Research Design and Standards Organization, Lucknow

Report no BS-111

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

Typical splice joint with HSFG bolts

June 2012
Foreword

Steel is an important material for construction of bridges. The connections in shop are now being made by submerged arc welding. But for field connections, rivets have been traditionally used. The riveted connections have served us well for over 150 years. But the rivets pose some difficulties:

1. In difficult and inaccessible areas, making rivets is difficult and often quality of rivets in such locations is very poor.
2. For large grips, longer rivets are required. The shanks of these rivets are difficult to be heated uniformly and while transporting the hot rivets, the same get differentially cooled and the rivets are not able to completely fill up the annular space all round.
3. With changing times, Indian Railways and the only major organization in India still using structural rivets and the availability of skilled labour required for riveting is diminishing.

RDSO has been seized of these issues and has been looking for replacement of the rivets with some other type of connections and High Strength Friction Grip (HSFG) bolts have been found suitable for the same. These can be used in road bridges as their use has been permitted by IRC codes. For railway bridges, the relevant codes are required to be changed (clauses pertaining to design of HSFG bolts for railway loading need to be introduced) before the HSFG bolts can be used for the same.

While preparing these guidelines IS codes, Eurocodes, American codes and literature on the subject have been referred. The drawings issued by zonal railways incorporating HSFG bolts for ROBs were also studied. RDSO has tried to make the guidelines comprehensive and cover the design, installation and maintenance aspects in the same. The concerns of engineers about theft and sabotage have also been addressed in the guidelines. The draft guidelines were published on internet for comments at RDSO website as well IRICEN website and lots of comments have been received. RDSO is thankful to Shri Gautam Bose from Panchsheel fasteners, Shri A Ghoshal from M/S STUP Consultants, Shri Naresh Lalwani, SPB2, IRICEN, Shri Y S Hooda, Director (B & S) RDSO, Shri Murthy Raju, DyCE/C/D S W Rly and Shri Radhakrishan, SSE(B), S Rly, for their very useful comments. The comments from Shri Lalwani and Shri Ghoshal were in detail and RDSO is thankful to them for devoting so much time for studying the draft guidelines closely.

The comments received have been incorporated in the guidelines. All the users, designers as well as field engineers are requested to give the feedback on HSFG bolts to RDSO at e mail id directorsteel2@gmail.com so that the codal provisions can be improved and practical difficulties, if any, in implementing the guidelines are taken care of.

Executive Director (B & S) RDSO
June 2012
Basics about HSFG Bolts

1. **Introduction:** Rivets have been used historically for making field connections in steel girders subject to railway and highway loadings. Rivets, however, require skilled workers and elaborate equipment/arrangements. With passage of time, the availability of such labour and equipment for small quantum of work is becoming difficult and Indian Railways (IR) is looking for alternatives to rivets. Also, rivets are difficult to make when the grip length increases as the uniform heating of longer rivets and also ensuring that rivets do not cool down before the same is driven becomes problematic in field. One option for substitute for rivets, namely High Strength Friction Grip (HSFG) bolts is covered in these guidelines. HSFG bolts are high strength structural bolts which have been tightened such as to induce predefined 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 frictional resistance. The bolts act differently than normal bolts or rivets as explained below:

- **Ordinary Bolt action 1:** Bearing of bolt/plate
- **Ordinary Bolt action 2:** Shearing of bolt

Friction along interface transmits 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 to help better understanding of the codal provisions.**
For actual design/ use, the source codes shall be referred to and followed. These guidelines cover the use of HSFG bolts in Road Over Bridges as well as Railway Bridges. At the moment, IRC codes allow use of HSFG bolts but IRS codes are silent. Correction slips are being proposed to IRS codes for incorporating provisions related to HSFG bolts after which, HSFG bolts can be used as an alternative to the rivets in all types of railway bridges. Due to different actions, HSFG bolts cannot be used in conjunction with rivets/ welds without considering the action.

