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SP 6-4 (1969): ISI Handbook for Structural Engineers -Part-4 Use of High Strength Friction Grip Bolts [CED 7: Structural Engineering and structural sections]

"ज्ञान से एक नये भारत का निर्माण"
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"ज्ञान एक ऐसा खजाना है जो कभी चुराया नहीं जा सकता है"
Bhartṛhari—Nītiśatakam
"Knowledge is such a treasure which cannot be stolen"

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ISI HANDBOOK
FOR
STRUCTURAL ENGINEERS

4. USE OF HIGH STRENGTH FRICTION GRIP BOLTS

BUREAU OF INDIAN STANDARD

ISI STRUCTURAL ENGINEERS' HANDBOOK No. 4

ISI HANDBOOK

FOR

STRUCTURAL ENGINEERS

4. USE OF HIGH STRENGTH FRICTION GRIP BOLTS

BUREAU OF INDIAN STANDARDS

BUREAU OF INDIAN STANDARDS

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CONTENTS

FOREWORD

This handbook, which has been processed by the Structural Engineering Sectional Committee, SMBDC 7, the composition of which is given in Appendix A, had been approved for publication by the Structural and Metals Division Council and the Civil Engineering Division Council of ISI.

Steel, which is a very important basic raw material for industrialization, had been receiving attention from the Planning Commission even from the very early stages of the country's First Five Year Plan period. The Planning Commission not only envisaged an increase in production capacity in the country, but also considered the question of even greater importance, namely, the taking of urgent measures for the conservation of available resources. Its expert committees came to the conclusion that a good proportion of the steel consumed by the structural steel industry in India could be saved if higher efficiency procedures were adopted in the production and use of steel. The Planning Commission, therefore, recommended to the Government of India that the Indian Standards Institution should take up a Steel Economy Project and prepare a series of Indian Standard specifications and codes of practice in the field of steel production and utilization.

Over sixteen years of continuous study in India and abroad, and the deliberations at numerous sittings of committees, panels and study groups, have resulted in the formulation of a number of Indian Standards in the field of steel production, design and use, a list of which is given in Appendix B.

In order to guide the engineers in the use of various Indian Standard codes of practice, ISI undertook preparation of a number of handbooks. This handbook, which is the fourth in the series, relates to the use of high tensile friction grip bolts. The first one on structural steel sections was published in 1959. The second and third covering beams and columns respectively were published in 1962.

This handbook is intended to present the important principles and assumptions involved in the use of high tensile friction grip bolts in structural fabrication and other engineering purposes and to provide illustrative examples to guide the designers in the analysis of practical design problems.

High tensile friction grip bolts are comparatively a recent development. Though the information on high tensile friction grip bolts published in the scientific and technical journals is voluminous, there was not a single publication giving all the information about their use. Necessity was, therefore, felt for a handbook to serve as a guide for design engineers.

The subject is introduced by considering the various limits and usefulness of high tensile friction grip bolts. Their advantages over the ordinary bolts have been explained.

The design of joints carrying different types of forces has been dealt with in **2**. The advantages of high tensile friction grip bolts in resisting dynamic forces and fluctuating stresses are described. Design examples have been included to make the different concepts clear.

Different methods of fabrication using high tensile friction grip bolts have been described in **3**. The inspection requirements of joints and connections have also been dealt with. Appendix C describes the typical flow diagram for computer programme to solve problems connected with high tensile friction grip bolts.

This handbook is based on and requires reference to the following publications issued by ISI:

IS:3757-1967 Specification for high tensile friction grip fasteners for structural engineering purposes

IS:4000-1967 Code of practice for assembly of structural joints using high tensile friction grip fasteners

In the preparation of this handbook, the technical committee has derived valuable assistance from Prof P.V. Pawar, M.Sc (Engg), London, DIC of College of Military Engineering, Poona. Prof Pawar prepared the preliminary draft of this handbook. This assistance was made available to ISI by the Government of Maharashtra when he was serving in the Maharashtra Engineering Research Institute, Department of Irrigation and Power, Government of Maharashtra.

The illustrations in Fig. 2, 3, 4, 5 and 12 have been provided through the courtesy of Messrs Guest, Keen, Williams Ltd, Howrah and those in Fig. 7 to 11 through the courtesy of the North Bar Tool Co Ltd, Bombay (Oxon). Messrs Cooper and Turner Ltd, Vulkan Works, Sheffield, UK, have furnished Fig. 13.

No handbook of this kind can be made complete for all times to come at the very first attempt. As designers and engineers begin to use it, they will be able to suggest modifications and additions for improving its utility. They are requested to send such valuable suggestions to ISI which will be received with appreciation and gratitude.

1. INTRODUCTION

1.1 History — Rivets have been used in the fabrication from the very beginning of the history of structures. In their use, it was common to notice a clamping force between the joint which generated as the rivets cooled down. This clamping force tended to produce a better performance of the joint in the prevention of slip due to the load applied. From a study of riveted and bolted joints, it was found that the riveted joints showed better fatigue resistance. The cause for this behaviour could not be detected in the early stages.

After the World War I, the high strength bolts manufactured from quenched and drawn carbon steel came to be used as fitting up bolts when the parts to be bolted were brought together by tightening the high strength bolts. Further to this, these bolts were used in the same manner in steel fabrication. The concept of tightening the high strength bolts to proof load was, however, not developed at the time.

The first laboratory tests on high strength bolts were conducted in USA by W. Wilson and F.P. Thomas at the University of Illinois in 1938. They concluded that the fatigue strength of high strength bolts with diameter appreciably smaller than that of the holes in the plates was as great as that of a well-driven rivet if the nuts were tightened to induce a high tension in the bolts.

Further developments took place by the work of Maney, Lenzen and others in USA. The American Society of Civil Engineers formed a research council on riveted and bolted structural joints in 1947. A series of tests were conducted on bolted joints having bolt tension much more than that used previously. It was found that such joints exhibited better fatigue strength. Detailed studies of the stresses and strains in the vicinity of the holes were conducted. They showed that the reduction in the stress concentration due to lack of bearing of bolts on plates was a primary cause of better fatigue strength.

Based on the above studies the use of high strength bolts was first made on an ore bridge in 1948. In 1949 the American Society for Testing and Materials issued a specification, ASTM A325 for high strength carbon steel bolts for joints, including suitable nuts and plain hardened washers. It was subsequently revised in 1951.

1.2 General Principles — In an ordinary bolted joint the force from one side is transferred to the other side through the interlocking and bearing of the bolts. In a friction grip joint, however, the force is transferred by virtue of the friction between the interfaces. To develop this friction a normal load is applied to the joint by using high strength bolts tightened to proof load. A study of Fig. 1 will make the point clear.
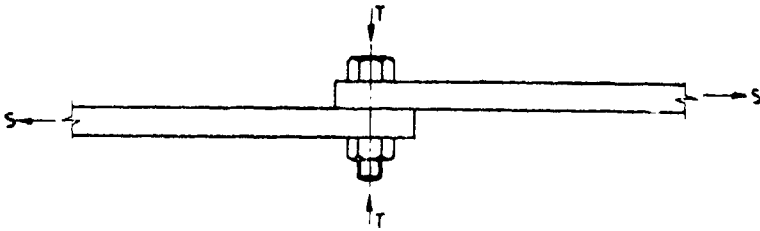
FIG. 1   A FRICTION GRIP JOINT

Let T = clamping force induced by the bolt,

μ = coefficient of friction between the interfaces, and

S = load carrying capacity of the joint in shear.

By the usual law of friction it may be seen that $S = \mu \times T$.   It means that if a load equal to S or less is applied, the joint will withstand it, and transfer it without any slip.   This is because of the normal load T and the friction between the faying surfaces.   This is in effect a friction grip joint.   The coefficient of friction is also termed slip factor.   The slip factor is defined as the ratio between the force causing the large displacement between the two interfaces of the plates connected together and the force normal to the interfaces due to the tension in the bolts.   A slip factor of 0·45 is stipulated by IS : 4000-1967* for surfaces which are free of paint, dirt, loose rust or mill scale.

1.3 Advantages of High Strength Bolts — The utility of joints using high strength bolts was primarily noticed in its higher fatigue strength.   More discussion would follow in the subsequent articles but it would suffice to say here that this is mainly due to the absence of heavy stress concentration due to bearing between the bolt and the plates and secondly due to less variation in the tension in the bolt as the total tension across the joint varies.   As the bolts are in tension up to proof load, they do not permit loosening of the nut and the washer.   This action is similar to that of a bolt with a spring washer.   Because of this property the high strength bolts are ideal where vibrations are involved as in a bridge or machine foundations.   A photograph of a friction grip bolt is shown in Fig. 2.   The various uses of friction grip bolts have been depicted in Fig. 3, 4 and 5.

The tightening of the high strength bolt is a job requiring set specifications, tools and equipment.   A person may easily be trained to tighten these bolts suitably and in accordance with specifications to derive

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*Code of practice for the assembly of structural joints using high tensile friction grip fasteners.
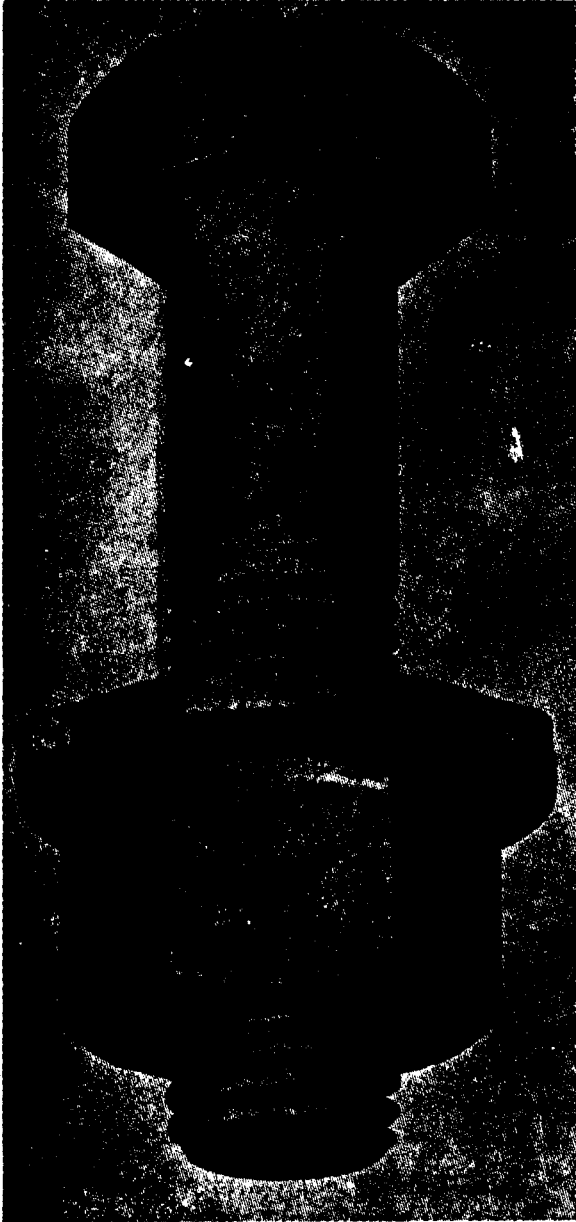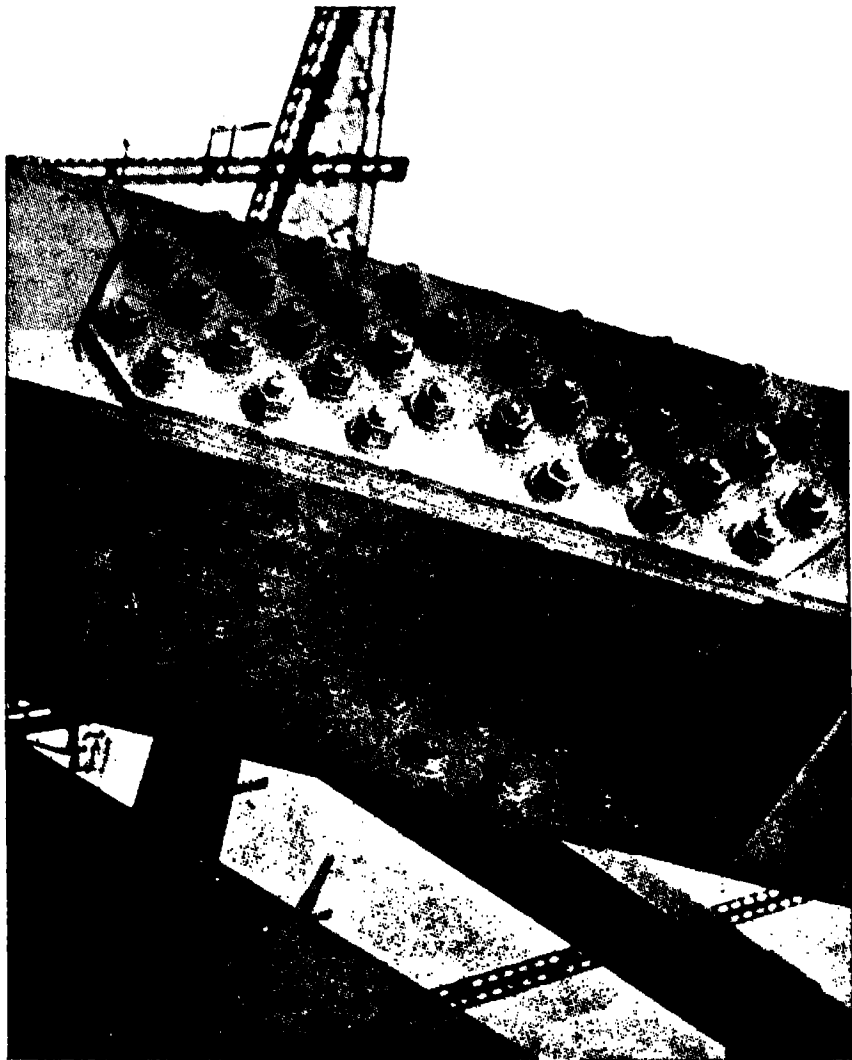
FIG. 2   GKN STANDARD HIGH STRENGTH BOLT

