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The Use of High Strength Bolts in Railway Girder Bridges

Emploi des boulons précontraints dans les ponts-rails à poutres

Die Verwendung von vorgespannten Schrauben bei Eisenbahn-Balkenbrücken

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1. Definition

This Paper is concerned with the use of bolts in large clearance holes and acting as permanent shear connectors through the friction grip resulting from the clamping effect brought about by tightening them sufficiently to prevent slip occurring between the parts joined together. The process here described as high-strength bolting depends on the friction caused by the clamping effect of the fasteners, and normally such a joint is deemed to have failed if the friction is overcome and the parts commence to slide, one upon the other. The expression high-strength bolt is taken to mean the same as high preload bolt, prestressed bolt, friction grip bolt, etc.

2. History

The use of high-strength bolts (38 tsi ultimate) for the permanent fastening together of mild steel plates and rolled sections originated in the United Kingdom with the pioneer work of the late Professor C. BATHO (Second and Third Reports of the Steel Structures Research Committee, H.M.S.O. 1934 and 1936 respectively). Subsequently the technique of high-strength bolting was developed in the U.S.A.; but it was the change over from riveted fabrication to welding that brought high-strength bolting to the fore. It was a shortage of skilled riveters and a dislike for site-welding, especially on railway bridge work that brought the high-strength bolt into regular use as a permanent fastener on British Railways.

3. The Friction Grip Joint

The high-strength bolted joint depends on the friction between the plies due to the clamping force resulting from tightening the bolts. The shear load strength of the joint is therefore dependent on:

a) The coefficient of friction of the faying surfaces, and
b) The tension in the bolts.

The bolts are in clearance holes, normally $^1/_{16}''$ larger, the amount of the clearance not greatly mattering between certain limits, see table 1. And because the tension in the bolts remains unaffected under increased shear loading on the joint, the technique gives fatigue resistance much superior to riveted work.

Since the coefficient of friction of the faying surfaces will vary according to the condition of those surfaces, this steel in contact is not normally oiled or painted.

The tension which can be developed in the bolts depends on the strength of the bolt steel, the torque characteristics of the threads, lubrication, and the method of tightening. Of the total work put into tightening a high-strength bolt, only about 10% is available for tensioning the bolt: the remainder being lost in overcoming friction in the threads and in the nut face bearing on the washers, vide fig. 1.

Table 1. Effect of Size of Clearance Hole in Structural Parts

Bolt Dia. (D)	Code symbol of NUT (B.S. 1083 Table 10)	Applied torque	Bolt tension due to applied torque	Code symbol of NUT (B.S. 1083 Table 10)	Applied torque	Bolt tension due to applied torque
	Hole dia. $= D+{}^1/_{16}''$			Hole dia. $= D+{}^1/_8''$		
inch		lb. ft.	ton		lb. ft.	ton
$^5/_8$	*A*	140	7.0	*P*	125*	6.25*
$^3/_4$	*A*	250	10.4	*A*	200*	8.3*
				P	250*	10.4*
$^7/_8$	*A*	300*	10.8*			
	P	390	14.1	*P*	310*	11.2*
1	*A*	480*	15.0*			
	P	600	18.7	*P*	510*	15.9*
$1^1/_8$	*A*	690*	19.4*			
	P	830	23.3	*P*	740*	20.8*

Note: Where marked (*) any higher tension would involve a risk of crushing the steel at the nut face. With the reduced tensions shown, the bolts will still function as effectively as hot-driven rivets.

Tightening is done either by the torque coefficient method where the bolt tension does not exceed the yield point, or by the part-torque part-turn technique.

4. Riveted and Bolted Friction Joints Compared

High-strength bolted friction joints have shear values in excess of the friction obtaining in a riveted joint. Rivets do not fill the holes *absolutely* and if the friction is overcome there is a small, even minute slip of the faying surfaces before the rivet commences to function as a dowel. In sound riveted

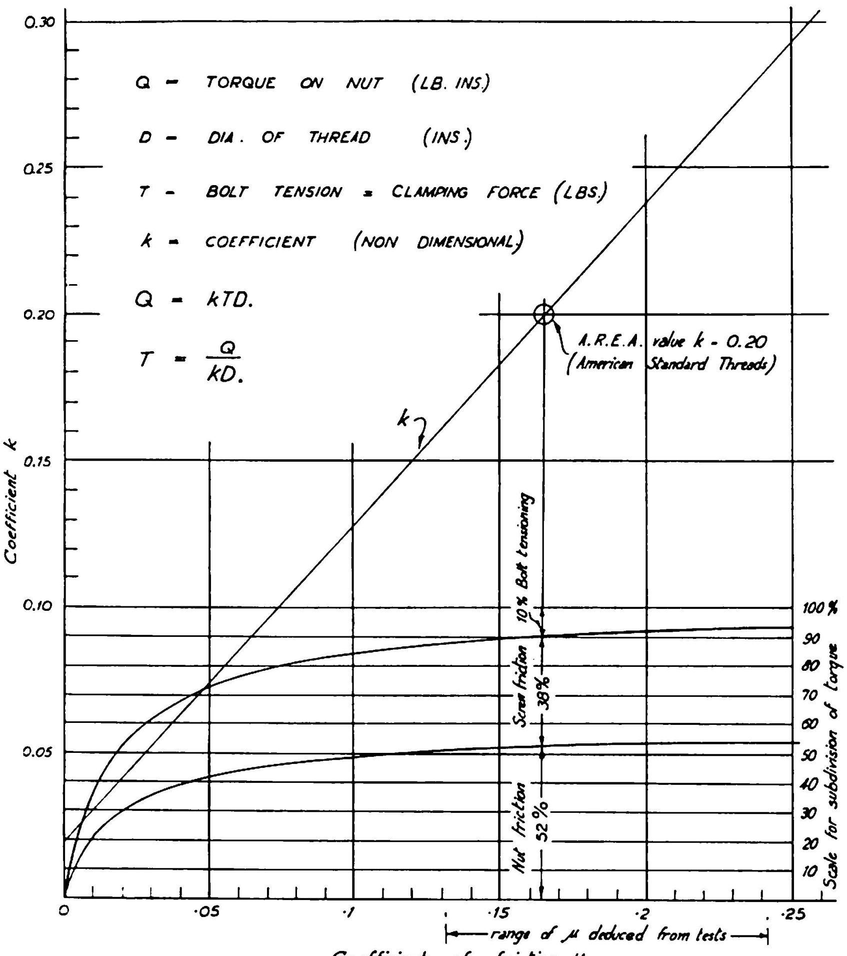
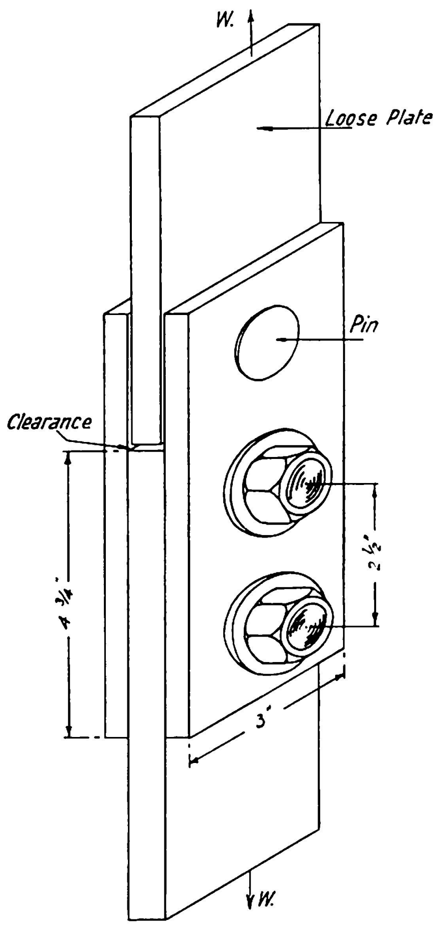


