ub}A_s$.

			Old	alternative
Determination for the combined coefficient of variation (Vkt) including the variations of the tools used for testing and installation			**Old**	**alternative**
Coefficient of variation k-factor (V_k) for bolt assemblies. allowed in clause 7.5.2 of EN 14399-3 and EN 14399-4		A	**0,10**	**0,06**

Coefficient of variation k-factor (V_k) for installation tools

EN 1090-2: the required accuracy of the torque in the second step ±4%				
From accuracy to ($V_{k.tool}$): Vk.too l= 0.04/1,65 = 0,024		B	0,024	0,024

Comined k-factor ($V_{comb.}$)	$(A^2 + B^2)^{0,5}$		**0,103**	**0,065**

Determination of the achieved reliability for the nominal minimum preload.

	top value for bolt assembly failure = 0,90		$f_{ub}A_s$	0,90	0,90
	bottom value for preload = 0,70		$f_{ub}A_s$	**0,70**	**0,70**
	coefficient of variation of k-factor (V_k) bolt assembly			0,10	0,10

a	Comined k-factor ($V_{comb.}$)			0,103	0,065
	Torque value for average target preload according to 8.5.3 line b)			1,10	1,100
b	target/mean value Normal distribution		$f_{ub}A_s$	0,77	**0,77**
c	β- index for reliability 95%			1,65	1,65

d	5 % top value, should be equal or below 0,90	(1 + 1,65 x a)b	$f_{ub}A_s$	0,901	0,852
e	percentage to bolt assembly failure, should be equal or below 100%	d / 0,90	%	**100,1**	**94,7**
f	real β-index for reliability	(0,90-b)/(a x b)		1,642	2,613
g	reliability for failure	van f naar g	%	95,0	99,6

h	95% bottom value, equal or higher than 0,70	(1 -1,65 x a)b	$f_{ub}A_s$	**0,639**	**0,688**
j	percentage compared to minimal preload, shall be equal or over 100%	h / 0,70	%	91,3	98,3
k	real β-index for reliability	(b-0,70)/(a x b)		0,884	1,407
L	**reliability for nominal minimum preload, shall be equal or over 95%**	**from k to L**	%	**81,2**	**92,0**

Annex: D.1.2

Determination reliability of the Torque method for tightening bolt assemblies.

Input: corrected V_k = 0,06 with mean value 0,784 $f_{ub}A_s$, alternative 0,80 $f_{ub}A_s$.

Determination for the combined coefficient of variation (Vkt) including the variations of the tools used for testing and installation		present	alternative
Coefficient of variation *k*-factor (V_k) for bolt assemblies. alternative on clause 7.5.2 of EN 14399-3 and EN 14399-4	A	**0,06**	**0,06**

Coefficient of variation *k*-factor (V_k) for installation tools			
EN 1090-2: the required accuracy of the torque in the second step ±4% From accuracy to ($V_{k.tool}$): Vk.too l= 0.04/1,65 = 0,024	B	0,024	0,024

Comined *k*-factor ($V_{comb.}$)	$(A^2 + B^2)^{0,5}$	0,065	0,065

Determination of the achieved reliability for the nominal minimum preload.

	top value for bolt assembly failure = 0,90		$f_{ub}A_s$	0,90	0,90
	bottom value for preload = 0,70		$f_{ub}A_s$	0,70	0,70
	coefficient of variation of *k*-factor (V_k) bolt assembly			0,10	0,10

a	Comined *k*-factor ($V_{comb.}$)			0,065	0,065
	Torque value for average target preload according to 8.5.3 line b)			**1,12**	
b	target/mean value Normal distribution		$f_{ub}A_s$	0,784	**0,800**
c	β- index for reliability 95%			1,65	1,65

d	5 % top value, should be equal or below 0,90	(1 + 1,65 x a)b	$f_{ub}A_s$	**0,868**	**0,885**
e	percentage to bolt assembly failure, should be equal or below 100%	d / 0,90	%	**96,4**	**98,4**
f	real β-index for reliability	(0,90-b)/(a x b)		2,290	1,934
g	reliability for failure	van f naar g	%	98,9	97,3

h	95% bottom value, equal or higher than 0,70	(1 -1,65 x a)b	$f_{ub}A_s$	**0,700**	**0,715**
j	percentage compared to minimal preload, shall be equal or over 100%	h / 0,70	%	100,1	102,1
k	real β-index for reliability	(b-0,70)/(a x b)		1,658	1,934
L	**reliability for nominal minimum preload, shall be equal or over 95%**	**from k to L**	%	**95,1**	**97,3**

Annex: D.2.1

Determination reliability of the HRC method for tightening bolt assemblies.
HRC method equitation present EN 14399-10 2:2015 and prEN 1090-2 revised

Input old EN 14399 version *Vk* = 0,10 and 2015 version Vk = 006 mean value 0,77 $f_{ub}A_{s}$.