FIG. 3 DETAILS OF A JOINT IN A GOLIATH CRANE

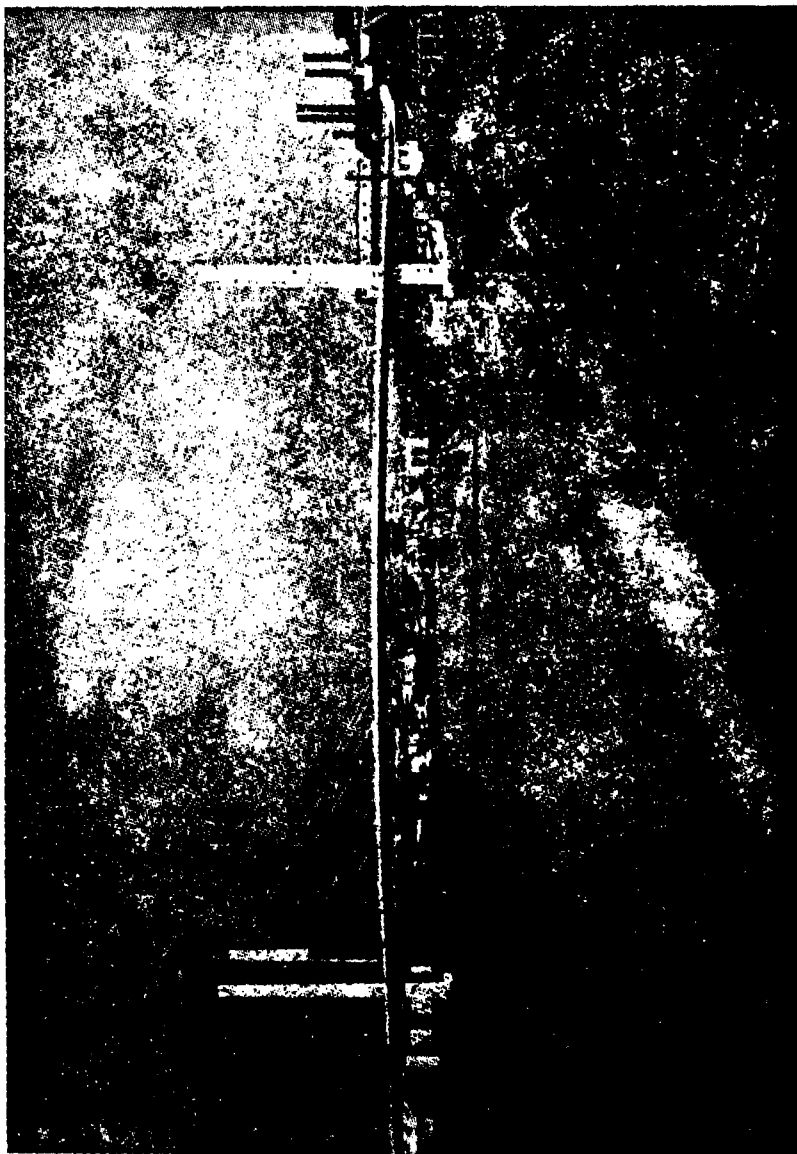FIG. 4   GOLIATH CRANE (GENERAL VIEW)

FIG. 5 NEW PORT ROAD BRIDGE

a uniform performance. Because of the checks, calibrations, etc, there is very little chance to make an error. No special equipment like furnaces is needed on site. In the absence of sparks, fire hazards are totally eliminated. The noise level is very low (as no hammers are needed) which is of special importance in residential areas. The joints are permanent for all purposes and exhibit characteristics similar to riveted joints. The friction grip joint may be dismantled with ease. The fabrication is also faster as the tolerances between the diameter of holes and the bolt sizes may be larger. This is because the strength of the joint is derived from the friction and not from the bearing which calls for closer tolerances. The inspection of these joints involves whether the surfaces have been cleaned suitably and whether the bolts have been tightened to the desired tension. This may be checked easily and corrections may be made simply by replacing the defective bolts.

1.4 Code of Practice — The provisions of IS:800-1962* are generally applicable for the design of joints with high tensile friction grip bolts. The special provisions for the use of these bolts are covered in IS:4000-1967†.

2. DESIGN OF JOINTS

2.1 General — In the early stages of the development of the friction grip joints, it was normal to design the joints by assuming the use of ordinary bolts or rivets and substitute them by high tensile bolts. Because of this practice all the inherent advantages of the bolts could not be fully utilized. However, in competitive spheres this was not much welcomed because of the higher cost of the high strength bolts. During this time, the research and development work was progressing. It lead to the formulation of the codes of practice.

The special features of high tensile bolts are their frictional properties in the joint by the virtue of applied preload in the form of tension in the bolts. This feature has made possible the use of fewer number of high tensile bolts than that of rivets or ordinary bolts.

2.2 Shear Connections — The formula $S = \mu \times T$ was established in **1.2** indicating the relationship between the shear carrying capacity and the normal load on the joint. If there are N interfaces, the formula becomes $S = N \cdot \mu \times T$. Dividing this by a safety factor, we get the formula as given in **4.3** of IS:4000-1967‡.

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*Code of practice for use of structural steel in general building construction (*revised*).

†Code of practice for the assembly of structural joints using high tensile friction grip fasteners.

‡Code of practice for assembly of structural joints using high tensile friction grip fasteners.

$$\text{Shear per bolt} = \frac{\text{Slip factor}}{\text{Factor of safety}} \times \text{No. of effective interfaces} \times \text{Proof load}$$

where

Shear per bolt = contribution of one bolt to the total shear strength of the joint,

Slip factor = coefficient of friction, and

Proof load = maximum permissible load in the bolt.

The total number of effective interfaces is determined by common contact surfaces between adjacent load transmitting structural members with forces in opposite direction, that is, excluding packing pieces through which the bolt passes.

The factor of safety assumed is 1·4 for all loads except wind load in which case it may be reduced to 1·2. The factor of safety allows for the stress relaxation in the bolts which may be of the order of 10 percent. Research has proved that stress relaxation in the bolt occurs mostly during first few days after the bolt is tightened. The slip factor may be taken as 0·45 for surfaces which are free of any paint, or other applied finish, oil, dirt, loose rust or mill scale. The proof loads of the bolts are given in Table 1.

TABLE 1 PROOF LOADS OF BOLTS
(*From Tables* 6 *and* 7 *of* IS : 3757 - 1967*)

BOLT DIA	PROOF LOAD	
	10 K Bolts	8 G Bolts kgf
(1)	(2)	(3)
mm		
12	5 900	5 058
14	8 050	7 500
16	10 790	9 120
18	13 440	11 520
20	17 150	14 700
22	21 210	18 180
24	23 710	21 180
27	32 130	27 450
30	39 270	33 660
33	48 580	41 640
36	57 190	49 020
39	68 920	58 560

NOTE — Proof load of the 10 K bolt is based on 70 kgf/mm² and that of 8 G bolt is based on the 60 kgf/mm² on the stress area of the bolt.

*Specification for high tensile friction grip fasteners for structural engineering purposes.

Design Example 1 — Lap Joint

Design a doubly bolted lap joint for a plate 20 mm thick to carry its full load. Design the same joint as a doubly bolted butt joint.

In a lap joint there is only one interface to transmit shear. The full load per pitch of the joint is first calculated. The tension in the bolt is then calculated using the formula given in **4.3** of IS : 4000-1967*. The type and best size of the bolt is related from Table 1.

The load that may be carried by the plate per pitch

= pitch × thickness × permissible tensile stress in plate

$= p \times 2 \cdot 0 \times 1\,500$

$= 3\,000\,p\ \text{kg}$

Since there are two bolts per pitch, the load carried by each bolt

$= 1\,500\,p\ \text{kg}$

From **4.3** of IS : 4000-1967* and since there is only one interface,

$$1\,500\,p = \frac{0 \cdot 45}{1 \cdot 4} \times 1 \times \text{Proof load}$$

Proof load $= 4\,660\,p\ \text{kg}$

If bolts are provided at a pitch of 75 mm:

Proof load $= 4\,660 \times 7 \cdot 5 = 34\,950\ \text{kg}$

Provide HTFG bolts M 30 (10 K) with a pitch of 75 mm and edge distance 50 mm.
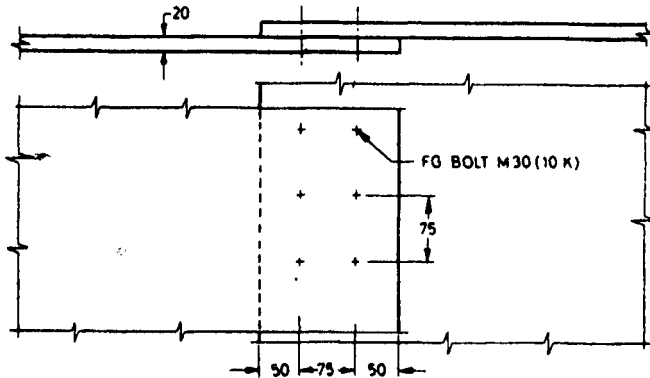
All dimensions in millimetres.

