Guidelines for use of High Strength Friction Grip (HSFG) bolts on bridges on Indian Railways

1. Introduction: High Strength Friction Grip Bolts (HSFG) bolts are high strength structural bolts which have been tightened such as to induce tension in the bolt shank. Due to the tension in the bolt, the interface between the plies (steel members in a joint) cannot move relative to each other because of the friction resistance. The bolts act differently than normal bolts or rivets as explained below:

Friction along interface takes load in case of HSFG Bolt subject to shear

2. Scope: These guidelines cover the use of HSFG bolts in friction type joints for bridges covered by IRS Steel Bridge Code, from sizes M16 to M36. Galvanized bolts are not covered in these guidelines. These guidelines are intended only to help better understanding of the codal provisions. For actual design/ use, the source codes shall be referred to and followed.

3. Hierarchy of Codes: The guidelines have been prepared based on IS and EN codes, with modifications to suit the conditions for Indian railways. The hierarchy of codes shall be as follows:
   I. Provisions of IRS codes.
   III. Where IRS codes are silent, relevant IS codes may be referred.
      Where both IRS and IS codes are silent, EN codes may be referred.

4. Reference Codes:
III. IS 6623:2004 - High Strength Structural Nuts - Specifications

IV. IS 6649:1985 - Specification for Hardened and Tempered Washers for High Strength Structural Bolts and Nuts.


IX. EN 14399 Part 1 to 10 – High strength structural bolting for preloading.

X. EN 1090:2008, Execution of Steel Structures and Aluminium Structures part 2 – Technical Requirements for Steel Structures.

5. **Types of Bolts:** For the purpose of HSFG connections, only high strength structural bolts can be used. IS 4000 gives two property classes: 8.8 and 10.9 suitable for the same. Bolts shall conform to IS 3757. The bolts have the following characteristics:

   I. **Property class:** A property calls has two parts separated by a decimal in the form x.y. The first part, x, indicates 1/100 of the nominal tensile strength in Newton per sq mm and y indicates ten times the ratio of the lower yield stress and nominal tensile strength.\(^1\) For example, property class 8.8 means that the bolt will have nominal Ultimate Tensile strength of 800 N/mm\(^2\), and lower yield stress of 80% of 800 N/mm\(^2\), i.e. 640 N/mm\(^2\).

   II. **Identification:** The property class of bolts (8.8 or 10.9) shall be embossed or indented as 8S or 10S respectively on the top of head along with the manufacturer’s identification symbol.\(^2\) Alternately, marking ‘8.8 S’ or ‘10.9 S’ are also acceptable. The suffix ‘S’ here denotes that the bolt is high strength structural bolt with a large series hexagon.

1 Clause 3 of IS 1367(Part 3).

2 Clause 9 of IS 3757.
III. **Diameter:** IS 4000 gives diameters of HSFG bolts as M16, M20, M24, M30 and M36. Other sizes given in IS 1367 include M18, M22 and M27 (referred to as ‘non-preferred’ sizes also). For bridge works, these can be used and M22 size is readily available in the market.

IV. **Length:** The length of bolt shall be chosen such as to hold the steel members in position, with provision for the nut and washer(s) beyond the nut. Not just the length of the bolt, but also the thread length has to be specified. At least 4 full threads shall remain clear between the bearing surface of the nut and unthreaded part of the shank. This means that at least 4 threads shall extend into the members being joined by the bolt. Further, minimum one full thread pitch must protrude from the bolt after tightening. Most manufacturers have ready tables for the bolt lengths depending upon the steel plates to be gripped. Still, it will be prudent on the part of the field engineer to cross check the computations before ordering the bolts. Maximum grip length of all plies, including packings and packing washers, shall not exceed 10 times the nominal diameter of the bolt.

V. **Surface Finish:** All bolts shall be supplied with coating consisting of zinc phosphate that is used in conjunction with suitable oil of rust preventive type as per IS 1367 (Part XII).

VI. **Other Types of Bolts:** There are other types of bolts, called twist-off bolts which have an additional stem at the end, which are tightened using double acting torque wrenches and the additional leg twists off when the desired torque is reached. The twist off occurs due to the torque applied and is not a direct indicator of the force in the bolt. For rusted bolts, the value of tension may be appreciably less than that indicated by torque, hence these bolts has not been favoured for use on Indian Railways.