Fig. 1. Bolt Tension Due to Nut Tightening (B.S.W.).



$^3/_4$" Dia high strength bolts with M.S. nuts and case hardened washers working in clearance holes.

Fig. 2. Diagram Showing the Arrangement of High Strength Bolted Friction Joint Used to Determine the Values of μ Coefficient of Friction.

work, the rivets are permanently strained up to the elastic limit. Rivet steel to B.S. 15 has an ultimate strength of 25 tsi, and a yield of about 13.75 tsi. In the process of heating and driving, the ultimate is increased some 10 to 15 per cent. Comparison of the grip applied to the plates joined with an *R* quality (45/55 tsi ultimate) high-strength bolt tightened to 90 per cent of the yield is as follows:

Rivet after closing	15.8 tsi
Tension in $^7/_8$ in. rivet ($^{15}/_{16}$ in. diameter)	10.85 tons
High-strength bolt *R* quality (34 tsi minimum yield)	30.6 tsi
Tension in $^7/_8$ in. diameter H.S. bolt (0.464 sq. ins. stress area $\times 30.6$)	14.1 tons

and so the ratio of bolt tension to rivet tension is 14.1 to 10.85 or 1.3.

5. Coefficient of Friction of the Faying Surfaces

The value of μ the coefficient of friction, for mild steel plates as rolled is generally taken as 0.33. Experiments on a bolted joint in double shear, fig. 2, were made to determine the variations in the coefficient of friction when the bolts were tightened to different torques under different surface conditions of the plies. The plates were fastened together with $^3/_4$ in. diameter bolts, the joint was pulled in a tensile testing machine and the load noted at which slip occurred. The results are given in table 2.

Table 2. Results of Friction Tests on a High Strength Bolted Joint

$^3/_4''$ Dia. H.T. Bolts in Double Shear

Condition of Surface	Applied Torque lb. ft.	Total Clamping Force Tons	Slip Load Tons	Coefficient of Friction μ
As received	150	11.4	8.3	0.37
As received	200	15.2	12.7	0.42
Hand Filed	50	3.8	3.4	0.45
Hand Filed	100	7.6	7.0	0.46
Hand Filed	150	11.4	12.6	0.55
Filed and Oiled	50	3.8	1.9	0.25
Filed and Oiled	100	7.6	3.5	0.23
Filed and Oiled	150	11.4	5.6	0.25
Filed and Oiled	200	15.2	8.3	0.27
Filed and Oiled	240	18.4	11.7	0.32
Filed and Painted (wet)	240	18.4	5.7	0.16

Similar tests to determine the effect of coating the faying surfaces with wet and dry red lead paint gave values of μ of 0.27 and 0.31 respectively. Wire-brushing and flame-cleaning increase the friction, the values of μ for mild steel (28/32 tsi ultimate) being 0.50 and 0.60 respectively.

6. Torque Coefficient

The torque coefficient method of tightening is based on the fact that the tension in the bolt varies directly as the torque, an assumption which because it neglects the effects of the condition of the threads and their lubrication, can result in tension 15 per cent above or below the value given by the torque. The torque coefficient is a non-dimensional constant given by the expression:

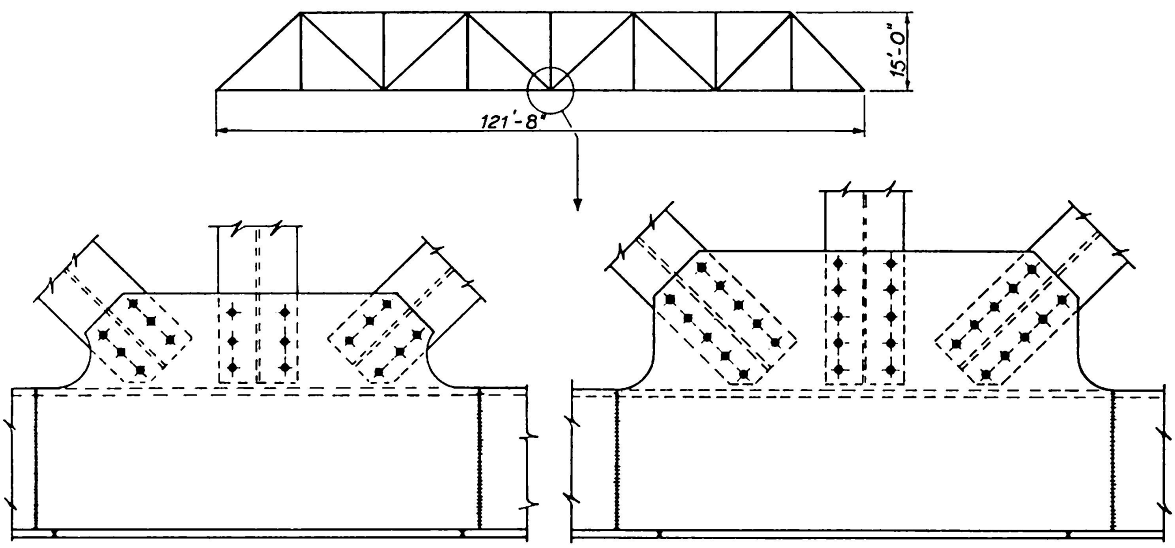
$$K = \frac{Q}{T\,d}.$$

Where Q is the torque applied (lbs. ins. units),
T is the bolt tension (lbs. units),
and d is the nominal thread diameter (inch units).

Experience shows that for Whitworth threaded bolts with no lubrication other than the oil applied by the makers, K has values ranging between 0.15 and 0.20.

7. Specifications

Bolts, nuts and washers comply with British Standard Specifications for materials as shown in table 3. The normal quality bolts are used in direct



V Quality Bolts (65/75 t.s.i. ult.) R Quality Bolts (45/55 t.s.i. ult.)