(*Continued*)

*Code of practice for assembly of structural joints using high tensile friction grip fasteners.

Design Example 1 — Lap Joint — Contd

The design of a double bolted butt joint is similar to the design of a lap joint except that there will be two interfaces to transmit the shear.
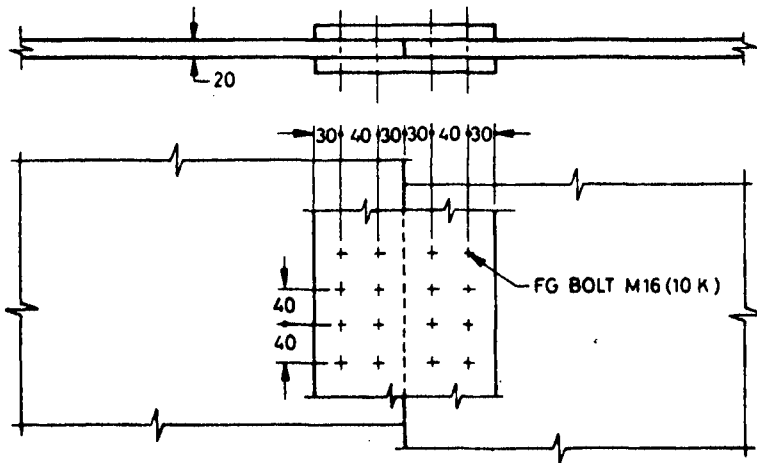
$$1\ 500\ p = \frac{0\cdot 45}{1\cdot 4} \times 2 \times \text{Proof load}$$

Proof load $= 2\ 330\ p$ kg

If the bolts are provided with a pitch of 40 mm:

Proof load $= 2\ 330 \times 4\cdot 0 = 9\ 320$ kg

Provide HTFG bolts M 16 (10 K) at a pitch of 40 mm.

All dimensions in millimetres.

Design Example 2 — Column Base Connections

A column (ISLB 200) carries a load of 25 000 kg. Design the base connection assuming that the column end is not machined and the whole load is being transferred to the base by flange angles.

a) *Bolts for gusset*

$$\text{Total shear} = \frac{\text{Slip factor}}{\text{Factor of safety}} \times 1 \times \text{Proof load}$$

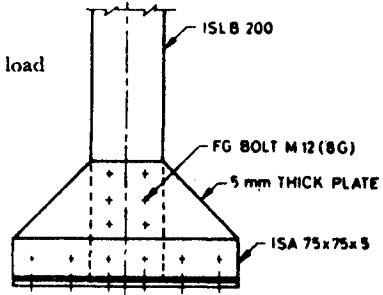$$25\,000 = \frac{0 \cdot 45}{1 \cdot 4} \times 1 \times \text{Proof load}.$$

$$\text{Proof load} = \frac{25\,000 \times 1 \cdot 4}{0 \cdot 45} \times 78\,000 \text{ kg}$$

Select HTFG bolts M 12 (8 G).

Proof load of each bolt $= 5\,058$ kg

No. of bolts required $\dfrac{78\,000}{5\,058} = 16$

Provide 8 bolts on each side.

b) *Thickness of gusset*

Load per gusset plate $= \dfrac{25\,000}{2} = 12\,500$ kg

Load per cm of plate $= \dfrac{12\,500}{30} = 416$ kg

Bending moment in the gusset at the edge of flange of ISLB 200

$$= \frac{416 \times 9 \cdot 5^2}{2} = 18\,800 \text{ kg·cm}$$

Modulus of section required $= \dfrac{18800}{1650} = 11 \cdot 4$ cm²

The depth of plate is fixed as 160 mm to accommodate the bolts.

Thickness of plate required $= \dfrac{11 \cdot 4 \times 6}{16^2} = 2 \cdot 68$ mm

Provide a plate of thickness 5 mm.

c) *Bolts in the base angle*

Maximum vertical shear in the gusset $= 416 \times 9 \cdot 5 = 3\,940$ kg

Shear per cm at the level of base angle $= \dfrac{3\,940 \times 0 \cdot 75 \times 7 \cdot 25 \times 12}{0 \cdot 5 \times 9 \cdot 3^3} = 63$ kg/cm²

Total horizontal shear $= 63 \times 9 \cdot 5 = 600$ kg

Since the bolts are in single shear:

Proof load $= \dfrac{600 \times 1 \cdot 4}{0 \cdot 45} = 1\,860$ kg

Provide HTFG bolts 12 M (8 G) 2 in number on either side.

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Design Example 3 — Moment Connection

Design a suitable moment connection to transfer a moment of 45 000 cm·kg from the top column to the column below.
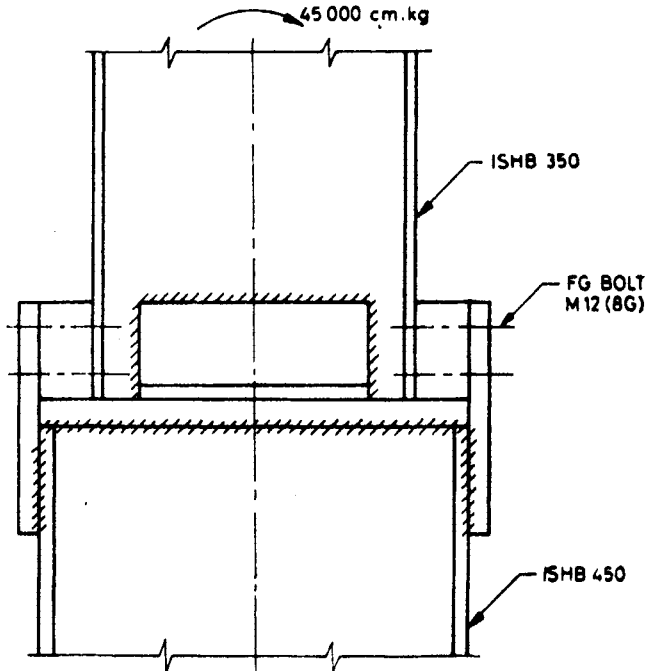
Assuming that the direct load is transferred to the lower column by the web connections, the flange connections should be designed to transfer the bending moment.

$$\text{Shear on the bolts at each flange} = \frac{45\,000}{35} = 1\,287 \text{ kg}$$

The bolts are in single shear and the packing material does not have any structural function.

$$\therefore \quad \frac{0.45}{1.4} \times \text{Proof load} = 1\,287$$

Proof load = 4 000 kg

Select HTFG bolts M 12 (8 G) 4 in number at each flange.

Design Example 4 — Flange Bolts of a Plate Girder

Total shear = 125 000 kg

Moment of inertia of the plate girder = 1 323 000 cm³

The longitudinal shear (q) per unit cm of the girder is given by the formula:

$$q = \frac{P\,A\,\Upsilon}{I} \text{ kg/cm}$$

where

P = Total shear in kg,

A = Area of the element to be connected in cm²,

Υ = Distance between the neutral axis of the section and the centre of gravity of the element to be connected in cm,

I = Moment of inertia of the entire section in cm⁴,

$$\therefore q = \frac{125\,000 \times 270 \times 95}{1\,323\,000}$$

$$= 2\,420 \text{ kg/cm}$$

Try HTFG bolt M 22 (10 K).   Proof load = 21 210 kg.

Shear carrying capacity of a pair of bolts

$$= 2 \times \frac{0.45}{1.4} \times 21\,210$$

$$= 13\,635 \text{ kg}$$

$$\text{Pitch} = \frac{13\,635}{2\,420} = 5.6 \text{ cm}$$

Provide the bolts at a pitch of 55 mm.
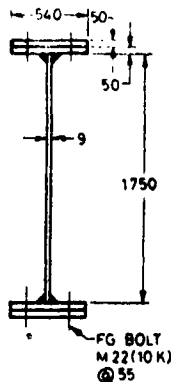
All dimensions in millimetres.

Design Example 5 — Column Bracket

A bracket to a column is supporting a gantry girder, as shown in the figure. The reaction from the gantry girder is 28 000 kg at 350 mm from the centre of the column.

Design the bolted connection for the bracket.
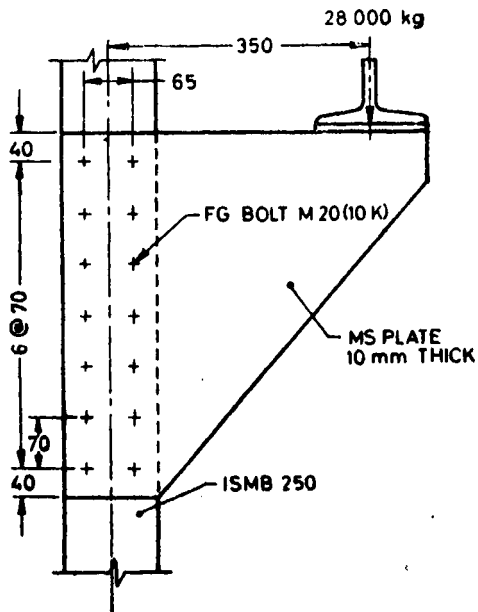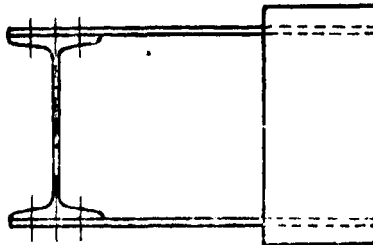
All dimensions in millimetres.

Assume the bolt pattern as shown in the figure. The bolts are in shear. In an arrangement like this it is possible to show that shear in each bolt

$$= \frac{M}{\Sigma \, (x^2 + y^2)} \times r$$

where

$M =$ Bending moment,

$x, y =$ Ordinates of bolts from the centre of gravity of the bolt groups, and

$r =$ Distance of the bolt in question from the centre of the bolt group.

(*Continued*)

It is evident from this formula that the bolt furthermost from cg of the bolt group carries the maximum shear.

$$\Sigma \, (\, x^2 + y^2 \,) = 4 \, (\, 3 \cdot 25^2 + 7^2 + 3 \cdot 25^2 + 14^2 + 3 \cdot 25^2 + 21^2 \,) + 2 \, (\, 3 \cdot 25 \,)^2$$
$$= 2 \, 890 \text{ cm}^2$$

$$\text{Maximum shear} = \frac{14 \, 000 \times 35 \times 21 \cdot 2}{2 \, 890}$$
$$= 3 \, 900 \text{ kg}$$
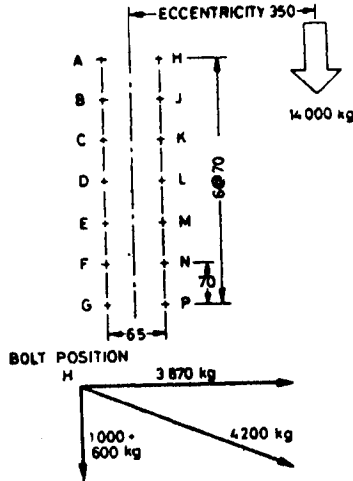
All dimensions in millimetres.

The vertical component of this shear $= \dfrac{3 \, 900 \times 3 \cdot 25}{21 \cdot 2} = 600$ kg

The horizontal component of the shear $= \dfrac{3 \, 900 \times 21}{21 \cdot 2} = 3 \, 870$ kg

In addition to the shear due to the bending moment the bolts also carry the normal load.