6. **Nut:** Each bolt shall be tightened using a high strength nut, conforming to IS 6623. The nut has to be strong enough to be able to impart the necessary torque to the bolt and also withstand the force during the life of the structure. Further, the nut shall be suitable for the threads in the HSFG bolt and shall be free running on the threads of the HSFG bolts.

I. **Property Class:** Nuts are designated by property class designation, which is equal to 1/100 of the minimum tensile strength in Newton per square mm of the bolt. For HSFG bolts, the property classes to be used are 8, and 10 as specified in IS 1367 (Part 8), suitable for bolts of property class 8.8 and 10.9 respectively. The nuts shall be hardened and then tempered at a temperature of at least 425°C. Normal height of nut shall be more than 0.8 times the nominal bolt diameter.

II. **Identification of Nut:** The nuts have the following markings:

   a) Manufacturer’s identification symbol.

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3 Clause 8.2.2 of EN 1090-2
4 Clause 8.3 of EN 1090-2
5 IS 3767 (Part 8).
6 Clause 5.1 of IS 6623.
7 Clause 10 of IS 6623.
b) Property class, marked as ‘8S’ or ‘10S’. (The suffix ‘S’ denotes a high strength structural nut with a large series hexagon.) Alternately, ‘8.8 S’ or ‘10.9 S’ are also acceptable.

![Typical markings on nuts](image)

The marking shall be either on the top or the bottom face of double chamfered nuts and shall be either indented or embossed on non bearing surface of washer faced nuts.

III. **Surface of Nut:** All nuts shall be supplied with coating consisting of zinc phosphate that is used in conjunction with suitable oil of rust preventive type as per IS:1367 (Part XII).

IV. **Position of nut in bolt:** To ensure that the nut is not easily accessible for opening out by anti-social elements, the same shall be provided preferably as follows:
   a) **In girder web:** Towards outside of the girder.
   b) **In flanges:** Towards bottom.
   c) **In composite construction:** Towards inside of concrete.
   d) **In bracing:** Towards the rolled section side so that the space for rotation of the nut is not readily available.
   e) Where **Tapered washer** is used, the nut shall preferably be on the other side.

7. **Holes for HSFG Bolts:** Normal holes in the steel members being connected by the rivets shall be used for HSFG bolts also, subject to the following:
   I. **Making of holes:** The holes shall be made by drilling only.
   II. **Nominal Diameter of Hole:** The nominal diameter of hole shall be 2 mm more than the bolt diameter \(^8\) i.e. for 20 mm dia HSFG bolt, the hole shall be 22 mm in diameter.
   III. **Oversize Holes:** In case the bolts are to be provided in existing structure, the maximum size of hole shall not exceed 1.25 d or d + 4 mm whichever is less i.e. for 16 mm dia bolt, the maximum diameter of hole shall not exceed 19 mm and for 24 mm dia bolt, the maximum diameter shall not exceed 28 mm.\(^9\)
   IV. **Use of Hardened Washers:** In case the hole diameter exceeds the bolt diameter by 2 mm, hardened washers shall be used in place of normal washers.

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\(^8\) Clause 6.1 of IS 4000.

\(^9\) Proposed correction slip to IRS Steel Bridge Code.
8. **Washer:** Annular rings which are provided between the bolt head/ nut and the members being joined are called washers. Washers for HSFG bolts shall conform to IS 6649. The washers have the following characteristics:

I. **Types:** Three types of washers have been specified in IS 6649, clause 2:
   a) Type A: Plain hole circular washers.
   b) Type B: Square taper washers for use with channels (6° taper)
   c) Type C: Square taper washers for use with I-beams (8° taper)

II. **Identification:** Type A washers shall be identified by provision of two nibs (small projections) and manufacturer’s identification symbol in indented character. The type B and C washers shall be identified by the type identification symbol, B or C and the manufacturer’s identification symbol.\(^{10}\)

![Typical markings/shapes on plain and tapered washers](image)

III. **Surface Finish:** All washers (except DTIs) shall be supplied with coating consisting of zinc phosphate that is used in conjunction with suitable oil of rust preventive type as per IS 1367 (Part XII).