Fig. 3.

Table 3. British Railways — Western Region. Specifications for High-Strength Bolts ($^5/_8$ to $1^1/_8$ inch diameter) Materials

Class of bolt		B.S. No. and code symbol	Minimum ultimate tensile stress tsi	Minimum yield stress tsi	Minimum percentage elongation on gauge length equal to $4\sqrt{\text{Area}}$	Minimum izod impact value ft. lb.		Brinell hardness number
						$^5/_8$ and $^3/_4$ in. dia.	Over $^3/_4$ in. dia.	
Normal	Bolt	B.S. 1083 *R* 45/55	45	34	20	40	35	201/271
	Nut	B.S. 1083 *P* 35/48	35	—	15	—	—	152/235
Special	Bolt	B.S. 1083 *V* 65/75	65	52	16	35	30	293/364
	Nut	B.S. 1083 *R* 45 min.	45	—	20	—	—	201/271
Torshear	Bolt	B.S. 1768 *T* 55/65	55	41	18	40	35	248/316
	Nut	B.S. 1750 2*H* 45/55	45	—	—	—	—	248/352

Table 4. Dimensions in Inches of Precision Hexagon Bolts and Nuts and Plain Washers

Nominal size	Bolt			Bolt and nut					Nut	Washer		
	Dia. of shank	Thickness of head	Radius under head	Threads per inch		Width across flats	Width across corners	Dia. of. washer face	Thickness	Dia. of hole	Outside dia.	Thickness
	min.	min.	max.	B S W U N C	B S F	min.	max.	min.	min.			
$^{5}/_{8}''$	0.619	0.48	$^{1}/_{32}$	11	14	1.000	1.17	0.975	0.552	$^{11}/_{16}$	$1^{3}/_{8}$	0.144
$^{3}/_{4}''$	0.744	0.59	$^{1}/_{32}$	10	12	1.190	1.39	1.165	0.677	$^{13}/_{16}$	$1^{5}/_{8}$	0.160
$^{7}/_{8}''$	0.867	0.65	$^{1}/_{32}$	9	11	1.288	1.50	1.263	0.740	$^{15}/_{16}$	$1^{7}/_{8}$	0.176
$1''$	0.992	0.76	$^{1}/_{32}$	8	10	1.468	1.71	1.443	0.865	$1^{1}/_{16}$	$2^{1}/_{8}$	0.176
$1^{1}/_{8}''$	1.117	0.87	$^{3}/_{64}$	7	9	1.658	1.93	1.628	0.990	$1^{3}/_{16}$	$2^{3}/_{8}$	0.192

Note: With the exception of the washers all dimensions are as B.S. 1083: 1951.

Table 5. The Effect of Thread Condition on Bolt Tension

The results tabulated below are from an examination made of bolt loading achieved due to various thread conditions. The same torque was applied to each nut regardless of thread condition and altered only when a change in the ultimate tensile strength was involved.

Condition of thread	Torque (lb. ft.)	Bolt tensile loading (tons)	Remarks
$^{7}/_{8}'' \times 3^{3}/_{4}''$ B.S.F. Bolts, ultimate tensile strength 50 tsi			
Dry- (Degreased in Trichlorethylene)	470	8.8 10.5 8.8	Sudden increase in torque at 6–7 tons bolt loading due to jamming. (See *)
Rusted- (Severe secondary oxidation of thread surface)	470	12.5 12.3 12.0	Higher bolt tension than anticipated, because of slight lubricating action of rust scale. (See *)
Normal blackened and oiled finish	470	18.5 17.9 19.0	The 90% torque figure is calculated on the basis of results obtained from this finish. (See *)
Zinc plated	470	20.5 21.0 20.0	Excellent finish for producing high uniform bolt tensions. (See *)
Lubricated with heavy silicone based grease	470	21.5 22.0 23.4	
* The required minimum bolt tension in the A.S.T.M. A. 325 Specification is 14.46 tons for this diameter of bolt.			
$^{7}/_{8}'' \times 7^{1}/_{2}''$ B.S.F. Bolts, ultimate tensile strength 65/75 tsi			
Dry- (Degreased in Trichlorethylene)	546	11.4 12.0 10.5	Nut jammed giving low bolt tensile loading.
Rusted- (Severe secondary oxidation of thread surface)	546	15.0 12.5 13.0	Thread lubricity assisted by rust scale
Normal blackened and oiled finish	546	25 24.5 23.5	
Zinc plated	546	25.5 27 26.8	
Lubricated with heavy silicone based grease	546	26.5 27 26	

General Remarks: For all tests, Nuts 45/55 ton/sq. in. were used with case-hardened washers. The torques applied were calculated to produce 90% of the yield stress of the bolt under normal conditions of thread lubrication etc.

substitution for mild steel rivets, the special are for new work designed to make better use of the technique of high-strength bolting. Fig. 3 shows the reduction in size of gusset plates in a truss span resulting from the use of higher tensile steel bolts. The quality of Torshear bolts, referred to later is also included in the table. The dimensions of the bolts and nuts used on British Railways are in accordance with B.S. 1083, the heads and nuts being either chamfered or washer faced. Screw threads are British Standard Whitworth. Washers (two per bolt) are made from medium carbon steel, double heat treated. The dimensions of the normal bolts, nuts and washers used on British Railways are given in table 4.

8. Bolt Threads

The condition of the threads, that is dry, rusty, lubricated, etc., the form of the threads and the method of forming the threads on the bolt have a marked effect on the value of the torque coefficient of a bolt. The results of tests carried out by a leading Scottish firm of bolt makers to determine the effect of the condition of the thread on bolt tension are given in table 5. The bolts used in these tests had British Standard Fine threads formed by a cold rolling process. A comparison between British Standard Whitworth and BSF threads is given in table 6 which shows the results of laboratory tests made to determine the effect of thread form and condition on bolt tension. It will be seen that the results are by no means consistent though on average the BSW generally appears to give the higher tension. This is perhaps to be expected since with a large proportion of the load carried on only one or two threads

Table 6. Test Results to Determine the Effects of Thread Form and Condition on Bolt Tension

Bolt size	Applied torque lb. ft.	Condition of threads	Statistical mean load tons			
			Type of Nut			
			B.S. 190		B.S. 1083	
			Whit	BSF	Whit	BSF
3/4″	240	Dry	10.0	9.2	10.25	10.0
		Oiled	10.5	9.25	10.45	10.6
		G.G.C.	10.95	9.7	10.65	11.2
7/8″	370	Dry	15.7	14.1	14.6	15.0
		Oiled	15.3	13.7	14.6	14.4
		G.G.C.	15.25	14.15	14.0	12.9
1″	560	Dry	17.25	18.65	20.95	18.8
		Oiled	17.55	17.95	19.25	16.65
		G.G.C.	17.9	15.9	18.9	16.7

(fig. 4 shows the distribution of stress in a bolt and nut assembly) the BSW has the greater strength. The effect of different methods of forming the threads is more marked, bolts with threads formed in a cold rolled process giving consistently higher values of tension under all conditions, vide table 7 summarizing the results of a further series of laboratory tests.