Normal load on each bolt $= \dfrac{14 \, 000}{14} = 1 \, 000$ kg

Total vertical component of the shear $= 1 \, 000 + 600 = 1 \, 600$ kg

The resultant shear $= \sqrt{(\, 1 \, 600^2 + 3 \, 870^2 \,)}$
$= 4 \, 200$ kg

From **4.3** of IS : 4000-1967*,

we have $\dfrac{0 \cdot 45}{1 \cdot 4} \times$ Proof load $= 4 \, 200$

$\therefore$ Proof load $= \dfrac{4 \, 200 \times 1 \cdot 4}{0 \cdot 45} = 13 \, 100$ kg

Use HTFG bolts M 20 (10 K)

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*Code of practice for assembly of structural joints using high tensile friction grip fasteners.

2.3 External Tension

2.3.1 The strength of a joint with high tensile friction grip (HTFG) bolts is developed as a result of the clamping force induced in the joint. This clamping force is caused by the tension in the shank of the bolt tightened to its proof load.

In certain types of joints the external load acting parallel to the shank of the bolts increases tension in the bolts thus reduces the clamping force. An example of such a loading is in the case of the dead end of a pressure vessel. When there is no internal pressure, the clamping force between the flange and the flange plate is fully effective. As the internal pressure increases, the flange plate is pushed away from the flange introducing an additional tension on the bolt shank. This tension, known as the external tension, reduces the clamping force.

2.3.2 The behaviour of a joint subjected to external tension is interesting. Consider the joint in Fig. 6. The bolt is tightened to a pre-load of 6 000 kgf. Assuming the contact area of the plates per bolt to be 10 cm^2

clamping force in the interface $= \dfrac{6\,000}{10} = 600$ kgf/cm^2
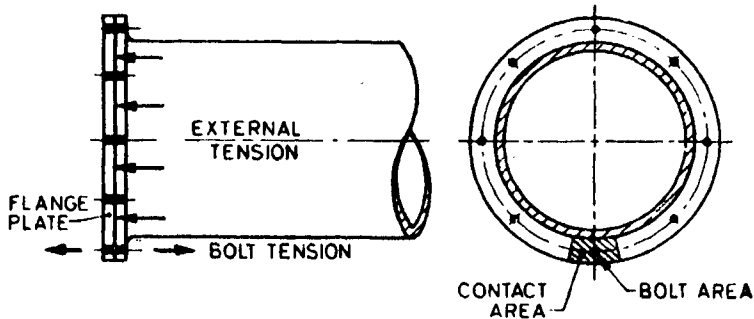
FIG. 6   EXTERNAL TENSION ON A FRICTION GRIP BOLT

If the joint is subjected to an external tension of 1·100 kgf, reduction in the clamping force $= \dfrac{1\,100}{11} = 100$ kg/cm^2 (the area comprises 10 cm^2 contact area and 1 cm^2 bolt area). There will also be an increase in the bolt tension by 100 kgf/cm^2 to 6 100 kgf/cm^2. The clamping force will be reduced by 100 kgf/cm^2 to 500 kgf/cm^2.

If, however, the external tension is increased to 6 000 kgf, the clamping force is completely neutralized causing separation of the interfaces. The

bolt tension having been counter-balanced by the external tension will again attain a value of 6 000 kgf/cm².

Any further increase in the external tension will increase the bolt tension also and separation of interfaces continues.

The behaviour of the high tensile friction grip bolts subjected to the external tension discussed above may be summarized as follows:

External tension, kg	0	1 100	6 000	7 000
Bolt tension, kgf/cm²	6 000	6 100	6 000	7 000
Clamping force, kgf/cm²	600	500	0	0
Remarks	—	—	Separation	

It may, therefore, be seen that if due care is taken to avoid separation of interfaces the relative change in the bolt tension is very small. As is very well known, the endurance limit in fatigue is more if the relative change of stress within the body for a cycle of loading is small. The friction grip joints are, therefore, ideal where fatigue is involved due to repeated variation of external tension.

2.3.3 To ensure that the clamping force is not fully neutralized by the external tension to avoid separation of the interfaces **4.4** of IS : 4000-1967* limits the external tension to 0·6 times the proof load and to 0·5 of the proof load when the joint is subjected to fatigue.

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*Code of practice for assembly of structural joints using high tensile friction grip fasteners.

Design Example 6 — Column Bracket

A bracket as shown in the figure carries a load of 20 tonnes. By resolving the force triangle it will be found that the horizontal member carries a load of 20 t thereby subjecting the bolts connecting it to the column flange to pure tension. It is required to design these bolts.
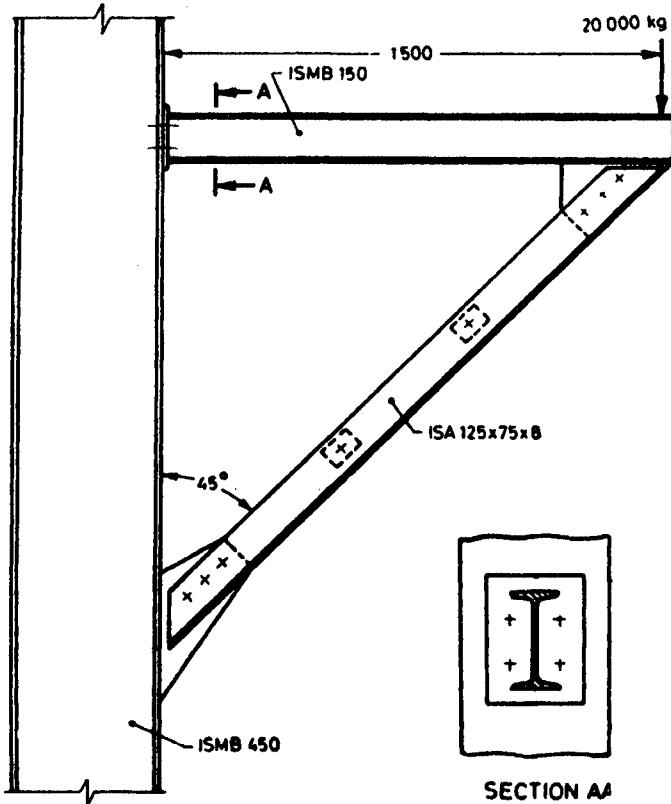
All dimensions in millimetres.

Providing an end plate and four bolts:

Tension per bolt $= \dfrac{20\,000}{4} = 5\,000$ kg

The bolts are to carry external tension which is not repetitive.

∴ 0·6 × Proof load = external tension
$= 5\,000$ kg

Proof load $= \dfrac{5\,000}{0·6} = 8\,333$ kg

Provide HTFG bolts M16 (8 G) — 4 numbers.

Design Example 7 — Flange of a Gas Cylinder

The pressure in a gas cylinder of internal diameter 100 cm varies between 4·5 kgf/cm² and 6 kgf/cm². It is required to design the flange connection.

FG BOLT M 16 (10 K) , 9 OFF
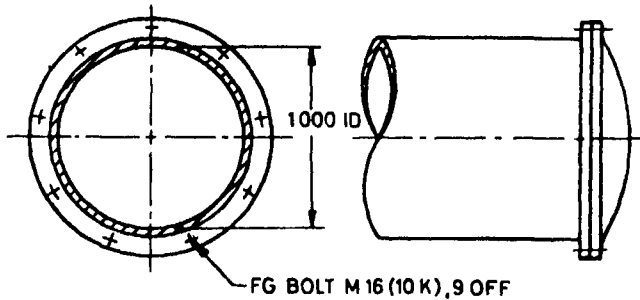
All dimensions in millimetres.

Total maximum pressure of gas on the flange

= Area of flange × Pressure

$$= \frac{\pi \times 100^2}{4} \times 6\cdot0$$

= 47 000 kg

The bolts are in tension which is fluctuating between 4·5 and 6·0 kgf/cm². The maximum permissible external tension should, therefore, be limited to 0·5 times the proof load according to **4.4** of IS : 4000-1967*.

0·5 × Total proof load = 47 000 kg

∴ Total proof load = 94 000 kg

Provide HTFG bolts M 16 (10 K) with proof load of 10 790 kg,

number of bolts required = $\dfrac{94\,000}{10\,790}$ = 9

———————
*Code of practice for assembly of structural joints using high tensile friction grip fasteners.

2.4 Combined Tension and Shear

2.4.1 *General* — Considerable research work has been carried out on the behaviour of high tensile friction grip bolts in joints subjected to a combination of tension and shear. Such combination may be formed in joints connecting columns and beams, brackets, stringer beams to floor beams etc.

Experiments conducted for various combinations of tension and shear indicate that the curve for the relationship between shear and tension at failure is elliptical of the nature:

$$\frac{x^2}{k^2} + y^2 = 1$$

where

$x =$ ratio of calculated shear on the bolt to the shear at failure,

$y =$ ratio of the calculated tension on the bolt to the tension at failure, and

$k =$ a constant dependent on the strength of bolt.

Value of k is found to be 0·83 if the bolts fail in shank and 0·64 if they fail in threads.

2.4.2 The ultimate strength of the bolt given by this formula increases with the grip of the bolt as the effect of shear loading on the shank bending becomes predominant. Also, the formula indicates the behaviour of bolts at failure and, therefore, is not easily applicable to the normal design purposes. A simpler formula has, therefore, been specified in **4.5** of IS :4000-1967* which reads as follows:

$$\frac{\text{Calculated shear}}{\text{Slip factor} \times \text{No. of interfaces}} + \text{Calculated tension} \times F$$

$$= \frac{\text{Proof load}}{\text{Factor of safety}}$$

where

$F = 1\cdot2$ when the tension is non-repetitive, or

$= 1\cdot43$ when the tension is repetitive.

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*Code of practice for assembly of structural joints using high tensile friction grip fasteners.

Design Example 8 — Column Bracket

A gantry girder transfers a load of 26·5 tonnes through a bracket with an eccentricity of 19·5 cm. Design the bracket.
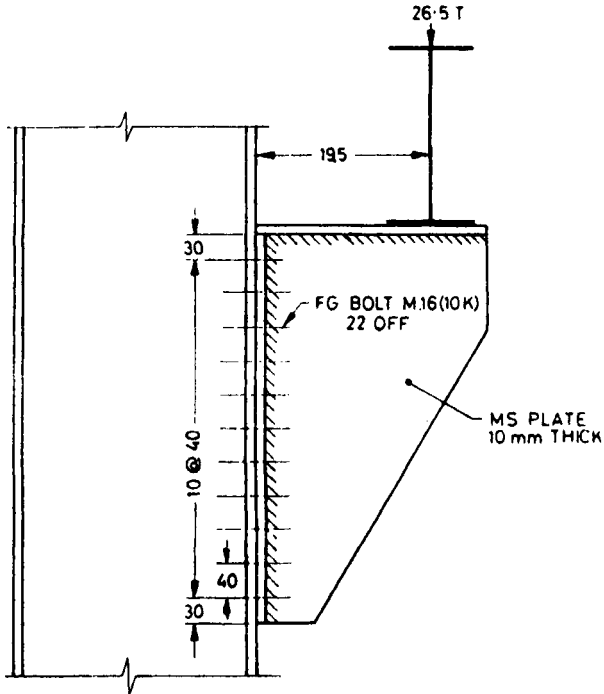
All dimensions in millimetres.

Bending moment $= 26·5 \times 19·5$

$\qquad\qquad\quad = 520 \text{ cm·t}$

Try HTFG bolts M 16 (10 K), 22 in number.

When there is no load on the bracket it is held on to the column by compression between the surfaces covered due to the bolt tension. This phenomenon, continues even when the load of 26·5 t, is applied since the joint will be designed for no separation criteria. The interface could, therefore, be considered as a plane in a monolithic beam of cross-section 10×46 cm.