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.
   II. Where IRS codes are silent, relevant IS codes may be referred.
   III. 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.
   VII. IS 1367 (Part 6) – 1994 (reaffirmed 2004) – Mechanical properties and test methods for nuts with specified proof loads
   VIII. EN 1993-1-8: 2005 – Design of Steel Structures – design of joints
   IX. EN 14399 Part 1 to 10 – High strength structural bolting for preloading.

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 for the same. Bolts shall conform to IS 3757. The bolts have the following characteristics:

   I. **Property class:** A property class 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. For example, property class 8.8 means that the bolt will have nominal Ultimate Tensile strength of 800 N/mm², and lower yield stress of 80% of 800 N/mm², i.e. 640 N/mm².

   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.

(a) A bolt assembly (b) Typical Marking on bolt-heads

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.

![Diagram](image)

**Fig: Typical Assembly of HSFG bolt**

IV. **Length:** The length of bolt shall be chosen such as to hold the steel members in position, with provision for the nut, washer(s) and some projection beyond the bolt. Along with the overall length of the bolt, 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\(^3\) (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 nut after tightening.\(^4\) The minimum length of bolt shall be worked out on the basis of maximum grip length covering maximum limits of ply thickness plus an additional allowance\(^5\) given in table 1 of IS 4000. Table 1 of IS 4000 is reproduced below:

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\(^2\) Clause 9 of IS 3757.
\(^3\) Clause 8.2.2 of EN 1090-2.
\(^4\) Clause 8.3 of EN 1090-2.
\(^5\) Clause 4.1.1 of IS 4000.
<table>
<thead>
<tr>
<th>Nominal Size of Bolt</th>
<th>Nominal Dia of Bolt</th>
<th>Allowance for Grip in mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>M 16</td>
<td>16</td>
<td>26</td>
</tr>
<tr>
<td>M 20</td>
<td>20</td>
<td>31</td>
</tr>
<tr>
<td>M 24</td>
<td>24</td>
<td>36</td>
</tr>
<tr>
<td>M 30</td>
<td>30</td>
<td>42</td>
</tr>
<tr>
<td>M 36</td>
<td>36</td>
<td>48</td>
</tr>
</tbody>
</table>

Table 1 of IS 4000

For M 22 bolts, the allowance for grip shall be 34 mm. 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 force in bolt 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 threads in nut shall be matching with the threads in the HSFG bolt and the nut 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 6), 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.

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.

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6 IS 3767 (Part 8).
7 Clause 5.1 of IS 6623.
8 Clause 10 of IS 6623.
Typical markings on nuts

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:** HSFG bolt cannot be easily opened out except by use of torque wrench. Still, as an additional precaution, it may be ensured 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 (Except when in composite construction).
   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\(^9\) 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 20 mm and for 24 mm dia bolt, the maximum diameter shall not exceed 28 mm.\(^{10}\)

   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.

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:

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\(^9\) Clause 6.1 of IS 4000.

\(^{10}\) Proposed correction slip to IRS Steel Bridge Code.
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 ($6^0$ taper)
   c) Type C: Square taper washers for use with I-beams ($8^0$ taper)

**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.\(^{11}\)

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

![Typical bolt head assembly with washer](image)

II. **Categories 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.\(^{12}\)

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\(^{11}\) Clause 12 of IS 6649.

\(^{12}\) Clause 8.2.4 of EN 1090-2
c) **Hardened washer**: For oversize holes, hardened washers shall be used.\(^{13}\) These washers are required to prevent punching of the nut in the annular space around the bolt shank.

**Note**: IS 6649 specifies only one type of washers, which are through hardened and tempered\(^ {14}\), so all the terms a), b) and c) above 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.\(^ {15}\)

### 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. Dimensional Deviation for 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.\(^ {16}\)

### V. Direct Tension Indicators (DTI):
The Direct Tension Indicators are special type of washers with indentations which get pressed when tension is applied. The pressing of indentations to required level indicates that the required tension has been applied in the bolts. Resemblance of DTIs with washers is incidental. In fact, these are precision engineered mechanical load cell which is the most reliable method for checking HSFG bolt tensioning. As shown in figure below, DTIs have multiple projections, between which the feeler gauge is to be inserted to check if the bolt has been sufficiently tightened or not. Complete closing of the projections, however, may indicate either overtightening or poor quality material in DTI.