It will be noticed that Torshear bolts referred to later on have Unified Coarse Threads (UNC). This happened to be the only thread available on these particular bolts at the time, and it is of but little consequence because the performance of this self-reactor bolt is dependent on a shear link embodied in the bolt and designed to fail in torsional shear when the bolt tension reaches the prescribed value.

Table 7. Test Results to Determine the Effects of Rolled and Cut Threads on Bolt Tension

Bolt size	Thread form	Type of nut	Applied torque lb. ft.	Condition of threads	Statistical mean load tons	
					Roll. thread	Cut thread
7/8″	B.S.F.	B.S. 1083 A 28 tsi ult	370	Dry Oiled G.G.C.	15.0 14.4 12.9	12.5 11.15 11.8

Note: G.G.C. indicates lubricated with Graphite Grease Compound.

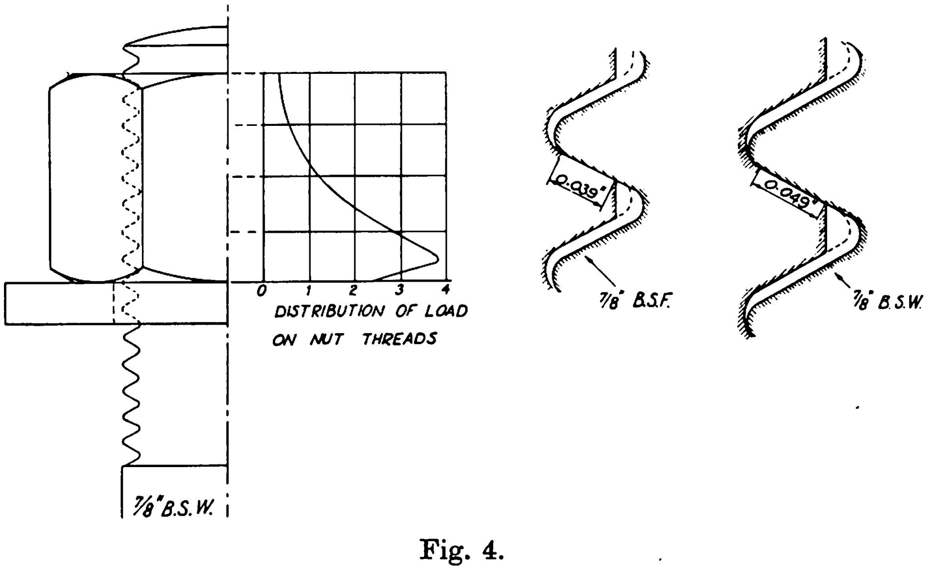


Fig. 4.

9. Assembly

It is specified that the surfaces of bolted parts adjacent to the bolt heads and nuts shall be parallel, tapered washers being used where necessary. The bolted parts have to fit solidly together and the faying surfaces have to be free of paint, oil, loose scale, burrs and other defects that might prevent the solid seating of the parts or might interfere with the development of the friction between them. Bolts tensioned by the torque coefficient method are tightened to the applied torques set forth in table 8.

Table 8. High-Strength B.S.W. Bolts

(1) Dia. of Bolt	(2) "Stress area" of thread (Note A)	(3) Applied torque	(4) Bolt tension due to applied torque	(5) Maximum permissible shear load (Note B)	(6) Maximum permissible tension due to external load (Note C)
inch	sq. in.	lb. ft.	ton	ton	ton
$^5/_8$	0.2271	140	6.9	1.84	3.29
$^3/_4$	0.3359	250	10.4	2.65	4.87
$^7/_8$	0.4636	390	14.1	3.61	6.72
1	0.6083	600	18.7	4.71	8.82
$1^1/_8$	0.7663	830	23.3	5.96	11.11
$1^1/_4$	0.9724	1170	29.8	7.36	14.10

Note A. "Stress area" is the area at the mean of the effective and minor diameters of thread. It is about 10 per cent greater than the area at root of thread and represents the nearest approach to the effective stress area of the threaded length.

Note B. Calculated at 6 tsi on gross cross-sectional area.

Note C. Calculated at 14.5 tsi on "stress area".

10. Bolt Loading by Torque Coefficient Method

The torque coefficient method of tightening is normally used in conjunction with ordinary hand spanners, the plies being drawn together and the bolts well bedded down before final tightening with a torque-measuring or a torque-limiting spanner. No additional lubrication is given to the threads, the bolts being oiled at the works before supply. The effect of lubrication on the threads determined by laboratory tests has been shown in table 6.

The following hand spanners are in use:

a) Torque-measuring spanners fitted with a dial from which the torque is read off at the moment the nut just ceases to move on conclusion of tightening, figs. 5 and 6.
b) Torque-limiting spanners adjusted to "collapse" at the prescribed torque. These are usually fitted with a ratchet, figs. 7 and 8.
c) A combination of torque-limiting spanner used with a torque-multiplying spanner, the latter designed to give a mechanical advantage of 6 when

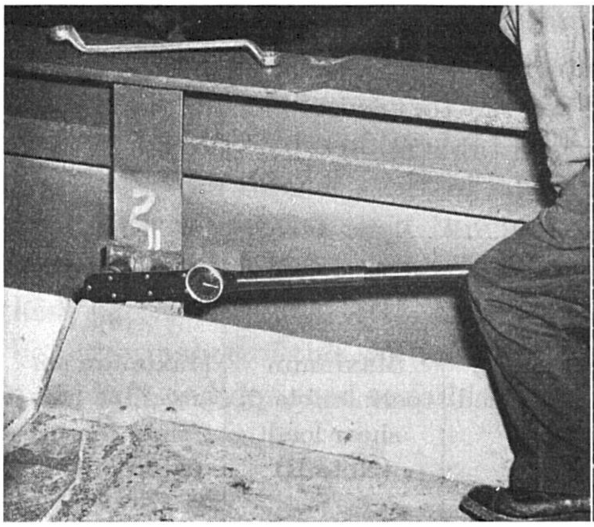


Fig. 5.