(Continued)

29

Design Example 8 — Column Bracket — Contd

$$\text{Maximum bending stress} = \frac{520\,000 \times 6}{10 \times 46^2}$$

$$= 147 \text{ kgf/cm}^2 \text{ tension or compression.}$$

$$\text{Bending stress at 5 cm from the top fibre} = \frac{147 \times 36}{46}$$

$$= 115 \text{ kgf/cm}^2$$

$$\text{Average stress} = \frac{147 + 115}{2} = 131 \text{ kgf/cm}^2$$

This average bending stress could be considered the external tension in the bolt.

Applied tension $= 131 \times 5 \times 5 = 3\,275$ kg per bolt

Applied shear $= \dfrac{26\,500}{22} = 1\,200$ kg

From the formula given in **2.4.1** above:

$$\frac{\text{Proof load}}{1 \cdot 4} = \frac{1\,200}{0 \cdot 45} + 3\,275 \times 1 \cdot 2$$

$$= 6\,600 \text{ kg}$$

Required proof load $= 6\,600 \times 1 \cdot 4$

$$= 9\,240 \text{ kg}$$

This is well within the actual proof load for M 16 (10 K) bolts. Hence OK.

Design Example 9 — Flange Connection in a Pipe Line

Design the flange connection for a pipe line of internal diameter 200 cm to carry a shear of 20 000 kg and a bending moment of 20 000 000 kg·cm.
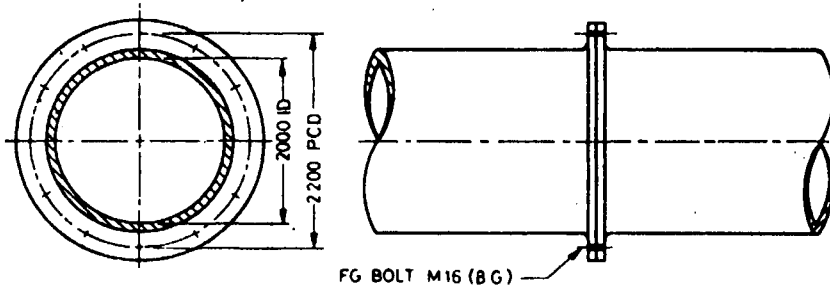
All dimensions in millimetres.

Try HTFG bolts M 16 (8 G) - 120 in number at a pitch circle diameter of 214 cm, outer diameter of the flange being 228 cm.

When the load on the flange is absent there will only be pure compression due to the pre-load in the bolts. With the application of the load the compression is relieved on one-half of the flange and is increased on the other half. Since the flange is designed with no separation criterion the usual beam theory could be applied.

Moment of inertia of the interface $= \dfrac{\pi}{64} (228^4 - 200^4) = 54 \times 10^6$ cm^4

Maximum bending stress $= \dfrac{20 \times 10^6 \times 114}{54 \times 10^6} = 42$ kgf/cm^2

The area of interface $= \dfrac{\pi}{4} (228^2 - 200^2) = 9\,400$ cm^2

The area of interface carried by each bolt $= \dfrac{9\,400}{120} = 78 \cdot 4$ cm^2

Assuming bending stress uniform over the interface maximum tension on each bolt

$= 42 \times 78 \cdot 4$

$= 3\,300$ kg

Shear per bolt $= \dfrac{20 \times 10^3}{120} = 167$ kg

From the formula given in 2.4.1

$\dfrac{\text{Proof load}}{1 \cdot 4} = \dfrac{167}{0 \cdot 45} + 3\,300 \times 1 \cdot 2$

$= 4\,323$ kg

Required proof load $= 1 \cdot 4 \times 4\,323 = 6\,050$ kg

The bolts M 16 (8 G) will be adequate since their actual proof load is 9 150 kg.

Design Example 10 — Stringer Beam Connection

Two stringers, ISLB 250 and ISLB 350, are connected through cleats to the web of the main beam ISLB 500. ISLB 250 transmits a shear of 4 500 kg and a moment of 75 000 kg·cm while a shear of 12 000 kg and moment of 350 000 kg·cm is transmitted by ISLB 350. Design the connection.

The bolts may be divided into three groups, namely, A, B and C, as shown in the sketch.

Design of bolt group A:

This bolt group is subjected to a shear of 12 000 kg and a bending moment of 350 000 kg·cm.
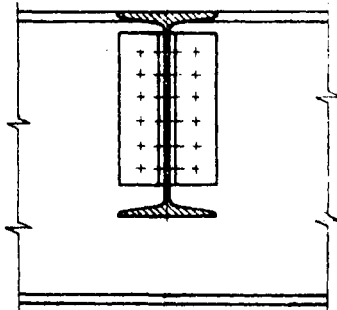
Polar moment of inertia of the bolt group

$$= 4 (2^2 + 2^2 + 2^2) + 4 (2^2 + 6^2 + 10^2)$$

$$= 608 \text{ cm}^2$$

Distance of the farthest bolt from the centre of gravity of the bolt group.

$$= \sqrt{(2^2 + 10^2)}$$

$$= 10 \cdot 2 \text{ cm}$$

Maximum shear in the bolt due to the moment $= \dfrac{350\ 000 \times 10 \cdot 2}{608}$

$$= 5\ 870 \text{ kg}$$

The horizontal component $= \dfrac{5\ 870 \times 10}{10 \cdot 2} = 5\ 750 \text{ kg}$

Vertical component $= \dfrac{5\ 870 \times 2}{10 \cdot 2} = 1\ 150 \text{ kg}$

Vertical load carried by each bolt $= \dfrac{12\ 000}{12} = 1\ 000 \text{ kg}$

Total vertical shear $= 1\ 150 + 1\ 000 = 2\ 150 \text{ kg}$

Resultant shear $= \sqrt{(5\ 750^2 + 2\ 150^2)} = 6\ 130 \text{ kg}$

(Continued)

Design Example 10 — Stringer Beam Connection — Contd

5 750 kg

5 870 kg

1150 +
1000 kg
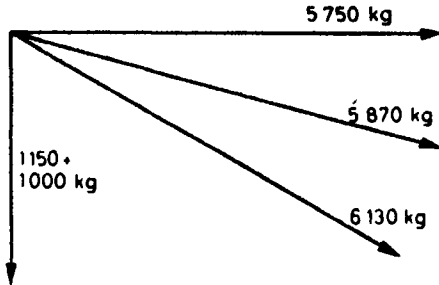
6 130 kg

The bolts are subjected to double shear.

From **4.3** of IS : 4000-1967*,

$$\frac{0.45}{1.4} \times 2 \times \text{proof load} = 6\ 130 \text{ kg.}$$

∴ Required proof load = 9 550 kg.

Provide HTFG bolts M 16 (10 K), 12 in number.

M 16 (10 K)
BOLT GROUP B

M 16 (10 K)
BOLT GROUP A

ISLB 250

ISA 125x75x8

←75→

M 16 (10 K)
BOLT GROUP C

←45│55├─ ISLB 350

ISLB 500
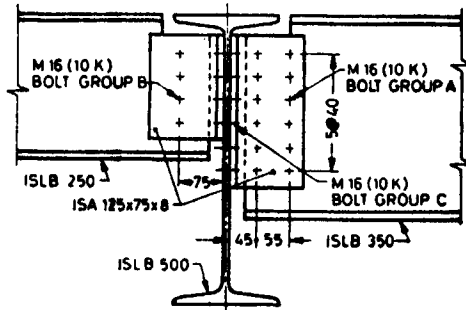
All dimensions in millimetres.

The bolt group B may similarly be designed to resist a shear of 45 000 kg and a bending moment of 75 000 cm·kg. It will be found HTFG bolts M 16 (8 G) — 4 in number would be suitable. But for the sake of uniformity for both A and B groups M 16 (10 K) bolts may be provided.

Design of bolt group C:

The bolt group is to resist shear forces and bending moments acting on either side of the main beam ISLB 500. The moment from one stringer beam reduces the clamping force on its side and increases clamping force on the other side. The interface should also not slip due to the vertical shear. The worst case for the joint is, therefore, the applied

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*Code of practice for assembly of structural joints using high tensile friction grip fasteners.

(*Continued*)

Design Example 10 — Stringer Beam Connections — Contd
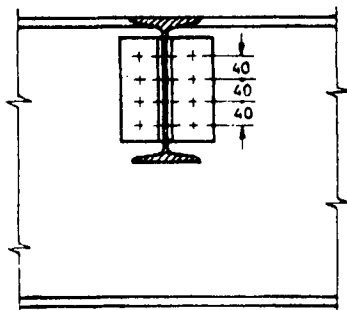
All dimensions in millimetres.

bending moment and shear force on each interface. There will, however, be an increase in the tension in half the number of bolts when the moment is applied on both the sides. Since the external tension in the bolts is limited to 0·6 times the proof load and since the percent increase in the bolt tension is very small its effect may be neglected:

Bolts on the ISLB 250 side:

Shear   = 45 000 kg

Bending moment = 75 000 kg·cm.

Following the procedure given in Design Example 9,

Maximum stress at the bolt = $\dfrac{75\,000 \times 6}{25 \times 16^2}$ = 70 kg/cm²

Total tension in the bolt = 70 × 4 × 6·25 = 1 750 kg

Shear in each bolt = $\dfrac{4\,500}{16}$ = 280 kg

From formula given in **2.4.1**,

$\dfrac{\text{Proof load}}{1\cdot4}$ = $\dfrac{280}{0\cdot45}$ + 1 750 × 1·2 = 2 720 kg

Required proof load = 3 820 kg

Bolts on the ISLB 250 side,

Shear   = 12 000 kg

Bending $\Big\}$ = 350 000 kg
Moment

The bolts may be designed adopting the same procedure as for the bolts on the ISLB 250 side.

Required proof load = 11 760 kg

Taking into account the fact that the pre-load would increase because of moments from both sides and, HTFG bolts M 16-10 K (actual proof load 10 790 kg) may be used even though they are overstressed by 970 kg.

2.5 Moment Connections

2.5.1 Moment connections are characterized by their response to rotation to the applied moment. Rigid joints have very slight rotation due to applied load whereas flexible joints have more rotation for the same amount of applied moment. The flexibility of the joint depends on the total number of bolts used, type of the cleat and separation or otherwise between the cleat and the column in the tension zone.

The friction grip joint in bending is always designed so that there is no separation of the interface while being stressed. This is done by limiting the bolt tension to 0·6 of the proof load. Thus, a friction grip joint exhibits a joint more rigid than the ordinary bolted or riveted joints. However, this should be accompanied by a good design of connection cleats, which should be rigid enough to distribute the moment effectively over the bolt group without excessive deformation.

2.5.2 The Steel Structures Research Committee (UK) have conducted research work on the behaviour of various moment connections. Their recommendations for semi-rigid design draft rules for design are given in Appendix A of IS : 800-1962*. Table XXII of this appendix gives sizes of high strength bolts for various classes of moment connections.

2.5.3 The moment may induce either tension or shear depending on the way the bolts are placed. If there is only shear one should check that there is adequate factor of safety against slip. For this, the formula in 4.3 of IS : 4000-1967† needs to be applied. If the bolts are such as to induce tension in them due to moment, the tension on the bolt should first be calculated assuming that there is no separation at the interface. This tension should then be limited to 0·6 of the proof load to ensure that no separation takes place. Where a shear is existing in addition to tension, the combined effect should be considered as shown in Design Examples 7, 8, 9 and 10.

2.6 Repeated Variation of Forces

2.6.1 The reduction of the strength of the structural joint and a member which is subjected to a cyclical loading depends very much, interalia, on the probable zone of higher stress concentration and the range of the induced stresses. The friction grip joint possesses special properties by virtue of its mechanism whereby the zone of higher stress concentrations are eliminated and the range of variation of the stress within the bolt and joint material is reduced for any given applied load cycle.