			Old	Adjusted
Determination for the combined coefficient of variation (Vkt) including				
Coefficient of variation *k*-factor (V_k) for bolt assemblies. allowed in clause 7.5.2 of EN 14399-3 and EN 14399-4		A	**0,10**	**0,06**
Coefficient of variation *k*-factor (V_k) for installation tools				
EN 1090-2: the required accuracy of the torque in the second step ±4%				
From accuracy to ($V_{k.tool}$):	Vk.too l = 0.04/1,65 = 0,024	B	0,000	0,000
Comined *k*-factor ($V_{comb.}$)			**0,100**	**0,060**

Determination of the achieved reliability for the nominal minimum preload.

				Old	Adjusted
	top value for bolt assembly failure = 0,90		$f_{ub}A_s$	0,90	0,90
	bottom value for preload = 0,70		$f_{ub}A_s$	**0,70**	**0,70**
	coefficient of variation of *k*-factor (V_k) bolt assembly			0,10	0,06
a	Comined *k*-factor ($V_{comb.}$)			0,100	0,06
	Torque value for average target preload according to 8.5.3 line b)			1,10	1,10
b	target/mean value Normal distribution		$f_{ub}A_s$	0,77	**0,77**
c	β- index for reliability 95%			1,65	1,65
d	5 % top value, should be equal or below 0,90	(1 + 1,65 x a)b	$f_{ub}A_s$	0,897	0,846
e	percentage to bolt assembly failure, should be equal or below 100%	d / 0,90	%	**99,7**	**94,0**
f	real β-index for reliability	(0,90-b)/(a x b)		1,688	2,814
g	reliability for failure	van f naar g	%	95,4	99,8
h	95% bottom value, equal or higher than 0,70	(1 -1,65 x a)b	$f_{ub}A_s$	**0,643**	**0,694**
j	percentage compared to minimal preload, shall be equal or over 100%	h / 0,70	%	91,9	99,1
k	real β-index for reliability	(b-0,70)/(a x b)		0,909	1,515
L	**reliability for nominal minimum preload, shall be equal or over 95%**	**from k to L**	%	**81,8**	**93,5**

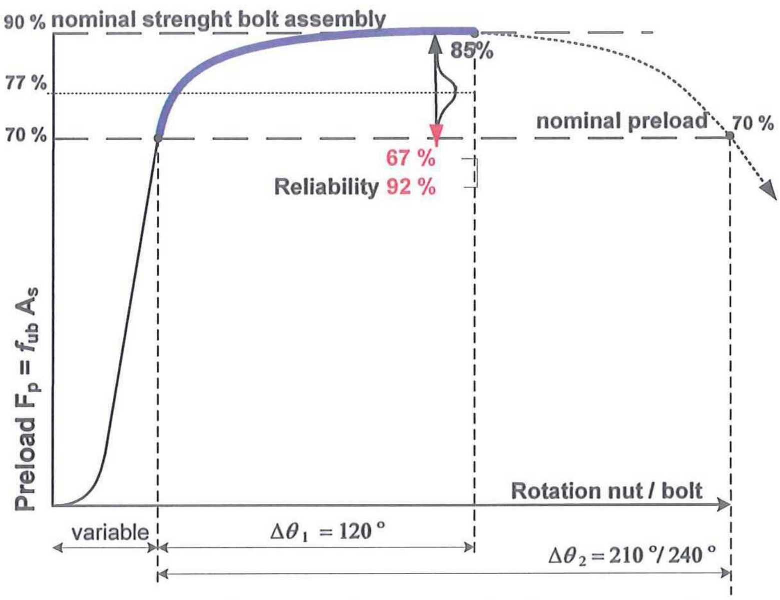
Annex: D.3

Differentiation of the to achieve preloads in the first step of the Combined preload method
using the in 8.5.4 EN 1090-2 allowed simplification $M_{r.1} = 0{,}125\ d\ F_{pC}$
in combination with the accuracies for the torquetools of 4% and 10%.

		maximum values		target value		minimum values
Allowed and ultimate values k_2 according to EN 1439-3 and	k_2	0,10		**0,125**		0,16
factors to k_{min} and k_{max}			1,25		0,781	
Differentiation factors	a		25%		21,9%	
Target value fist step Fp.1 = 0,75 $F_{p.C}$= 0,525 $f_{u.b}$	$f_{u.b}$ A_s			**0,525**	$f_{u.b}$ A_s	
Maximum and minimum values first step	$f_{u.b}$ A_s	0,656				0,410
combination factor + 4% torque (a^2 + 4^2)^0	4%		25,3%		22,2%	
	$f_{u.b}$ A_s	0,658				0,408
combination factor + 10% torque (a^2 + 10^2)^0,	10%		26,9%		24,1%	
	$f_{u.b}$ A_s	**0,666**	$f_{u.b}$ A_s		$f_{u.b}$ A_s	**0,399**
Maximum and minimum values first step, plus or minus 10%	$f_{u.b}$ A_s	0,722	+ 10%		- 0,10 %	0,369