IV. **Types of washers:**
   a) **Plain washer:** HSFG bolts shall be provided with minimum one washer. Normally plain washer is provided. The washer(s) is (are) provided to prevent wear of the steel members being joined and coating thereon during the tightening of bolt.
   b) **Packing washers:** If the bolt is longer than required, packing washers may be used. **However, the maximum number of packing washers shall be limited to 3, with maximum total combined thickness of 12 mm.**\(^ {11}\)
   c) **Hardened washer:** For oversize holes, hardened washers shall be used.\(^ {12}\) These washers are required to prevent punching of the nut in the annular space around the bolt shank.

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\(^{10}\) Clause 12 of IS 6649.

\(^{11}\) Clause 8.2.4 of EN 1090-2

\(^{12}\) Clause 6.3.2 (a) of IS 4000
Note: IS 6649 specifies only one type of washers, which are through hardened and tempered\textsuperscript{13}, so all the above terms i), ii) and iii) refer to the same type of washer only.

d) **Tapered Washer:** Where the angle between the axis of bolt and the joint surface is more than 3 degree off normal, a tapered washer shall be used against the tapered surface. Non rotating surface shall preferably be placed against tapered washer.\textsuperscript{14}

V. **Inspection of Washers:** All washers shall be flat with a maximum deviation not exceeding 0.25 mm from straight edge laid along a line passing through the center of the hole.\textsuperscript{15}

VI. **Direct Tension Indicators (DTI):** The Direct tension Indicators are special type of washers with indentations which get pressed when the tension is applied. DTIs are very good method of ensuring that the bolts are tightened properly, and shall be preferred over plain washers. The DTIs normally are patented products and shall be supplied preferably with zinc phosphate coating as for other washers, but alternatively can be with any other corrosion prevention treatment given to the surface as specified by the manufacturer. These shall normally be provided below the head of the bolt in case nut is rotated. In case the bolt is to be rotated, an additional washer shall be provided on the DTI side to protect the protrusions from damage due to the abrasion during bolt tightening. Measuring the amount by which the indentations have been pressed indicate if the bolts have been tightened to the desired tension level. The DTIs used shall be the ones which are compatible metallurgically and also suitable for the bolts of property class 8.8 and 10.9. Action of DTIs is as indicated below:

VII. **Other Types of Tension Indicators:** There are other proprietary tension indicators such as those that have squirting action, those having rubber projections which shear off when full tension load is applied etc. These tension indicators have not been considered in these guidelines.

\textsuperscript{13} Clause 6 of IS 6649.
\textsuperscript{14} Clause 7.1.2 of IS 4000.
\textsuperscript{15} Clause 3.1 of IS 6649
VIII. **No of washers to be provided:**

a) Each bolt of property class 8.8 shall have minimum one plain washer, which shall be provided in the part being rotated.\(^{16}\) Mostly the nut is rotated, but if space constraint is there, the reverse is true.

b) For class 10.9 bolts, two washers shall be provided, one against head and one against the nut.\(^ {17}\) The two washers are required in this case because of very high tension is imparted to the bolt, which can damage the steel members, especially softer mild steel members used on Indian Railways most commonly.

c) In case DTI is being provided, the same will count as one washer. If the nut is rotated, the DTI shall be provided under the head, and if the head is rotated, the DTI is to be provided under the nut. If DTI is used under the nut, washer faced nut as per IS 6623 shall be provided.

9. **Surface preparation for steel interface before providing HSFG bolts:** The steel interface between the plies which form a joint having HSFG bolts shall have special surface preparation so that sufficient slip factor is available. The following surface preparation shall be done:

   I. **New construction:** The interface between the plies which are connected together by the HSFG bolts shall be “Aluminium metallised without any over coating”. The aluminium metallising shall be as per para 39.1 of IRS B1 and shall have nominal thickness of 150 μm.