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*Code of practice for use of structural steel in general building construction (*revised*).
†Code of practice for assembly of structural joints using high tensile friction grip fasteners.

2.6.2 In friction grip joint, the bolt does not bear against the holes in the plates to react the applied load. This avoids the heavy stress concentration that occur in ordinary bolt and rivet due to slip and bearing against plates. Further, as all the load is transferred by friction; shear, bearing or bending stresses are not present in the bolt. Slight variation in the axial stress may exist due to Poisson's effect but this effect will be comparatively small. As detailed in **2.3** on joints subjected to external tension the actual variation of the axial stress of the bolt is much smaller than the variation of the external tension expressed as percentage. This is because the whole of the joint acts monolithically to react the tension. Also, the high clamping force tends to distribute the applied load over a relatively large area thereby reducing the range of the induced stresses. Furthermore, repeated variation of forces tends to loosen the ordinary nuts. In a high tensile bolt the nuts are held in position by the reaction against threads which are similar in effect to a bolt tightened using a spring washer.

2.6.3 It will be thus seen that high strength bolts are especially suitable for the conditions where repeated reversals of load are encountered as in road and railway bridges, gantry girders, machine foundations, etc. A great deal of research has been done on this property of the friction grip bolts. It has been shown that the fatigue strength of the friction grip joint is about 25 percent greater than that of the ordinary riveted joint. It is for this reason that IS : 4000-1967* does not reduce the working stresses for joints subjected to repeated variation of loads except the connections subjected to external tension. In such a case there will be slight variation in the axial stress, and the maximum permissible external tension on any bolt is limited to 0·5 of the proof load.

3. FABRICATION

3.1 General — As indicated elsewhere, the characteristic of the friction grip joint depends on the proper clamping force induced by the high tensile bolts. This should correspond to the proof load according to the grade and the stress area of the bolt and should be within the permissible limits of variations. The permissible limits have not been specified in IS : 4000-1967* as the measurement of the tension in all the bolts by direct method is not feasible on site. Instead, it specifies two well-known methods, though indirect, of achieving the desired effect and details the methods of quality control.

The indirect methods are:

a) torque control method, and

b) part turn method.

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*Code of practice for assembly of structural joints using high tensile friction grip fasteners.

These methods will achieve the desired effect with a variation of ± 15 to 30 percent. A greater variation due to these methods, however, may contribute to the factor of safety against slip as the zero setting is invariably kept on the higher side.

Recently somewhat direct methods have been introduced. They are:

a) load indicating bolt, and

b) load indicating washer.

These two methods give results within ± 6 percent.

The quality control on site is effected by the regular calibration of the torque spanner in case it is used. Subsequent to that there is no visual check or inspection possible except that some bolts may be checked by re-tightening with the help of a calibrated spanner. Other methods visually indicate the final state of the bolt or the nut thus making the inspection much easier. Apart from these methods of introducing the desired preload in the bolts, it is necessary to control the coefficient of friction of the interfaces. In IS:4000-1967* the coefficient of friction is assumed to be 0·45 and a suitable criterion is laid down to achieve this.

In the subsequent articles the methods of tightening the bolts and the assembly of the joint will be described in detail.

3.2 Torque Control Method

3.2.1 *General* — The method is based on the linear relationship between the torque necessary to turn the bolt and induced tension in the bolt up to the proof load. After the proof load, there is very little increase in the tension with the applied torque.

The relationship between the torque and the tension may be expressed as:

$$M = KTD$$

where

M = applied torque,

T = proof load,

D = nominal diameter of the bolt, and

K = a non-dimensional torque coefficient.

The constant K is a function of the inclination of the threads, coefficient of friction at the threads and also at the nut and the washer. The value of K may be taken as 0·15 if the bolt is slightly lubricated and as 0·25 if it is rusty.

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*Code of practice for assembly of structural joints using high tensile friction grip fasteners.

Spanners called 'Torque Limiting Spanners' or the hand wrenches and impact wrenches working on the air pressure are used to apply the predetermined torque to the bolt. They are so designed that they are unable to apply any more torque than the preset value. This limiting value is set by the use of the formula and then calibrated to give a more precise setting. This is done by tightening a sample bolt against a load cell or similar apparatus (*see* **3.2.2**). The load cell is designed to show the direct tension induced in the bolt. The torque spanner is adjusted to produce a tension 10 percent higher than the proof load of the bolt. The bolt used for calibration is not to be used elsewhere as a friction grip bolt.

Such calibration is made once or more per shift depending on the work load. It is also necessary when the condition of the bolt, size, length, grade, etc, are changed. It may, therefore, be necessary to keep differently calibrated equipment ready for speedy work.

The inspection of the bolt tightened by this method is done by selecting suitable sample of bolts and finding the torque required to retighten them further by using a hand wrench or an impact wrench. If the torque required is found to be below the requirement, every bolt in the batch should be examined and further tightened. The quality control also includes frequent calibration of the tool used.

The advantages and disadvantages of the method may be summarized as follows:

a) The limit of variation is between ± 15 to 30 percent.

b) Re-calibration is necessary for different sizes and grades of the bolts.

c) On a job where different grades and sizes of the bolts are used the method becomes unwieldly.

d) There is no visual check on the completion of the job.

e) Special tools are necessary which may not be easily available.

3.2.2 *Equipment* — The torque control method requires a torque spanner (*see* Fig. 7). The torque spanner is adjusted to predetermined torque at the handle end. The spanner works up to this set torque and collapses if torque to be reacted exceeds. The collapse of the spanner is both seen and felt. When every large bolt sizes are used it is necessary to apply heavy torques. It may lead to the danger of straining or slipping of the personnel. This difficulty is avoided by using torque multipliers (*see* Fig. 8) to give a mechanical advantage up to 25 : 1.

Fig. 7 Torque Spanner
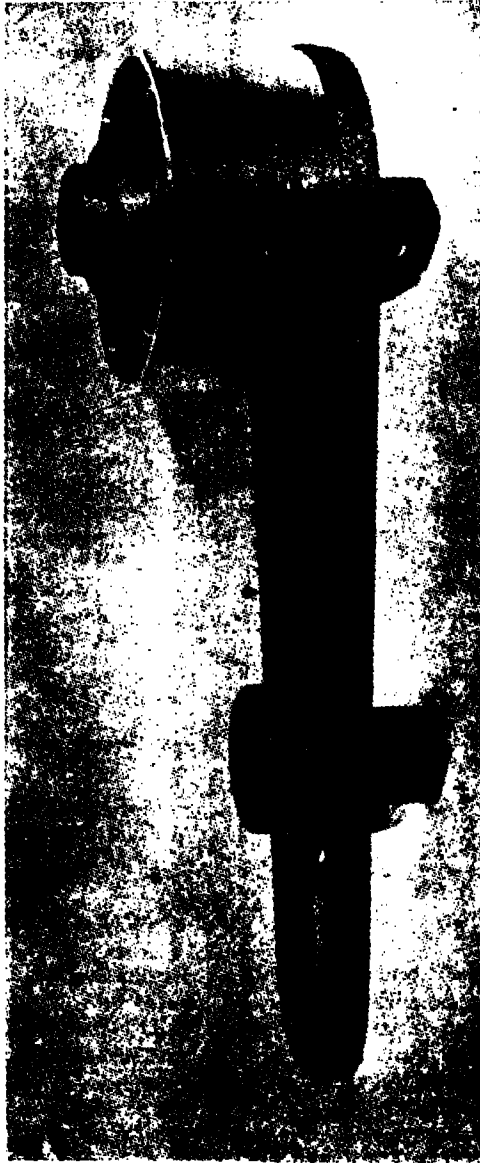
FIG. 8 TORQUE MULTIPLIER

The calibration needed may be determined by the use of the following meters:

a) Static torque meter (*see* Fig. 9). This checks the accuracy of the setting of the predetermined torque on the torque spanner;

FIG. 9 STATIC TORQUE METER

b) Torque tension meter. This instrument enables the torque/tension ratio of many standard fasteners to be quickly obtained and easily read from two dials; the variables that may prevent accurate calculation of the bolt tension are automatically accounted for in this calculation; and

c) **Bolt load meter** (*see* Fig. 10). This equipment is designed to measure the bolt load only, which enables nut runners, impact wrenches or torque spanners to be calibrated directly to give the desired tension in the bolt. Torque measurement, which is an intermediate step, may be eliminated. Where torque recommendations are still required to be satisfied, a sample of six fasteners may be selected at random and the torque to which they have been tightened found out by retightening them by a calibrated spanner. Use of torque spanner and torque multiplier is shown in Fig. 11.
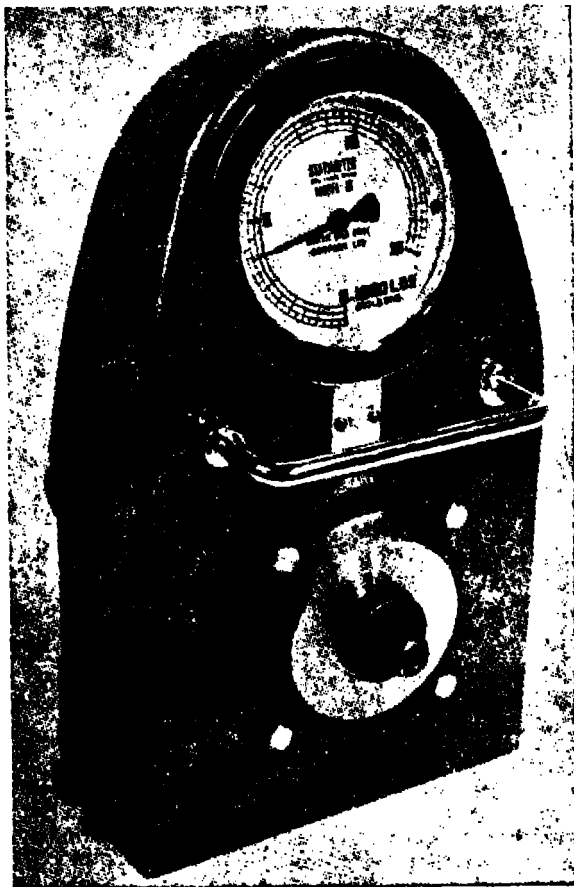
FIG. 10   BOLT LOAD METER
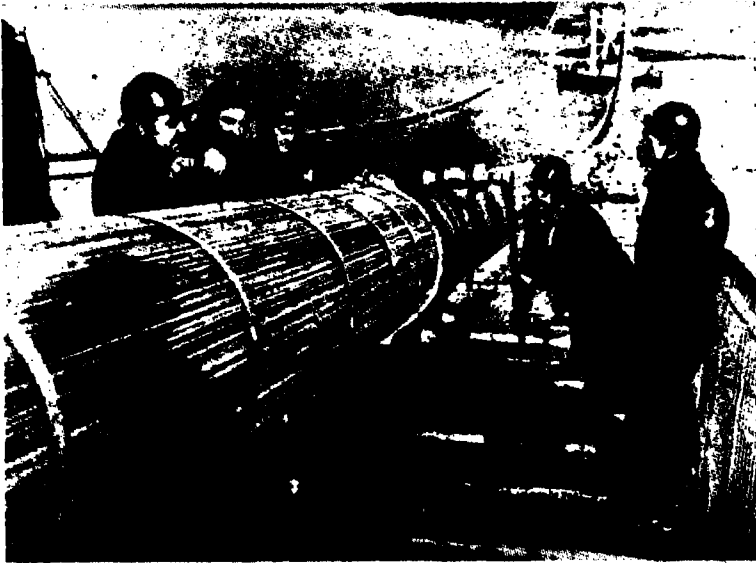
FIG. 11 USING TORQUE SPANNER WITH THE HELP OF
TORQUE MULTIPLIER

3.3 Part Turn Method -- What is essentially required in a friction grip joint is preload in the bolt and the accompanying elongation of the bolt. This may be achieved by turning the nut after the bolt is made just tight. The method based on this principle is called 'Part Turn Method'.