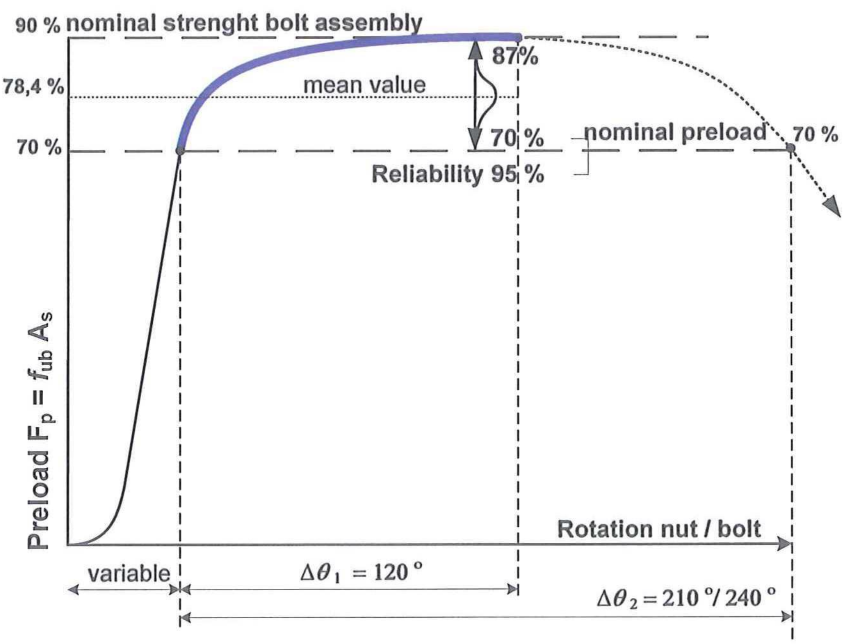
NOTE: Increase of the k-factor (friction) means decrease of the preload.

Figure D.1



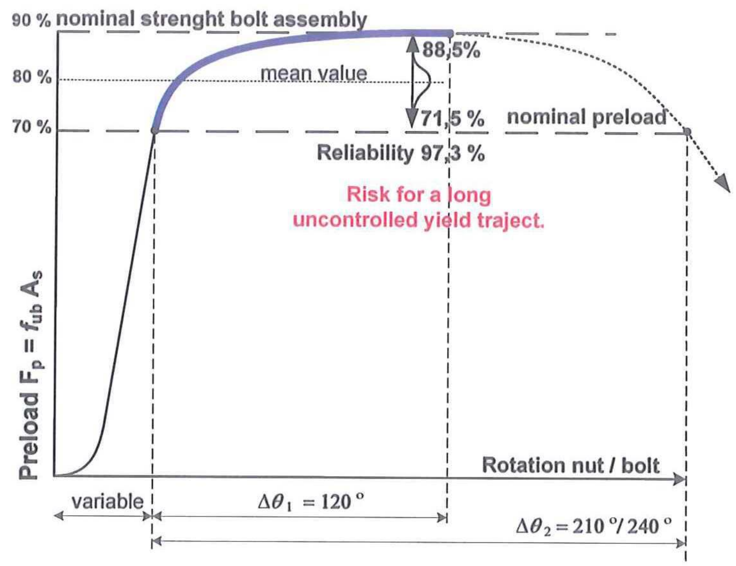
Torque method, distribution preloads according to EN 1090-2 art. 8.5.3
Version V_k = 0,06 with mean value 1,10 x 0,70 = 0,77 f_{ub} A_s