   II. **Existing structures:** The interface of plies which are to be included in the HSFG bolts shall be cleaned by wire brushing/ flame cleaning equivalent to the surface specified in IRBM para 217, 1 (b), (i) to (iv).\(^ {18}\) The surfaces shall be cleaned to remove all loose rust and paint layers (Only isolated patches of coatings/ rust can remain). If, however, in existing structures, rivets are to be replaced by bolts but no surface preparation is possible, the slip factor shall be suitably reduced.

10. **Installation of bolts:**

   I. Basic principles: The HSFG bolts work on the principle of applying a specified pre-load on the joint such that the plies in the joint are joined together without any gap.

      a) **Basic principle of tightening:** The tightening of HSFG bolts is to be done at stress level which is beyond the yield point, i.e. the plastic flow of material shall take place. This is important because the yield point of bolt material is well defined and after this level, the strain increases without increase in stress, as shown in figure below:

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\(^{16}\) Clause 7.1.1 of IS 4000.  
\(^{17}\) Proposed correction slip to IRS B1.  
\(^{18}\) Proposed correction slip to IRS Steel Bridge Code.
The effort through the tightening procedures is to lead the bolt into the horizontal part of the bolt tension/ elongation curve as shown above.

b) **Sequence of tightening:** The following steps shall be followed for tightening of bolts:
   i. The holes shall be brought in alignment by using drifts etc such that the bolt threads are not damaged during insertion of bolts. Drifting shall not distort the metal or enlarge the holes.\(^{19}\)
   ii. The tightening shall not proceed until the gap between the plates has been closed as given below.
   iii. HSFG bolts may be used temporarily during erection to facilitate assembly, but if so, the bolts shall not be finally tensioned until all bolts in joint are tightened to first stage.\(^{20}\)
   iv. During tightening of bolts also, the steel members can continue to deform and hence the tightening of subsequent bolts can lead to loosening of already tightened bolts. In order to minimize the loosening of already tight bolts, tightening in the two stages shall be done starting from the stiffest part to the free edges.\(^{20}\) Stiffest parts of joint are generally towards the center of the joint.

c) **Max gap at edge:** The plates/ members shall be fitted together and bolts shall be tightened. The residual gap shall be limited to 2 mm only at edges, provided it is certified that the central portion is in close contact after the corrective action (i.e. straightening of plates) is taken on the steel components.\(^{21}\)

II. **Installation Using direct Tension Indicator:** This is the preferred method of installation of HSFG bolts.

a) **Calibration of Direct Tension Indicator:** Before the DTI are brought to site, the same shall be tested in the presence of engineer. Three nos bolts of similar diameter and property class as shall be used in the work shall be taken and installed with DTI. The installation procedure to be followed shall be similar to the one given for plain washers. On full tightening, the projections on DTI washers shall meet the

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\(^{19}\) Clause 7.1.4 of IS 4000.

\(^{20}\) Clause 7.1.5 of IS 4000

\(^{21}\) Clause 8.5.1 and 8.3 of EN 1090-2
requirements of checks specified after second stage tightening using DTIs. **Only the DTIs which satisfy the calibration shall be brought to site for work.**

b) **Procedure:**\(^{22}\) The tightening is done in two steps so that the bolts already tightened do not get loose when the subsequent bolts are tightened.

i. **First Stage of Tightening:** As a first stage, all bolts in the joint shall be tightened to ‘snug tight’ condition. Snug tight condition means the nut is tightened using an ordinary wrench by an average worker, applying maximum force on the wrench. This stage is required to bring the plies in close contact.

ii. **Checks after First stage tightening:** After first stage of tightening, the joint shall be checked to see if the plies are in close contact and the clearances are not exceeded.

iii. **Second Stage of Tightening:** During the second stage of tightening, torque wrench is used to tighten the bolts until the indentations on the DTI indicate full tightening.

iv. **Checks after Second stage tightening:**\(^{23}\) Feeler gauge shall be used to check 100% of the bolts for proper tightening. The feeler gauge shall be 0.40 mm thick. The feeler gauge shall be used to determine if the bolt has been sufficiently tightened, as follows:

<table>
<thead>
<tr>
<th>Number of positions of indicator gauge refusals*</th>
<th>Minimum number of feeler gauge refusals*</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>9</td>
<td>5</td>
</tr>
</tbody>
</table>

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

\(^{22}\) Based on clause 8.5.6 of EN 1090-2.