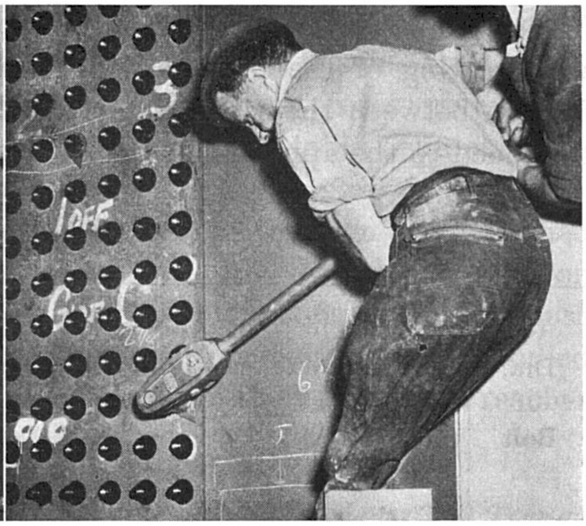


Fig. 6.

tightening bolts requiring a torque in excess of 600 lb. ft. This is also used for bolts in confined spaces, see fig. 9. With the torque-multiplying spanner, it is, of course essential to use some torque reaction fitting to prevent the tool from turning.

The nut running impact type of pneumatic wrench can be used provided the torque is checked afterwards. There are also pneumatic impact wrenches on the market which can be set to give a controlled torque, fig. 10. They give an accuracy of ± 20 per cent if the air pressure is kept quite constant; but fluctuations in the air supply can greatly alter the rate of tightening which in turn can result in a wide scatter in the torque.

Calibrated shear links introduced between the tool and the nut socket have been used in high precision work with unskilled labour. The link contains a groove designed to shear at the desired torque load. Such shear links cost about 6 shillings each and their use is expensive; but they can be used more economically in conjunction with a pressure regulator in the air line within 20 feet of the tool. The air pressure is increased slowly from a low reading, the operator waiting after each increase until the tool stalls, until finally the shear link breaks. The regulator is then locked, and provided the air supply is not allowed to drop, any number of bolts can be tightened, the torque remaining constant as the tool stalls.

11. Bolt Loading by Turn of the Nut Method

This method, applicable with hand or power wrenches, involves bedding down the bolts and then tightening them by turning the nuts a precise amount. It is defined as the part-torque part-turn method. The initial tightening, any amount between one quarter and three quarters of the nominal torque that


g. 7.

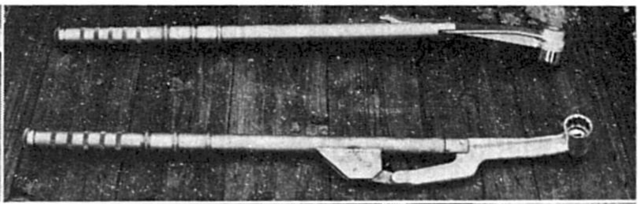
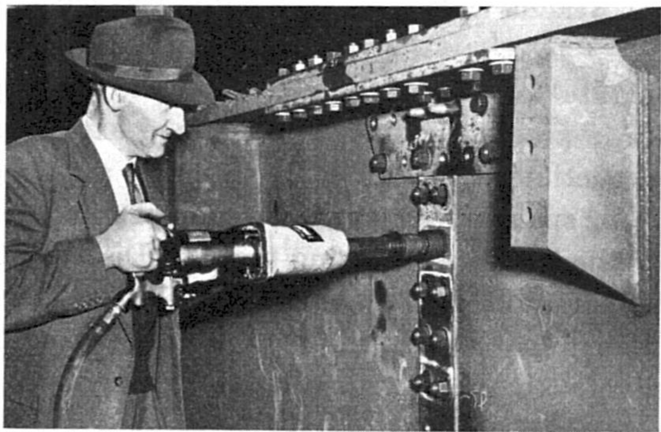


Fig. 8.


Fig. 9.


g. 10.

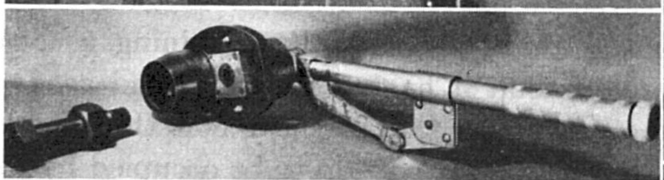

ig. 11.


Fig. 12.


Fig. 13.

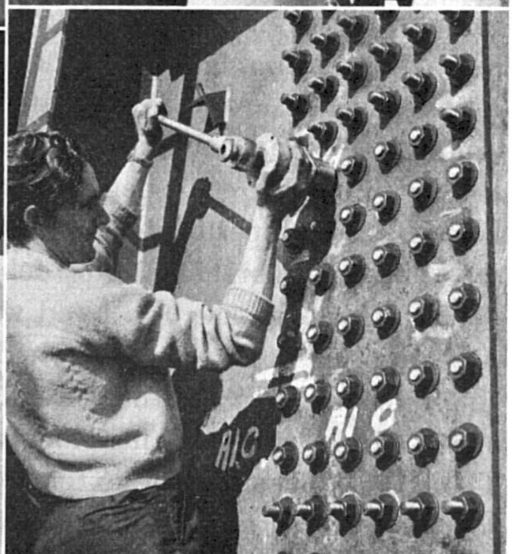


Fig. 1

would be necessary if using the torque coefficient method, is followed by a further turning of the nut by:

$$\text{Degrees of turn} = (180^\circ + x) \times \frac{TPI}{10},$$

where x = a quarter turn for every 6 inches length of bolt,
and TPI = threads per inch.

Thus for bolts with a grip of less than 6 inches, the nut, after an initial half turn, would, after an additional half turn, have been tensioned beyond 90 per cent of the yield.

It is significant that it would have taken at least another $1^1/_2$ turns of the nut to cause the bolt to break. And the effect on the final tightening caused by a variation of as much as between one quarter and three quarters of the initial torquing, makes only 7 per cent difference in the final tensioning.

12. Self-Reactor Bolts

To overcome the need for separate torque reaction fittings, the prolong bolt has been introduced, fig. 11. The prolong bolt with its splined extension overcomes the need for a separate reaction fitting. It is tightened by a special torque-multiplying and torque-limiting spanner, a remarkably compact machine which fits over the spline and holds the bolt while turning the nut. Disadvantages are the increased length of the bolt and the increased depth of the spanner making it difficult to apply in confined spaces, and the liability to damage of the spline when the bolts are delivered bagged; and, of course, the prolong bolt costs more than a plain high-strength bolt.

A more advanced development is the Torshear bolt combining a shear link in the bolt itself. Like the prolong bolt it has an extension and needs a special wrench to tighten it. The extension of the Torshear bolt threaded in the normal way is separated from that threaded portion to be occupied by the nut after tensioning, by a concentric machined groove. The extension breaks off through failure in torsion at the groove, the diameter of which is designed (and made to an accuracy of ± 0.002 inches) so that the bolt will have been loaded to within ± 10 per cent of the required tension. The cost of Torshear bolts is only 20 per cent more than that of a plain high-strength bolt. Figs. 12 and 13 show Torshear bolts being tightened with pneumatic wrenches, and fig. 14 shows the use of a hand wrench.