Figure D.2



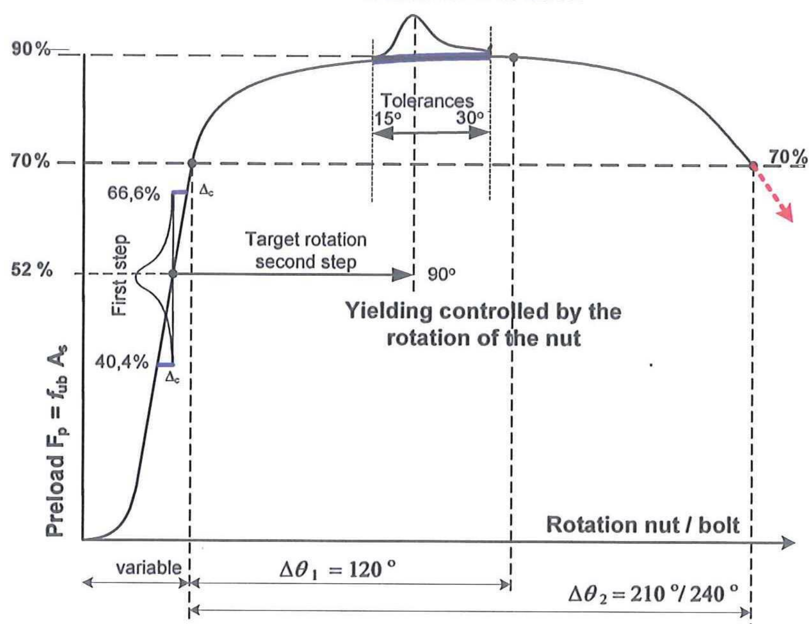
Torque method, distribution preloads according to EN 1090-2 art. 8.5.3
Version V_k = 0,06 with mean value 1,12 x 0,70 = 0,784 f_{ub} A_s

Figure D.3



Torque method, distribution preloads according to EN 1090-2 art. 8.5.3
Version V_k = 0,06 with mean value 0,80 f_{ub} A_s

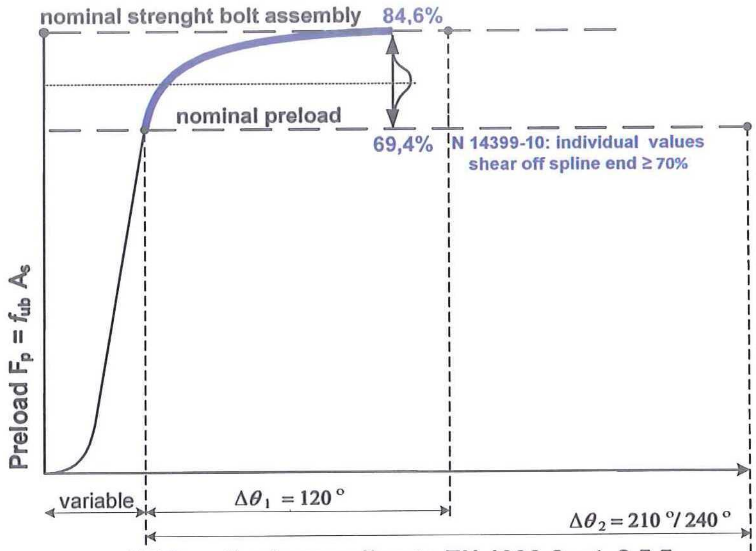
Figure D.4



Combined method, ditribution preoads according to EN 1090-2 art. 8.5.4

distribution second step with rotation differences Δ_c
In the first step neglected

Figure D.5

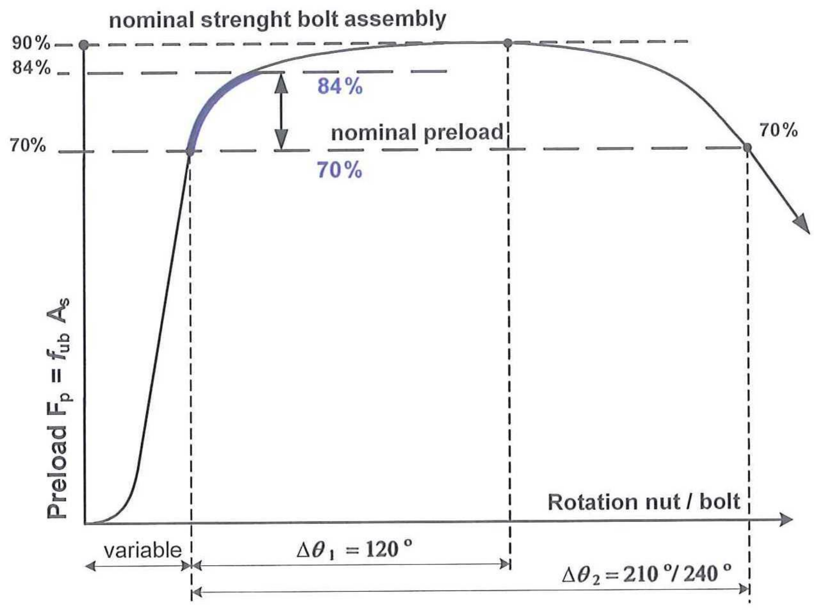


HRC method acoording to EN 1090-2 art. 8.5.5 and EN 14399-10

V_k = 0,06 mean value 0,77 $f_{ub}A_s$

The spline end of the bolt shall shear off before full strenght of bolt is reached

Figure D.6



DTI method, distribution according to table 4 of EN 14399-9