\(^{23}\) Annexure J of EN 1090-2.
III. **Installation With ordinary washers:** If there is some problem with availability of DTIs, plain washers may be used for installation of HSFG bolts using the following procedure:

**Procedure:** The tightening is done in two steps so that the bolts already tightened do not get loose when the subsequent bolts are tightened.

i. **First Stage Tightening:** In the first stage, a calibrated wrench with an accuracy of ±10% shall be set to 75% of the torque computed for the complete tightening of the bolt. All the bolts in the joint shall be tightened to this torque. After checking all bolts after the first stage, permanent marks shall be made with suitable marker on the bolt as well as nut to indicate the relative position of the two. The mark shall be such that the same shall be visible for inspection upto 1 year after the date of installation.

ii. **Checks after first stage:** After the first stage of tightening, following shall be checked:

a) The steel members that make up the plies of the joint with HSFG bolts shall be checked for proper contact.

b) 10% bolts shall be checked with a separate calibrated wrench set at 75% of the proof load for the bolt and any bolt turning by more than 15° during the same shall be rejected. If the loose bolts thus found are more than 5 but less than 1% of the total, another 10% of the bolts shall be checked. If the total loose bolts thus found exceed 1% of the total, the torque wrench shall be calibrated afresh and the entire lot shall be checked for tightness.

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24 Based on clause 8.5.4 of EN 1090-2.
iii. **Second Stage Tightening:** Then the bolts shall be turned by a further amount as specified below:

<table>
<thead>
<tr>
<th>Total nominal thickness “t” of parts to be connected (including all packing and washers), d = dia of bolt</th>
<th>Further rotation to be applied, during the second stage of tightening</th>
</tr>
</thead>
<tbody>
<tr>
<td>t &lt; 2d</td>
<td>60</td>
</tr>
<tr>
<td>2d ≤ t &lt; 6d</td>
<td>90</td>
</tr>
<tr>
<td>6d ≤ t ≤ 10d</td>
<td>120</td>
</tr>
</tbody>
</table>

iv. **Checks after second stage tightening:** After the second stage of tightening, following shall be checked:

a) 100% bolts shall be checked and certified to have been turned through the requisite amount by verifying the permanent marks on the nut and the bolt.

b) 1% of the bolts, subject to minimum of 10 per size of bolts shall be checked for gross under-tightening as per procedure given in Annexure D of IS 4000.25

IV. **Retensioning of bolts:**

a) The HSFG bolts are tightened beyond yield stress level and undergo plastic deformation once tightened fully. If the bolt is opened out after complete tightening, its length gets increased permanently as compared with the initial length. The initial few threads which transfer the load from the nut to the bolt suffer the maximum damage. Therefore, a bolt completely tightened shall not be reused under any circumstances.26

b) The bolt tensioned completely can be identified by damage to the threads especially near the front end of nut where most of the load is transferred. The coating, if any, may also show signs of damage. The free running of the nut on the threads may also be affected.

c) A bolt which has been snug tightened or partially tightened and then opened out will not be considered to have been retensioned and reuse of such bolts will be permissible in the same or different holes, as required.

V. **Specifications of torque wrench:** Except for works of minor nature where number of HSFG bolts to be installed is very less, only mechanical torque wrenches (pneumatic, hydraulic, electronic etc) shall be used for tightening of bolts.27 For small quantum of work, manual torque wrenches may be used.

VI. **Calibration of torque wrench:** Calibrated torque wrenches, accompanied with a certificate to the effect, shall be brought to site. Torque wrenches shall be calibrated periodically once in a year to an accuracy of ±10%. These shall be re-calibrated in case of any incidence involving the wrench during use resulting in heavy impact (such as fall,

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25 Proposed correction slip to IRS B1.
26 Proposed correction slip to IRS B1.
27 Proposed correction slip to IRS B1.
mishandling etc). The procedure for calibration of torque wrench shall be as specified by the manufacturer.

VII. **Other methods of Tensioning:** There are other methods of tensioning, but only the two methods outlined above have been found to be suitable as per the field conditions prevailing on Indian Railways.