DTIs are very good method of ensuring that the bolts are tightened properly, and this method of tightening shall be preferred over the method with plain washers. The DTIs normally are patented products and shall be supplied preferably with zinc phosphate coating, 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 (with projections towards bolt head) in case nut is rotated. In case the bolt is to be rotated, DTI shall be provided under nut (with projections towards nut) and in this case, 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.

\(^{13}\) Clause 6.3.2 (a) of IS 4000
\(^{14}\) Clause 6 of IS 6649.
\(^{15}\) Clause 7.1.2 of IS 4000.
\(^{16}\) Clause 3.1 of IS 6649
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. Suitable markings identifying the bolt manufacturer, property class of DTI and its diameter shall be engraved suitably on the DTI. Action of DTIs is as indicated below:

VI. **Other Types of Tension Indicators:** There are other proprietary tension indicators such as those having squirting action in which material squirts off and those having rubber projections which shear off when required tension load is applied. These tension indicators have not been considered in these guidelines.

VII. **Number 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.\(^{17}\) 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.\(^{18}\) 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.

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\(^{17}\) Clause 7.1.1 of IS 4000.

\(^{18}\) Proposed correction slip to IRS B1.
c) **One DTI shall be used in one bolt.** In case DTI is being provided, the same will count as one washer and in class 10.9 bolts, one DTI and one plain washer shall be provided. In class 8.8 bolts only one DTI washer needs to be provided. 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 39.2.1 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). 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:

   ![Bolt Tension vs Elongation Curve](image)

   The effort through the tightening procedures is to lead the bolt into the horizontal part of the bolt tension/ elongation curve as shown above.

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19 Proposed correction slip to IRS Steel Bridge Code
Manual Torque wrenches of two different sizes

b) **Tension to be given:** The bolt shall be tightened to minimum loads specified in IS:4000. For bolts subject to only tension, the force shall be $P_{\text{m}}$ as specified in table 2 of IS:4000. For other joints, the same shall be as per table 3 of IS:4000, reproduced below:

<table>
<thead>
<tr>
<th>Nominal Size of Bolt</th>
<th>Minimum Bolt Tension in kN for Bolts of property class 8.8</th>
<th>Minimum Bolt Tension in kN for Bolts of property class 10.9</th>
</tr>
</thead>
<tbody>
<tr>
<td>M 16</td>
<td>94.5</td>
<td>130</td>
</tr>
<tr>
<td>M 20</td>
<td>147</td>
<td>203</td>
</tr>
<tr>
<td>M 24</td>
<td>212</td>
<td>293</td>
</tr>
<tr>
<td>M 30</td>
<td>337</td>
<td>466</td>
</tr>
<tr>
<td>M 36</td>
<td>490</td>
<td>678</td>
</tr>
</tbody>
</table>

**Table 3 of IS 4000**

For M 22 bolts, which are non standard as per IS codes, the minimum bolt tension shall be 182 kN for property class 8.8 and 251 kN for property class 10.9.

c) **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.\(^{20}\)

ii. The members being joined shall be held in position by insertion of few HSFG bolts (tightened to first stage only). These bolts shall not be tightened to second stage till all the bolts in a joint are inserted and tightened to first stage.

iii. The bolts shall be inserted and tightened upto first stage of tightening. The drifts inserted as above shall also be removed one by one.

\(^{20}\) Clause 7.1.4 of IS 4000.
iv. The final tightening shall not proceed until the gap between the plates has been closed such that the residual gap, if any, is less than 2 mm at edges.\(^{21}\) There shall, however, be no gap in the central portion. In case the central portion is not in close contact or gap at edges is more than 2 mm, straightening of members may be done after opening out the bolts inserted and the entire procedure i) to iii) above shall be repeated.

v. 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.\(^{22}\) Stiffest parts of joint are generally towards the center of the joint.