Torshear bolts are tightened with special patented torshear wrenches. These wrenches grip the threaded extension on the bolt with a 4-toothed chuck, and apply an anti-clockwise torque while rotating the nut clockwise. The torque between the extension of the bolt and the nut increases until the torsional stress on the bolt exceeds the calculated maximum torsional shear strength at the reduced area (at the groove), and the extension twists off, so preventing any further tightening of the nut. Reversal of the wrench causes the tool to eject the sheared end of the bolt extension. The action of the wrench is smooth and in the case of the pneumatic wrench it is a continuous and deliberate motion, and the final bolt loading is wholly independent of the pressure in the air line (so long as it is sufficient to work the tool, no matter how slowly) or the capacity of the air compressor. Thus the Torshear technique is one that can be relied upon with an unskilled operator to give the correct bolt loading so long as the groove has been machined to the correct torsional strength and the quality of the steel of the bolt is consistent. Advantages of Torshear are that the head of the bolt does not have to be held in any stage of the tightening, and visual inspection of the ends of the bolts is all that is needed to see whether all the bolts in a group have been properly tensioned. It should, of course, be noted that the plies must be properly in contact and all the bolts in a large group fully bedded down before commencing to shear off any of the extensions. This is, of course, a condition which applies to any bolting technique whether shear links are used or not. The need for observing this technique was demonstrated when tightening a large group of Torshear bolts in the flange and web joints of a plate girder. Two groups of bolts (25 in each) were tested in the web splice. The thickness of the web was $^3/_4$ inch, and

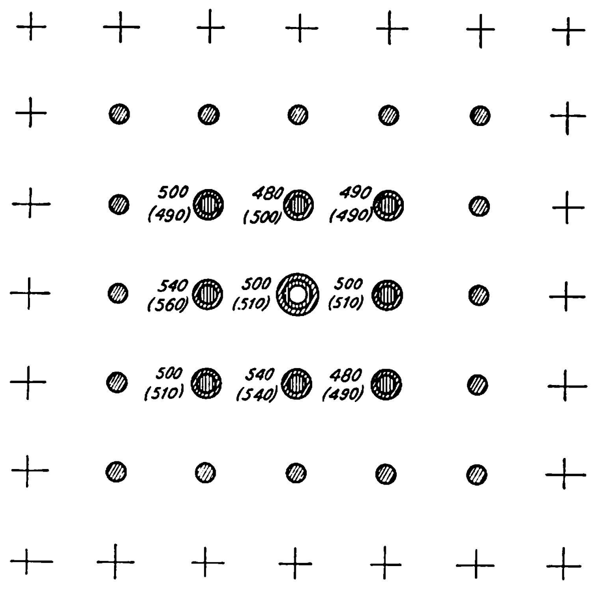


Fig. 15. All Bolts Pre-Tightened to Approximately 200 lbs ft.

Phase 1. O Central bolt tightened to 500 lbs ft.
Phase 2. Inner ring of 8 No. bolts tightened and central bolt checked. Values shown thus 543.
Phase 3. Outer ring of 16 No. bolts tightened, inner ring and central bolt checked. Values shown thus (543).

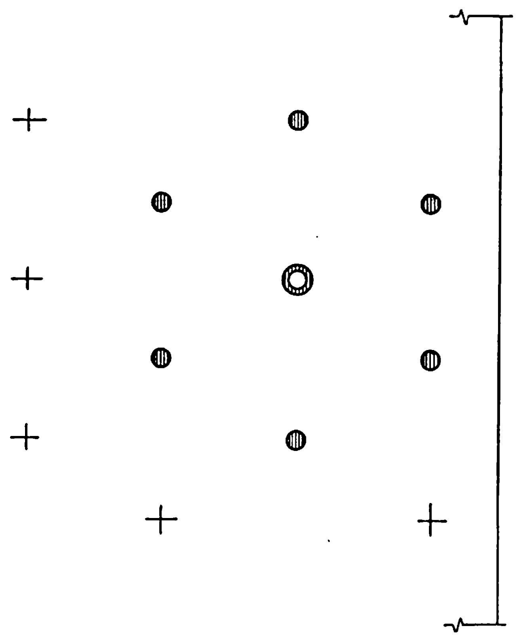


Fig. 16. Bolts *Not* Pre-Tightened.

Torque in central bolt: after initial tightened 520 lbs ft.; after adjacent bolts tightened 210 lbs ft.

the two covers were $^5/_8$ inch. The $^7/_8$ inch diameter Torshear bolts were initially torqued to 200 lbs. ft. They were then torsheared commencing with the middle bolt and working round the next innermost bolts, and finally the outer "ring". Subsequent checking with a torque-measuring spanner gave the results shown in the accompanying figs. 15. In the girder flange joint where the thickness of the plies was $1\,^1/_2$ inch, $1\,^3/_4$ inch and 2 inch, four groups of $^7/_8$ inch diameter Torshear bolts (7 in each) were similarly tested but with the nuts only finger tight before torshearing. In these cases very serious slackening of the central bolts occurred after the surrounding bolts had been tightened, vide fig. 16.

13. Experience in Bridgework

The first instance of the use of high-strength bolts in bridgework on British Railways was in the joints between cross girders and the sloping flanges of tee-shaped stiffeners on the main girders of half-through type spans described in Discussion III 2, page 391 of the Final Report on the Fifth Congress of the IABSE, Lisbon 1956. It was for tightening these bolts in the somewhat confined space that the special torque-multiplying spanner, fig. 9 was designed. Here the high-strength bolts were used not in friction grip joints but in direct tension. So successful did they prove that their use was extended to all fasteners in site joints, whether in direct tension or in shear, for new bridges and for

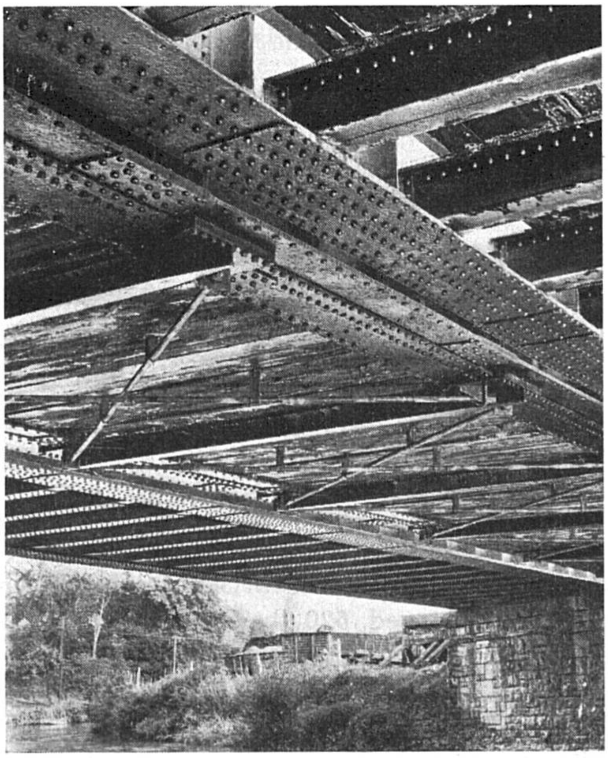


Fig. 17.