11. **Maintenance of HSFG bolts:**

   I. **Anti-theft and Anti-sabotage measures:** HSFG bolts upto 20 mm diameter can be opened, especially in the bracing/ cross frames near the supports or in accessible girder locations. Larger bolt diameters require considerable force to open and cannot be opened by stealth. **Where it is apprehended that theft/sabotage might take place, the bolt threads may be destroyed by applying welding tack to the bolt projection beyond the nut after final tightening and inspection. The tack shall not be more than 5 mm long and not more than 3 mm in size.** It shall be especially ensured that too much heat is not imparted to the bolt as to alter its metallurgical properties. Further, **hammering of bolts to damage its threads is likely to affect the entire bolt assembly and is not recommended.**

   II. **Inspection:** During inspection, the bolts shall be seen for the following:
      a) **Broken/ missing bolts.**
      b) **Loose bolts:** The identification of loose bolts shall not normally require testing by hitting etc. Looseness can be identified by looking at the signs such as water ingress in the joint, signs of rust coming from inside the joint and fine powdery material coming out of joint etc. If it is suspected that the bolts are loose, the same shall be checked as per procedure given in Annexure D of IS 4000. **Loose bolts shall be marked by a round circle all around it and shall be replaced expeditiously. Retightening of bolts is not allowed.**

   III. **Painting:** The HSFG bolts shall be painted as per normal painting schedules and painting methodologies as specified in the Indian Railways Bridge Manual for the girder as a whole.

**DESIGN:** Bearing type joints as defined in IS 4000 shall not be provided on bridges covered by IRS Steel Bridge Code. Only friction type joints shall be provided for all structures covered under IRS Steel Bridge Code.

1. **Plies:** The plates/ members joined together through HSFG bolts are called plies. To join dissimilar members, suitable packing shall be provided if the difference in thickness is more than 1 mm. From maintenance considerations, too thin packing plates are not desirable. In design, no additional factor need be considered for the packing thickness.\(^\text{28}\)

2. **Diameter of bolt:** Normally, for structural design, 20 mm or 22 mm dia bolts shall be chosen. However, if the joints are to be made smaller and for better detailing 24 mm and larger diameter bolts can be used. The bracing can also be design with 20 mm/ 22 mm dia bolts. However, if the load is too less, such as in foot over bridges, smaller diameter bolts can be used.

\(^{28}\) Clause 5.5.1 of IS 4000
3. **Diameter of hole**: The nominal diameter of hole shall be 2 mm more than the bolt diameter\(^{29}\) i.e. for 20 mm dia HSFG bolt, the hole shall be 22 mm in diameter. If the HSFG bolts are being used in existing structures, the oversize holes may be permitted subject to maximum of 1.25 d or d + 4 mm, whichever is less.

4. **Deduction for holes**: The deduction for holes and for asymmetric connections to get the effective area of the members shall be done in a manner similar to the one adopted for the holes for rivets and other bolts, as per provisions of IRS Steel Bridge Code.

5. **Property class to be chosen**: Property class 8.8 bolts are better as these are ductile and have good reserve strength. However, if the joints are to be made smaller and/or for better detailing, we can go for property class 10.9.

6. **Slip factor to be adopted**: Following values of slip factor shall be used in design:\(^{30}\)

<table>
<thead>
<tr>
<th>S No</th>
<th>Surface Preparation of the interface between plies in a HSFG bolted joint</th>
<th>Slip factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Surface blast cleaned and spray metallized with aluminium (thickness &gt; 50 µm), with no over coating</td>
<td>0.40</td>
</tr>
<tr>
<td>2</td>
<td>Surfaces cleaned by wire brushing or flame cleaning, with loose rust and paint layers removed (Only isolated patches of coatings/ rust can remain)</td>
<td>0.25</td>
</tr>
<tr>
<td>3</td>
<td>Any other surface preparation</td>
<td>To be established as per procedure given in Annexure B of IS 4000.</td>
</tr>
</tbody>
</table>

**Note**: HSFG bolts shall not be provided in existing structures, unless it has been assured that adequate slip factor is available.\(^{31}\) If it is not possible to make proper surface preparations as given in S No 2 above, the HSFG bolts shall not be provided and the existing rivets shall be replaced by appropriate close tolerance turned bolts as per IS 1364 and para 28.6 and 28.7 of IRS B1.