II. **Procedure for Installation of HSFG Bolts 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 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:**\(^{23}\) The tightening is done in two stages 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:**\(^{24}\) 0.40 mm thick feeler gauge shall be used to check 100% of the bolts for proper tightening. The feeler gauge shall be used to determine if the bolt has been sufficiently tightened, as follows:

<table>
<thead>
<tr>
<th>Number of indicator positions in DTI washer</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>
</tbody>
</table>

\(^{21}\) Clause 8.5.1 and 8.3 of EN 1090-2

\(^{22}\) Clause 7.1.5 of IS 4000

\(^{23}\) Based on clause 8.5.6 of EN 1090-2.

\(^{24}\) Annexure J of EN 1090-2.
The total number of indicators in a bolt connection shall be counted and it shall be ensured that not more than 10% exhibit full closure i.e. zero gap after tightening.

III. Procedure for Installation of HSFG Bolts Without DTI washers: If there is some problem with availability of DTIs, plain washers may be used for installation of HSFG bolts after approval of SAG officer in-charge of the work, using the following procedure:

Procedure:  

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

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25 Based on clause 8.5.4 of EN 1090-2.
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\(^\circ\) 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.

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 Degrees, 1/6 Part turns</td>
</tr>
<tr>
<td>2d ≤ t &lt; 6d</td>
<td>90 Degrees, 1/4 Part turns</td>
</tr>
<tr>
<td>6d ≤ t ≤ 10d</td>
<td>120 Degrees, 1/3 Part turns</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.\(^{26}\)

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.\(^{27}\)

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\(^{26}\) Proposed correction slip to IRS B1.

\(^{27}\) Proposed correction slip to IRS B1.
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 fully tensioned bolt, opened out for any reason whatsoever, needs to be rejected and removed from the site of work. Along with the bolt, the nut, washer(s) and DTI(s) used on that bolt also need to be rejected and removed from the site of work.

d) 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. 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, 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. Economics of HSFG bolts: The HSFG bolts are direct replacements of rivets and with proper design, the number HSFG bolts in a joint/ splice shall be less than or equal to the number of rivets. At current prices, the cost of rivets and HSFG bolts are comparable to each other. Cost of HSFG bolts is likely to go down as the volume of work grows and multiple manufacturers are available. HSFG bolts bring other benefits to the railway, namely:

I. Reduced time of assembly/erection.

II. Reduced requirement of scaffolds.

III. Less skilled manpower requirement.

IV. Less rejections and easier supervision.

V. Providing quality HSFG bolts is feasible as compared to other alternatives: welds in field are non feasible, whereas rivets are getting difficult to execute day by day.

12. Maintenance of HSFG bolts:

I. Anti-theft and Anti-sabotage measures: 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

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28 Proposed correction slip to IRS B1.
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. Alternatively, use of proven bonding agent to seize or lock the bolt in position may be applied to the threads projecting beyond the nut. Experimentally, RDSO has found that 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. It may be noted that 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 shall 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. If loose bolts are found, the same shall be marked by a round circle all around and shall be replaced expeditiously. HSFG bolts are one time use item and retightening of these bolts is not allowed.

c) HSFG Bolts cannot be used for isolated renewal of loose/defective rivets as their action is different from rivets. In such situations, high tensile turned bolts shall be used.

III. Painting: The HSFG bolts shall be provided with similar coating(s) as applied to the main structure. During maintenance these shall be repainted at the same frequency as the main structure.
DESIGN of HSFG Bolts

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.\(^{29}\)

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.

3. **Diameter of hole:** The nominal diameter of hole shall be 2 mm more than the bolt diameter\(^{30}\) 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:\(^{31}\)

<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.\(^{32}\) 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.

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\(^{29}\) Clause 5.5.1 of IS 4000

\(^{30}\) Clause 6.1 of IS 4000.

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

\(^{32}\) Proposed correction slip to IRS Steel Bridge Code.
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\(^{33}\):

\[
\text{Slip factor \times Number of Effective Interfaces \times Minimum Bolt Tension} \quad \frac{\text{Factor of Safety}}{\text{Minimum Bolt Tension}}
\]

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 design.\(^{34}\)

In other words, the factor of safety shall be adopted 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.

For Foot Over Bridges, where wind load is a primary load, the same may be taken as 1.4.