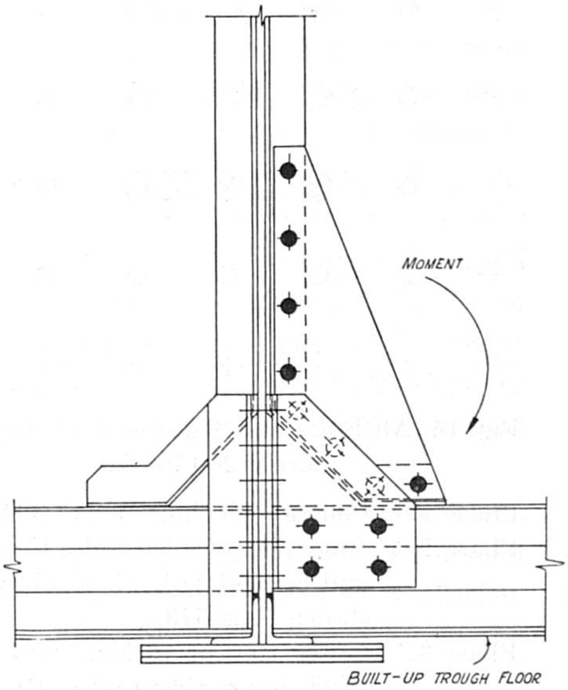


Fig. 18. Centre Main Girder.

the repair of old ones. The first use of high-strength bolts as shear connectors was in the joints between newly-fitted lateral bracings between the bottom flanges of the main girders of an 80-ft. wrought iron plate girder span carrying a busy single track on a main line, see photo of lateral bracings on span over Fowey River, fig. 17. This bridge, in service since 1858 consists of two hog-backed plate girders with a decking of transverse timbers resting on the bottom flanges, and a few iron ties to hold the girders in against the ends of the decking. The addition of the lateral bracing greatly improved the behaviour of the bridge under fast traffic, lateral oscillation at the centre being reduced from $^3/_4$ inch to less than $^1/_8$ inch. The bolts, $^7/_8$ inch diameter in $^{15}/_{16}$ inch holes, were based on the American ASTM A-325 specification, and were tightened to a torque between 400 and 450 lbs. ft. to give a gripping tension of 14.4 tons. For design purposes the shear-transfer properties of these bolts were assumed to be the same as for hot-driven mild steel rivets. Case-hardened washers were provided under the machined surfaces of the head of the bolt and the nut. The bolts were tightened by hand in the first place with ordinary spanners and finally with a 42-inch long Delapena Torquometer spanner fitted with a dial gauge measuring up to 600 lb. ft. Subsequent checking with a torque-limiting spanner five years after the fitting of the laterals confirmed the claim that these high-strength bolts could be relied upon to stay tight under vibratory loading.

A typical use of high-strength bolts in the repair of existing bridges has been the substitution of these bolts in the place of rivets (which had perpetually worked loose in the past) in the connections between the transverse trough flooring and the main girders of a double track three-girder half-through type bridge. This particular bridge, see figs. 18 and 19 carries very fast traffic on a main line and the connections are subject to severe shock loads. The

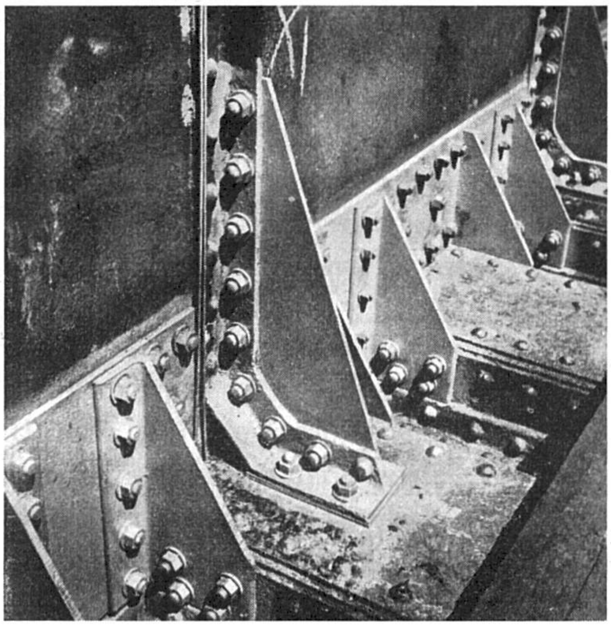


Fig. 19.

bolts used were $^7/_8$ inch diameter and they were in direct substitution for the $^7/_8$ inch rivets in $^{15}/_{16}$ inch holes. Examination, $3^1/_2$ years after fitting the bolts, showed that these bolts have retained their original tensions.

14. Web and Flange Joints in Continuous Girders

Mention has already been made of the use of Torshear bolts in the web and flange site joints of some 200-ft. long plate girders continuous over two openings. Ordinary high-strength bolts were used in 170-ft. long plate girders continuous over three openings across the River Vyrnwy near Llanymynech. There were two site joints in each of these girders and they had to be bolted up while the parts were held in mid-air by cranes. The correct alignment was ensured by the use of black bolts in combination with close-tolerance parallel shank drifts. The accompanying fig. 20 shows the arrangement and the order for the removal of the black bolts and the substitution of the permanent high-strength bolts, and fig. 21 is a site photograph of the joint. The high-strength bolts were tightened with torque-limiting pneumatic impact tools. In spite

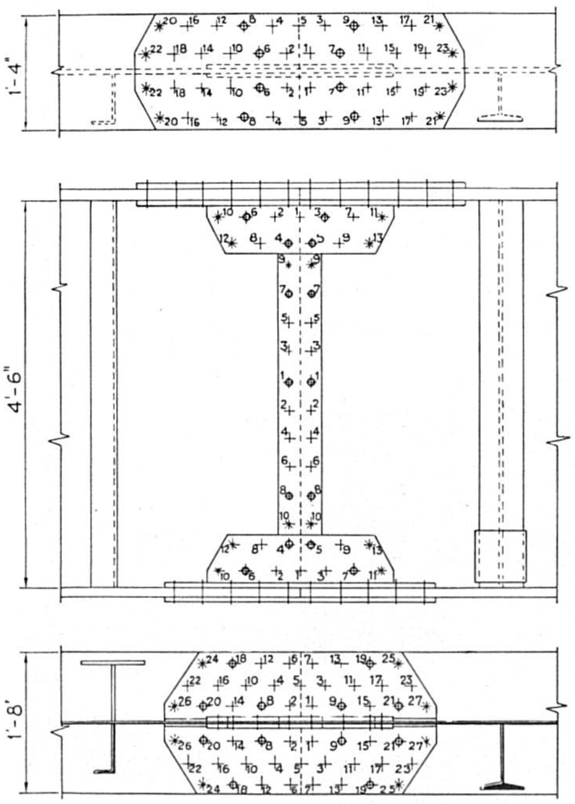


Fig. 20. Main Girder Joints in River Vyrnwy Bridge Near Llanymynech.