The preparation of surface by removal of paint is not allowed for new construction. If interface has been painted inadvertently, the same shall be sand/grit blast cleaned and metallising shall be done, even if the surface was already metallised.

7. **Design of joints subject to shear**: Most of the bolts in girders such as those that connect the bracing, cross frames, flange angles with web etc are subject to pure shear loading only. The design of HSFG bolts for such applications shall be such as to ensure that the shear force applied does not exceed\(^{32}\):

The minimum bolt tension is as specified in table 3 of IS 4000 and factor of safety shall be 1.4 under normal loads. Where the effect of wind load has to be considered on the structure, this factor of safety may be reduced to 1.2, provided the connections are adequate when (i) wind forces are not considered, and (ii) wind load is not the primary loading for the purpose of

\(^{29}\) Clause 6.1 of IS 4000.

\(^{30}\) Proposed correction slip to IRS Steel Bridge Code.

\(^{31}\) Proposed correction slip to IRS Steel Bridge Code.

\(^{32}\) Clause 5.4.2 of IS 4000.
design.\textsuperscript{33} In other words, the factor of safety shall be adopted 1.4 for Foot Over Bridges where wind load is a primary load. The same may be taken as 1.4 or 1.2 as per load case in case of Railway girders, Road Over bridges and turn tables etc where wind load is not a primary load.

8. **Design of joints subject shear as well as tension**: Some joints such as the connection of the bracket sideways on a column are of the nature of partial fixity. The bolts might be subject to some axial loads along with shear in such a case. Due to externally applied tension, the effective clamping action of a bolt is reduced. To account for this, bolt shall be proportioned to satisfy the expression:

\[
\text{The value of factor F shall be taken as 2.0 if external force is repetitive and 1.7 if non repetitive.}
\]

A question might arise here in the mind of designers that the tension in bolt ought to be reduced to allow for the tension which is coming from the load. However, it has been found that the actual tension change in the bolt due to the applied load is very less and the full tension may be applied, provided the tensile load is not too much large as compared with the shear load.

9. **Limitation of Shear Transmitted to Plies**: The bearing force transmitted between any bolt and any ply shall not exceed 1.2 $f_y d t$ where $f_y$ is yield stress of the ply, $d$ is nominal dia of HSFG bolt and $t$ is the thickness of ply. In addition, the component of force acting on the edge of a bolt in the direction of the minimum distance toward the edge of a ply shall not exceed $e \times f_y d t/1.4$.\textsuperscript{34} (where $e$ is edge distance of bolt plus half the bolt diameter, in mm). These provisions are meant to prevent failure of the steel members joined together by the HSFG bolts.

10. **Design of joints subject to pure tension**: Normally the bolts in railway application are not subject to pure tension. However, if such joints are to be designed, the tension in the bolts shall be limited to the values given in table 2 of IS 4000. (Which are equal to 0.6 times the minimum bolt tension specified in table 3 of IS 4000).\textsuperscript{35} In case the bolts are subject to tension in fatigue conditions, the minimum tensile force in the bolt shall not exceed 50% of the minimum bolt tension values specified in table 3 of IS 4000.\textsuperscript{36} It may be noted that at these lower tension levels, the bolt will not be tightened beyond yield point and will behave like an ordinary bolt. Suitable safeguards to ensure that the bolts do not get loose under loads need to be taken.

11. **Fatigue design**: The HSFG bolts are pre-tensioned and the level of this tension does not change much even when subjected to repetitive loads, so these need not be designed separately for fatigue.\textsuperscript{37} The structural steel plies which are connected by the HSFG bolts shall be designed for fatigue, if these are subjected to fluctuating loads as given in IRS Steel Bridge code. The fatigue category of the steel members shall be as given in IRS Steel Bridge Code (The provisions of IRS Steel Bridge Code regarding fatigue are under revision, and the HSFG or preloaded bolts are

\textsuperscript{33} Clause 5.4.2 of IS 4000.
\textsuperscript{34} Clause 5.3.4 of IS 4000.
\textsuperscript{35} Clause 5.2 of IS 4000.
\textsuperscript{36} Clause 5.2.1 of IS 4000.
\textsuperscript{37} Clause 5.4.2 of IS 4000, subject to provisions of Clauses 5.2.1 and 5.4.3.
covered under the fatigue categories in the proposed correction slip). It is worth mentioning here that the fatigue category of members connected by HSFG bolts is higher than that for the members connected by rivets. This is because the shank and hole edges, where stress concentration is there in case of rivets, do not come into action in case of HSFG bolts, resulting in better fatigue performance of members.