8. **Design of joints subject to 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:

\[
\frac{\text{Calculated Shear}}{\text{Slip Factor \times No of Effective Interface}} \leq \frac{(\text{Proof Load} - \text{Calculated Tension \times F})}{\text{Factor of Safety}}
\]

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 fy x d x t where fy 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 x fy x t/1.4.\(^{35}\) (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.

\(^{33}\) Clause 5.4.2 of IS 4000.

\(^{34}\) Clause 5.4.2 of IS 4000.

\(^{35}\) Clause 5.3.4 of IS 4000.
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).\(^{36}\) 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.\(^{37}\) 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.\(^{38}\) 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. 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 joints shall be done carefully ensuring that for all the bolts, access for fixing of torque wrench head (approximately 100 mm) is available on one side while the other side can be held with normal spanner. The detailing of the joints with HSFG bolts shall be done as per IRS Steel Bridge Code rather than IS 800 mentioned in clause 1.3 of IS 4000.\(^{39}\) In other provisions also, where IS codes are referred and IRS code provisions are also available, 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>Edge distance (Minimum)</td>
<td>Clause 7.5.1 of IRS Steel Bridge Code</td>
</tr>
<tr>
<td>1.75 d for sheared or hand flame cut edges</td>
<td></td>
</tr>
<tr>
<td>1.5 d for rolled, machine flame cut, sawn or planed edge</td>
<td></td>
</tr>
<tr>
<td>Edge distance (Maximum)</td>
<td>Clause 7.5.2 of IRS Steel Bridge Code</td>
</tr>
<tr>
<td>4 t + 40 mm from nearest edge.</td>
<td></td>
</tr>
<tr>
<td>c/c spacing (Minimum)</td>
<td>Clause 7.3 of IRS Steel Bridge Code</td>
</tr>
<tr>
<td>2.5 d’</td>
<td></td>
</tr>
<tr>
<td>c/c spacing (Maximum) Adjacent rivets in tension/ compression</td>
<td>Clause 7.4.1 of IRS Steel Bridge Code</td>
</tr>
<tr>
<td>32 t or 300 mm whichever is lesser</td>
<td></td>
</tr>
<tr>
<td>c/c spacing (Maximum) Bolts lying in direction of stress tension/ compression</td>
<td>Clause 7.4.2 of IRS Steel Bridge Code</td>
</tr>
<tr>
<td>16 t or 200 mm whichever is lesser</td>
<td></td>
</tr>
</tbody>
</table>

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36 Clause 5.2 of IS 4000.
37 Clause 5.2.1 of IS 4000.
38 Clause 5.4.2 of IS 4000, subject to provisions of Clauses 5.2.1 and 5.4.3.
39 Proposed correction slip to IRS Steel Bridge Code.
| c/c spacing (Maximum) | 12 t or 200 mm whichever is lesser  
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. | Clause 7.4.2 of IRS Steel Bridge Code |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>c/c spacing (Maximum) Staggered, gauge not exceeding 75 mm</td>
<td>50 % more than the values given in clause 7.4.2 and 7.4.3</td>
<td>Clause 7.4.3 of IRS Steel Bridge Code</td>
</tr>
<tr>
<td>Maximum Length of Bolt</td>
<td>The grip including the plies, packings and packing washers shall not exceed 10 times the nominal bolt diameter.</td>
<td>Proposed correction slip to IRS Steel bridge Code.</td>
</tr>
</tbody>
</table>

Where d is diameter of hole  
t is thickness of thinner outside plate  
d’ is the nominal diameter of the bolt/ rivet
DOs AND DON’Ts FOR CONSTRUCTION ENGINEERS

DOs:

• Do ensure that all bolts, washers and nuts are accompanied by manufacturer test certificates and appropriate markings indicating that these bolts are as per relevant codes.
• Do metallise the surface which is to be connected by the HSFG bolts.
• 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 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 properly check the bolts after initial tightening and after second stage tightening.
• Do ensure that protrusions of the DTI are towards the bolt head or towards the nut depending on whether the DTI is provided under the head or nut of HSFG bolt.
• 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’Ts:

• 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 Indicators which have not been calibrated.