1. Drifts *. 2. H. S. service bolts ⊕ (not fully tightened). 3. All H. S. bolts tightened to 390 lb. ft. torque in numbered order.

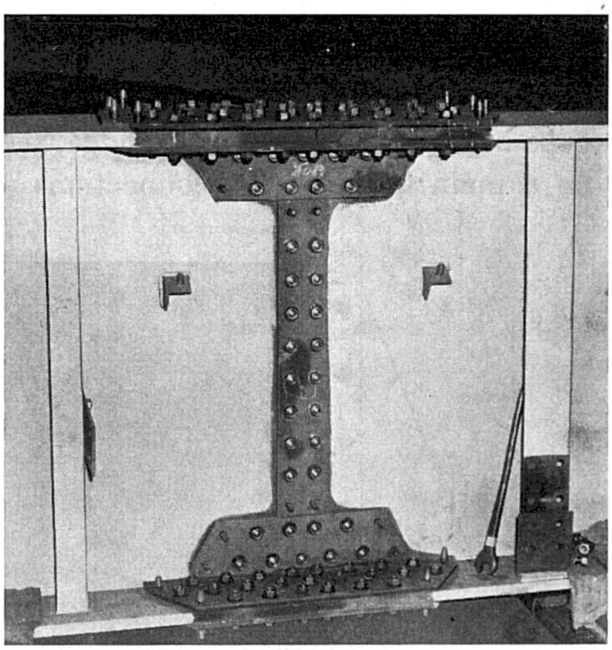


Fig. 21.

of the use of a special light-weight hose near, these machines, weighing $31^1/_2$ lbs. apiece, proved cumbersome and heavy to operate, and the results were not as reliable as those obtained when Torshear bolts were used.

15. High-Strength Bolting in the Future

The trend of constructional girder bridging like other classes of structural building is towards a maximum amount of prefabrication by electric arc welding in the shops, followed by high-strength bolting together on site. And it is for this function that the high-strength bolt serves as the ideal complement to the welding in the shops; it needs but little skill to ensure correct tightening on site where time and supervision are so often at a premium.

16. Acknowledgments

The Author is grateful to Mr. M. G. R. SMITH, M.B.E., Chief Civil Engineer, Western Region, British Railways, for permission to contribute this Paper to the Sixth Congress of the IABSE. He thanks Mr. T. BALDWIN, Superintendent of the Engineering Division of the Research Department of the British Transport Commission, Messrs. A. P. Newall Ltd. of Glasgow for permission to reproduce the results of laboratory tests and Mr. F. M. EASTON for allowing the reproduction of figs. 1 and 4. He is especially grateful to Mr. C. S. GREED and those other members of the Steelwork Office at Paddington for their patient help and advice in the preparation of the Paper.

Summary

The Paper describes the use of high strength bolts in large clearance holes for permanent shear connectors fastening together on site the prefabricated parts of girder bridges on British Railways.

Comparison is made between the high strength bolt (45 tsi ultimate) and the higher strength bolts (65 tsi ultimate) and attention is drawn to the potential advantages of the latter.

Torque limiting and torque multiplying spanners are used for tightening high strength bolts by hand; and reference is made to the use of pneumatic impact wrenches and of special spanners.

Surface preparation of the plies is specified to ensure the maximum possible limiting friction between the parts fastened together. The torque-tension ratio is given for various threads and conditions of lubrication; and the proportions of work done in overcoming nut/washer-face friction, screw thread friction, and the residue available for tensioning the bolt, are shown.

The advantages of the high strength bolt compared with riveting are summarized in favour of the former.

Résumé

L'auteur expose les conditions d'emploi des boulons précontraints, dans des trous de grand diamètre, pour la réalisation des joints de friction établis sur le chantier entre pièces préfabriquées des ponts à poutres des Chemins de Fer Britanniques.

Il compare les boulons à haute résistance ayant une tension de rupture de 70 kg/mm² avec ceux de 100 kg/mm² et attire particulièrement l'attention sur les avantages que l'on peut tirer de ces derniers.

Pour le serrage des boulons à la main, on emploie des clés à couple à déclenchement automatique, ainsi que des clés à réduction de couple. L'emploi des clés pneumatiques et des clés spéciales est également exposé.

Le mode de préparation des surfaces des joints est prescrit, afin d'obtenir le plus grand frottement possible entre les pièces de l'assemblage. Le rapport entre le couple et la tension des boulons est indiqué pour différents filetages et diverses conditions de lubrification. La répartition du couple mis en jeu au cours du serrage d'un boulon entre le frottement entre écrou et rondelle et le frottement sur les filets est indiquée, ainsi que le couple résiduel correspondant à la précontrainte. Les avantages des boulons précontraints sont comparés avec ceux des rivets, qu'ils surclassent.

Zusammenfassung

Die Arbeit beschreibt die Verwendung von vorgespannten Schrauben in Löchern mit großem Durchmesser für auf der Baustelle hergestellte Reibungsstöße zwischen den vorfabrizierten Teilen von Balkenbrücken der British Railways.

Es werden die hochfesten Schrauben von 45 tsi Bruchspannung mit denen von 65 tsi verglichen. Besondere Aufmerksamkeit wird den möglichen Vorteilen der letzteren gewidmet.

Zum Anziehen der Schrauben von Hand werden automatisch ausschaltende Drehmomentenschlüssel sowie solche mit einer Momentenübersetzung gebraucht. Die Verwendung von Druckluft- und von Spezialschlüsseln wird ebenfalls beschrieben.

Zwischen den Bearbeitungsarten der Stoßflächen wird unterschieden, damit die maximal mögliche Reibung zwischen den vereinigten Teilen erkannt werden kann. Das Verhältnis zwischen Drehmoment und Schraubenspannung wird für verschiedene Gewinde und Schmierbedingungen angegeben. Die Verteilung der beim Anziehen der Schraube aufgewendeten Arbeit auf die Reibung zwischen Mutter und Unterlagsscheibe und auf die Gewindereibung sowie der für die Schraubenvorspannung bleibende Rest werden gezeigt.

Die Vorteile der vorgespannten Schrauben werden mit denen der Nietung verglichen und zu Gunsten der ersteren zusammengefaßt.