In this method the interfaces are cleaned of all dirt, burrs, loose mill-scale, etc, by using suitable tools. The members forming the joint are then carefully brought together without using any force or making undue deformation. The interfaces are again inspected to see whether any loose particles like that of sand, metal, etc, are lodged within or not. The bolts are then introduced and subjected to preliminary tightening so that they are just tight and it becomes impossible to turn them any further by fingers. If power operated wrenches are used, they are set to 5 percent of the total torque as required by the torque control method. This 5 percent is taken as 'a just tight bolt condition' before giving the final turn as specified.

After this mark is made on the nut and the protruding thread portion of the bolt to record the initial position, the nut is tightened so that the relative turn corresponds to that specified in Table 2.

TABLE 2   FINAL TIGHTENING OF BOLTS

(*Clause* 3.3)

All dimensions in millimetres.

NOMINAL DIAMETER OF BOLT	GRIP OF BOLT FOR ROTATION OF THE NUT (RELATIVE TO THE BOLT SHANK)	
	Not Less Than 1/2 Turn	Not Less Than 3/4 Turn
(1)	(2)	(3)
M 16	Up to 114	
M 20	,, ,, 114	Over 114 to 216
M 22	,, ,, 114	,, 114 ,, 280
M 24	,, ,, 165	,, 165 ,, 360
M 27	,, ,, 165	,, 165 ,, 360
M 33	,, ,, 165	,, 165 ,, 360

As will be seen, this method does not require any sophisticated tools to achieve a preload as ordinary spanners may be used for tightening. The method gives freedom to engineers on site to choose any lubricant or the condition of the bolt without affecting the final result.   The inspection is also made easy as this needs to check the final position of the marks previously made on the nuts and the bolts.   However, the efficiency of this method very much depends on the initial condition of the joint before giving the final turn.

Tightening the bolts by a torque wrench set to 5 percent of the total torque is to some extent satisfactory.   In addition to this, one should make sure that there is no extraneous matter within the joint which would break or yield plastically as further load is applied.   In spite of this, the final preload depends on the condition of the surface and gaps between the components.   Therefore, this method tends to give the percentage variation in the induced load somewhat greater than the torque control method.

3.4 Recent Developments in High Strength Bolts

3.4.1 *General* — The methods described in **3.2** and **3.3** are indirect methods of achieving the bolt tension.   They require some form of supervision and special tools as in the case of a torque control method. With this basis, the variation in the results achieved is between 15 to 30 percent.

With this background, GKN Bolts and Nuts Ltd, UK; Cooper and Turner Ltd, UK; and others developed suitable bolts and washers to ensure a correct tension with little variation.

3.4.2 *Load Indicating Bolt* — This is developed by GKN Bolts and Nuts Ltd, UK. The head of the load indicating bolt is so shaped that before tightening it makes contacts with the steel with its four corners only. This leaves a gap between the steel and the underside of the bolt head. As the bolt is tightened, the part of the bolt head yields and causes a gradual closure of this gap. These experiments show that to ensure a correct bolt load it would only be necessary in practice to make sure that the widths of the gaps under the head were reduced to less than 0·8 mm. This may be done visually or by using a simple feeler gauge (*see* Fig. 12).

3.4.3 *Load Indicating Washer* — This special washer is developed by Cooper And Turner Ltd, UK (*see* Fig. 13). The washer has protrusions on its surface. When it is fitted under the bolt head, there is left a gap between the general surface of this washer and the underside of the bolt head. The bolt is then tightened until the gap is reduced to an average of 0·4 mm as measured by a feeler gauge. If the gap is inadvertantly closed to less than that it is to be allowed to remain so and on no account adjusted by slackening the nut.

3.4.4 Apart from the above mentioned methods GKN Bolts and Nuts Ltd, have developed a torshear bolt. The correct tension is achieved by a grooved extension machined to a calculated depth which shears off when the correct tension is applied preventing further tightening. This ensures that the correct tension is automatically applied and makes inspection easy and visual. The bolt needs a special tool for tightening.

3.5 Assembly of Joints

3.5.1 *Bolt Sizes* — Once the bolt diameter has been decided upon it is necessary to calculate the length of the bolt for ordering the material from the suppliers. The length of the bolt is given by the following formula:

$$l = \text{Grip} + m + t + 3p$$

where

l = required length of the bolt,

m = thickness of friction grip nut based on ' S ' grade finish as defined in IS : 3757-1966*,

t = the value of maximum negative tolerance on bolt length applicable for individual diameters, and

p = thread pitch ($3p$ is meant to cover bolt end pointing).

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*High-tensile friction grip fasteners for structural engineering purposes.
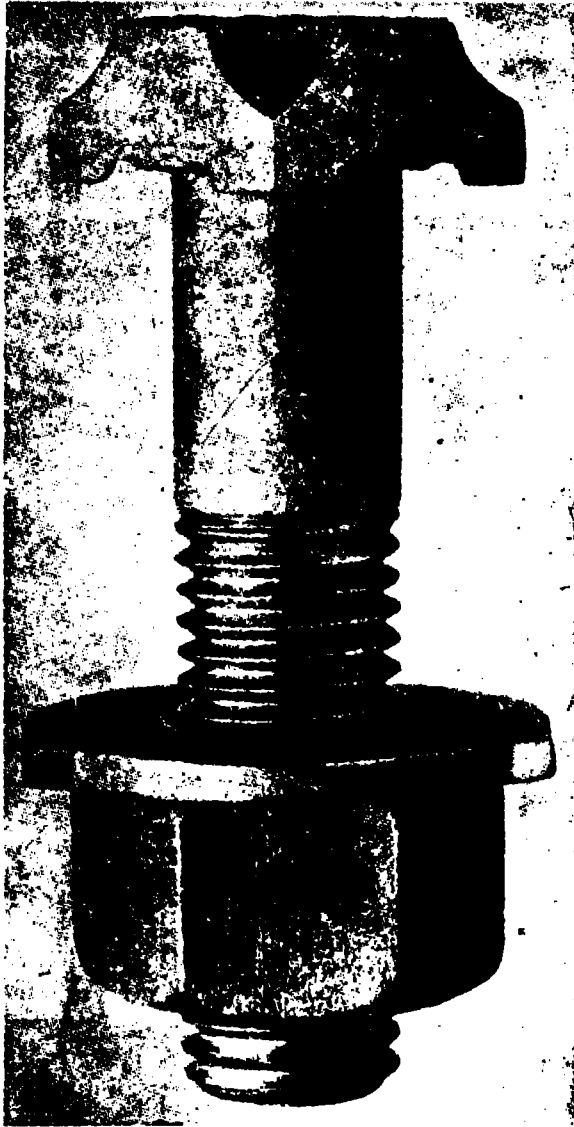
FIG. 12   GKN LOAD INDICATING BOLT

FIG. 13 'Y' GRADE HIGH STRENGTH FRICTION GRIP BOLT WITH CORONET LOAD INDICATOR

Preferred length — diameter combinations are given in Table 3.

The following table gives the length to be added to the grip length to get the overall length of the bolt. This table can be used instead of the Formula given above. This does not provide for thickness of washers. Thickness of washers if used should be included in the grip length. The table does not allow for the variation in the grip length.

Bolt Size	Add to Grip	Bolt Size	Add to Grip
12	17	27	34
16	22	30	38
20	27	33	40
22	29	36	44
24	31	39	46

To be precise one should allow for both positive and negative tolerance in the plates in the grip of the joint. In order to allow this, the grip

length should be increased by the positive tolerance and the threaded length should be increased by the difference between the negative and positive tolerance. However, in practice it is rare that a joint would consist of all members with the tolerance on one side only. As such the sum of the thickness of each member would neutralize the positive and negative tolerances giving the grip with much less variation. If in any special case the structural members are having tolerances on one side only, the designer will have to order the bolts as specials having longer threads.

TABLE 3 PREFERRED LENGTH DIAMETER COMBINATIONS FOR BOLTS

(*Clause* 3.5.1)

LENGTH E (J 17)			M 12	M 16	M 20	M 22	M 24	M 27	M 30	M 33	M 36	M 39
Nom	*Max*	*Min*										
30	31·0	29·0	×	—	—	—	—	—	—	—	—	—
35	36·5	34·0	×	—	—	—	—	—	—	—	—	—
40	41·5	39·0	×	×	—	—	—	—	—	—	—	—
45	46·5	44·0	×	×	—	—	—	—	—	—	—	—
50	51·5	49·0	×	×	—	—	—	—	—	—	..	—
55	56·5	53·5	×	×	×	—	—	—	—	—	—	—
60	61·5	58·5	×	×	×	×	—	—	—	—	—	—
65	66·5	63·5	×	×	×	×	×	—	—	—	—	—
70	71·5	68·5	×	×	×	×	×	×	—	—	—	—
75	76·5	73·5	—	×	×	×	×	×	—	—	—	—
80	81·5	78·5	—	×	×	×	×	×	×	—	—	—
90	92·0	88·5	—	×	×	×	×	×	×	—	—	—
100	102·0	98·5	—	×	×	×	×	×	×	×	×	×
110	112·0	108·5	—	—	×	×	×	×	×	×	×	×
120	122·0	128·0	—	—	×	×	×	×	×	×	×	×
130	132·0	128·5	—	—	×	×	×	×	×	×	×	×
140	142·0	138·0	—	—	—	—	×	×	×	×	×	×
150	152·0	148·0	—	—	—	—	×	×	×	×	×	×
160	162·0	158·0	—	—	—	—	—	×	×	×	×	×
170	172·0	168·0	—	—	—	—	—	—	—	×	×	×
180	182·0	178·0	—	—	—	—	—	—	—	×	×	×
190	192·0	187·5	—	—	—	—	—	—	—	×	×	×
200	202·5	197·5	—	—	—	—	—	—	—	×	×	×

3.5.2 *Holes in Members* — In IS : 4000-1967* it is specified that all the holes shall be drilled and burrs removed. Where the number of plies in the

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*Code of practice for assembly of structural joints using high tensile friction grip fasteners.

grip does not exceed three, the diameter of the hole shall be 1·6 mm larger than that of the bolt. Where the number of plies exceed three, the diameter of the holes in the outer two plies shall be as above and the diameters of the holes in the inner plies shall be not less than 1·6 mm and not more than 3·2 mm larger than those of the bolts.

If it is necessary to drift the holes, it shall be done so as to prevent distortion of the metal. If the holes need enlargement it shall be done by reaming provided the requirement of the maximum diameter is adhered to. If the holes are badly matched the members shall be rejected. But in no case the bolts shall be driven.

3.6 Preparation of Surfaces — To develop the desired friction, the interface should be free from all millscale, oil, paint, lacquer, galvanizing or aluminizing or similar finishes. In addition to this, there should be no gasket or similar material sandwiched between the plates. This will ensure that the desired coefficient of friction is developed and that there is no comparatively weak material which would deform by sliding or get compressed under the load. It may be noted that IS:4000-1967* does not allow for painting even for protection against corrosion. If the steelworks need to be supplied painted in shop, the contact surfaces should be masked. In USA, research work is in progress to evaluate the performance of the contact surfaces to which a thin primer is applied immediately after grit blasting. It is learnt that the primer does not lower the coefficient of friction.

Therefore, the only way to protect the steelworks is to clean the interface and bolt them tightly, wirebrush the completed assembly and apply the paint.