12. **Detailing:** The detailing of the HSFG bolts shall be done as per IRS Steel Bridge Code rather than IS 800 as mentioned in clause 1.3 of IS 4000. Other provisions where IS codes are referred, IRS codes shall take precedence. Where both IRS and IS codes are silent, Euro codes shall be referred. Some provisions of the IRS Steel Bridge Code are enumerated for information below:

<table>
<thead>
<tr>
<th>Provision</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Edge distance (Minimum)</strong></td>
<td>1.75 d for sheared or hand flame cut edges &lt;br&gt;1.5 d for rolled, machine flame cut, sawn or planed edge</td>
</tr>
<tr>
<td><strong>Edge distance (Maximum)</strong></td>
<td>4 t + 40 mm from nearest edge.</td>
</tr>
<tr>
<td><strong>c/c spacing (Minimum)</strong></td>
<td>2.5 d’</td>
</tr>
<tr>
<td><strong>c/c spacing (Maximum) Adjacent rivets in tension/ compression</strong></td>
<td>32 t or 300 mm whichever is lesser</td>
</tr>
<tr>
<td><strong>c/c spacing (Maximum) Bolts lying in direction of stress tension/ compression</strong></td>
<td>16 t or 200 mm whichever is lesser</td>
</tr>
<tr>
<td><strong>c/c spacing (Maximum) Bolts lying in direction of stress compression</strong></td>
<td>12 t or 200 mm whichever is lesser &lt;br&gt;<strong>If load is transferred by butting in compression members, for a length equal to 1.5 times width, the spacing shall not exceed 4.5 d.</strong></td>
</tr>
<tr>
<td><strong>c/c spacing (Maximum) Staggered, gauge not exceeding 75 mm</strong></td>
<td>50% more than the values given in clause 7.4.2 and 7.4.3</td>
</tr>
<tr>
<td><strong>Maximum Length of Bolt</strong></td>
<td>The grip including the plies, packings and packing washers shall not exceed 10 times the nominal bolt diameter.</td>
</tr>
</tbody>
</table>

Where d is diameter of hole <br>t is thickness of thinner outside plate <br>d’ is the nominal diameter of the bolt/rivet

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38 Proposed correction slip to IRS Steel Bridge Code.
DO’S AND DON’T’S FOR CONSTRUCTION ENGINEERS

DO’s:

- Do ensure that all bolts, nuts and washers are coated with zinc phosphate, sealed with suitable oil of rust-prevention type (Only DTIs may have other surface coatings as approved by the manufacturer).
- Do metallise the surface which is to be connected by the HSFG bolts.
- Do make sure that there is proper storage arrangement for the bolts, nuts and washers away from moisture, rain, dust, dirt and sunlight.
- Do clean and lubricate the bolt and nut threads if these are dirty.
- Do ensure that the nut moves freely on the bolt threads.
- Do use only calibrated torque wrench (Calibrated within last 1 year).
- Do check at least 10% of the bolts after initial tightening and 100% after second tightening.
- Do use tapered washers wherever required.
- Do check the tightening procedure if bolt breaks during tightening operation. It obviously means that the bolts are being over-tightened.
- Do tighten the bolts starting from the stiffest part (middle of the joint) to the free edges.
- Do provide small welding tack after final tightening and inspection to damage the threads to prevent the bolt from being opened where threat of sabotage/theft is apprehended.

DON’T’s:

- Don’t paint the interface which has been metallised.
- Don’t reuse a bolt which has been fully tightened once.
- Don’t use rusted and dirty bolts.
- Don’t hammer the bolts to damage the threads.
- Don’t overheat the bolt while making welding tack as the bolt might get damaged.
- Don’t use Direct Tension Indicator which have not been calibrated.