It is obvious that cleaning the interface improves the efficiency and reliability of the joint. This may be done by:

a) removing traces of oil, chemically, if necessary;

b) stripping the paint; and

c) wirebrushing or grit blasting the surface to remove all loose material.

Among these, grit blasting improves the coefficient of friction of all the interfaces and effectively remove all the traces of oil and paint if still persistent after stripping. It consists of blasting the surface with abrasive material accelerated to a high velocity by the pressure of air or a rotating wheel. In some cases, a suspension of the abrasive in water is used which is then accelerated by using high pressure air.

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*Code of practice for assembly of structural joints using high tensile friction grip fasteners.

Preliminary tests were conducted by Metallisation Ltd (UK), on sprayed friction grip joints. The tests indicated that:

a) Galvanizing and painting should be avoided,

b) Freshly sprayed coating of zinc and aluminium increased slip factor well above the level normally required, and

c) In a second series of tests the structural members were subjected to weathering for three months. The tests indicated that slip factor does not fall below the desired level after weathering.

3.7 Procedure for Tightening — If due care is taken in the workmanship while manufacturing the members, it should be easy to assemble the joints. Such a joint may be held in position using a few ordinary or high strength bolts. If high strength bolts are used, they should not be included in the final assembly. After this temporary assembly, the bolts should be replaced by high strength bolts. Washers are introduced under the nut or the bolt head whichever is being turned, if tightening is done by torque control method. Bevelled washers are used to compensate for the lack of parallelism if the slope is more than 1 : 20. The bolts are tightened using a suitable method from the centre of the bolt group outwards.

If high strength bolts get slackened off for any reason they should be discarded. If, however, load indicating bolts or washers are used, they may be re-tightened to the desired gap.

On no account the bolts should be slackened purposely, that is, if the desired tension is exceeded or if the gap was closed too much.

3.8 Inspection

3.8.1 *Bolts, Nuts and Washers* — Samples of the bolts are taken and tested for proof load in accordance with IS : 3757-1966*.

3.8.2 *Interfaces of Structural Members* — The holes should be carefully checked for burrs, tolerances and physical damage. The interface should be checked to see that it is according to requirement, that is, free from oil, paint, etc. In partial assembly there should be no gaskets, grit or other weak material.

3.8.3 *Equipment* — The torque limiting spanner should be checked for calibration. The method adopted for calibration itself should be checked.

3.8.4 *Inspection after Tightening the Bolts* — The mode of inspection varies according to the method of tightening and the type of the bolt used.

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*Specification for high tensile friction grip fasteners for structural engineering purposes.

3.8.4.1 *Torque control method* — Sample bolts should be tried for re-tightening to see whether they are undertorqued.

3.8.4.2 *Part turn method* — The inspection will include checking the final turn as indicated by the displacement of the original marks on the nut and the bolt shank.

3.8.4.3 *Torshear bolt* — The bolt shank should be broken off at the pre-determined location on the shank.

3.8.4.4 *Load indicating bolt or a washer* — The desired gap should be checked by using feeler gauges.

3.9 Sampling — If the number of joints is too large it is not convenient to check all of them. It is, therefore, necessary to select some of them at random from each batch. The batch means the group of joints with identical conditions regarding tightening. Therefore, the batch should consist of the amount of work done by one gang of men using the same tool with single calibration and done in one unit time, say, a day. Out of such a batch the inspector should select at least one-third joints at random. If each joint is numbered, he may take the help of the tables of random numbers to select them. It is unlikely that the total number of joints in a sample will constitute a large amount of work for inspection. However, if it is found to be so because of a consistantly large volume of batch, it will be useful to use double sampling technique wherein the preliminary sample is small and the result of which guides the inspector to reject all the batch as below standard or take a further sample, if necessary.

APPENDIX A

(*see* Foreword)

COMPOSITION OF STRUCTURAL ENGINEERING SECTIONAL COMMITTEE (SMBDC 7), AND OF PANEL FOR CODE OF PRACTICE FOR USE OF HIGH TENSILE FRICTION GRIP FASTENERS (SMBDC 7/P 12)

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APPENDIX B

(*see* Foreword)

INDIAN STANDARDS AND OTHER PUBLICATIONS OF ISI RELATING TO STRUCTURAL ENGINEERING

ISI has so far issued the following Indian Standards in the field of production, design and utilization of steel:

Structural Sections:

IS:808-1964   Rolled steel beam, channel and angle section (*revised*)

IS:811-1965   Cold formed light gauge structural steel sections (*revised*)

IS:1173-1967   Hot rolled and slit steel tee bars (*revised*)

IS:1252-1958   Rolled steel sections bulb angles

IS:1730-1961   Dimensions for steel plate, sheet and strip for structural and general engineering purposes

IS:1731-1961   Dimensions for steel flats for structural and general engineering purposes

IS:1732-1961   Dimensions for round and square steel bars for structural and general engineering purposes

IS:1852-1967   Rolling and cutting tolerances for hot-rolled steel products (*revised*)

IS:1863-1961   Dimensions for rolled steel bulb plates

IS:1864-1963   Dimensions for angle sections with legs of unequal width and thickness

IS:2314-1963   Steel sheet piling sections

IS:2713-1964   Tubular steel poles for overhead power lines

IS:3443-1966   Crane rail sections

IS:3908-1966   Aluminium equal leg angles

IS:3909-1966   Aluminium unequal leg angles

IS:3921-1966   Aluminium channels

IS:3954-1966   Hot rolled steel channel sections for general engineering purposes

IS:3964-1967   Light rails

IS:5384-1969   Aluminium I-Beams

Codes of Practice:

IS:800-1962   Use of structural steel in general building construction (*revised*)

IS:801-1958   Use of cold formed light gauge steel structural members in general building construction

IS:802 (Part I)-1967   Use of structural steel in overhead transmission line towers: Part I Loads and permissible stresses

IS:803-1962   Design, fabrication and erection of vertical mild steel cylindrical welded oil storage tanks

IS:805-1969   Use of steel in gravity water tanks

IS:806-1968   Use of steel tubes in general building construction (*revised*)

IS:807-1963   Design, manufacture, erection and testing (structural portion) of cranes hoists

IS:3177-1965   Design of overhead travelling cranes and gantry cranes other than steel work cranes

IS:4000-1967   Assembly of structural joints using high tensile friction grip fasteners

IS:4014-(Part I)-1967   Steel tubular scaffolding: Part I Definitions and materials

IS:4014 (Part II)-1967   Steel tubular scaffolding: Part II Safety regulations for scaffolding

IS:4137-1967   Heavy duty electric overhead travelling cranes including special service machines for use in steel works

Handbooks

Handbook for structural engineers : 1   Structural steel sections

Handbook for structural engineers : 2   Steel beams and plate girders

Handbook for structural engineers : 3   Steel columns and struts

General

IS:804-1967   Rectangular pressed steel tanks (*revise1*)

APPENDIX C

(*see* Foreword)

USE OF DIGITAL COMPUTERS FOR DESIGN OF JOINTS

The use of computers will greatly simplify the procedure if the joints to be designed are of the repetitive nature. For example, in a multi-storey building most of the joints will be of column-to-beam type with applied moment and shear. Such joints would occur in multitude and would require too much of time in the design offices.

The use will of course introduce some form of restriction of the trivial nature like the total number, maximum size and general arrangement of the bolts. For example, the restriction may be a maximum of 16 bolts, M 30 size and an arrangement of two rows with the minimum pitch.

A flow diagram (*see* Fig. 14) is suggested herewith. Accordingly, the computer is fed with the initial data, that is, the bolt diameter, pitch, end distance and proof load. The computer then reads the forces and the moments acting on a particular joint. Additional information, that is, fatigue, number of shear faces, grades of bolts, is then fed to it. Now, the computer is ready to design a particular joint. It assumes a low bolt size and their numbers, calculates the polar moment of inertia based on the preconceived notion of arrangement of bolts. A combined effect of all forces and moments is worked out by using well-known expressions. The result is checked. · If it is not satisfactory or if the resultant load on a bolt becomes greater than the proof load, the computer increases the number of bolts and tries again until the conditions are satisfied. If during this operation the total number of bolts becomes larger than the stipulated number, the computer takes the next larger bolt size and tries all over again. Even after this if no result is possible the computer will print out a 'NIL' report and proceed to the next joint. The designer may pick these unsolved joints and use his better skills to designer such joints and if possible improve the programme so that a solution is available next time.

It may be seen that a reiterative procedure has been adopted which probably is the easiest method for computers. It is estimated that one joint should not take more than I·5 seconds for solution.

The suggested flow diagram map be put into a computer programme by any body with a knowledge of the computer language and the design methods of friction grip joints.
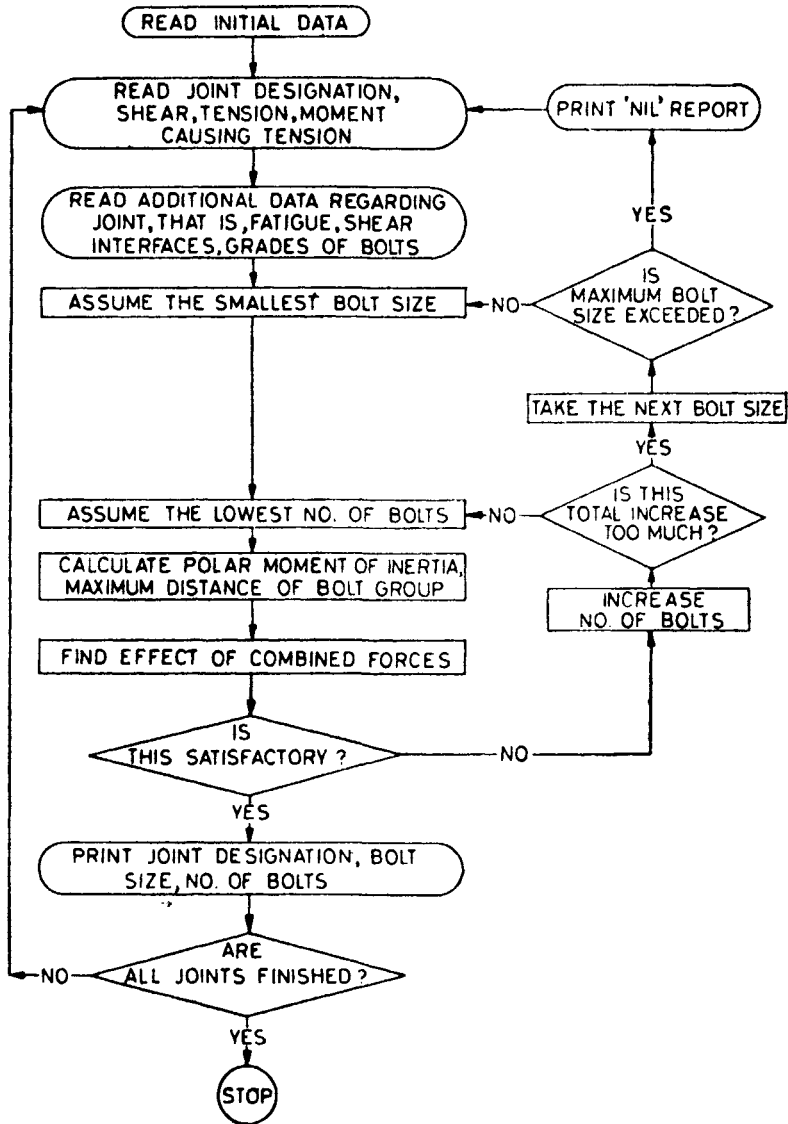
Fig. 14 Typical Flow Diagram for Computer Programme for Solving Problems Connected with Friction Grip Bolts

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