Use of high tensile (low alloy) steels in bridges: Recent development in British practise

Autor(en): **Kerensky, O.A.**

Objekttyp: **Article**

Zeitschrift: **IABSE publications = Mémoires AIPC = IVBH Abhandlungen**

Band (Jahr): **9 (1949)**

PDF erstellt am: **10.07.2024**

Persistenter Link: https://doi.org/10.5169/seals-9705

Nutzungsbedingungen
Die ETH-Bibliothek ist Anbieterin der digitalisierten Zeitschriften. Sie besitzt keine Urheberrechte an den Inhalten der Zeitschriften. Die Rechte liegen in der Regel bei den Herausgebern.
Die auf der Plattform e-periodica veröffentlichten Dokumente stehen für nicht-kommerzielle Zwecke in Lehre und Forschung sowie für die private Nutzung frei zur Verfügung. Einzelne Dateien oder Ausdrucke aus diesem Angebot können zusammen mit diesen Nutzungsbedingungen und den korrekten Herkunftsbezeichnungen weitergegeben werden.
Das Veröffentlichen von Bildern in Print- und Online-Publikationen ist nur mit vorheriger Genehmigung der Rechteinhaber erlaubt. Die systematische Speicherung von Teilen des elektronischen Angebots auf anderen Servern bedarf ebenfalls des schriftlichen Einverständnisses der Rechteinhaber.

Haftungsausschluss
Alle Angaben erfolgen ohne Gewähr für Vollständigkeit oder Richtigkeit. Es wird keine Haftung übernommen für Schäden durch die Verwendung von Informationen aus diesem Online-Angebot oder durch das Fehlen von Informationen. Dies gilt auch für Inhalte Dritter, die über dieses Angebot zugänglich sind.

Ein Dienst der *ETH-Bibliothek*
ETH Zürich, Rämistrasse 101, 8092 Zürich, Schweiz, www.library.ethz.ch

http://www.e-periodica.ch

Use of High Tensile (Low Alloy) Steels in Bridges (Recent Development in British Practice)

Die Anwendung von hochwertigen (schwach legierten) Stählen im Brückenbau
(Neueste Entwicklung in der britischen Praxis)

Emploi des aciers à haute résistance (à faibles teneurs en éléments additionnels) dans la construction des ponts
(Progrès récents de la technique britannique)

O. A. Kerensky, B. Sc., A. M. I. C. E., M. Inst. W., London

Introduction

In 1914, J. A. L. Waddell, in a paper to the American Society of Civil Engineers on ''The Possibilities in Bridge Construction by the use of High Alloy Steels'', said:

> ''As the future development will necessitate the building of many very long span bridges, it is almost a necessity that there be found an Alloy Steel of great strength and of moderate cost. Such an Alloy is not going to be discovered by accident, but only by a lengthy and exhaustive series of experiments, laid out systematically in advance.''

Waddell visualised Steels with yield stresses of up to 45 tons per sq. inch. In the last 30 years one important step has been made towards this achievement, namely, Structural Steels with a yield stress of 23 Tons/sq. inch have been commercially produced and successfully used in many structures.

Steels with a yield stress of 45 Tons/sq. inch have been produced and used in other branches of engineering, but none of these have the physical properties nor can be produced at a cost which would enable them to be used as structural Steels.

The need to conserve coal and make the greatest use of the production capacity of steel will no doubt lead to further advances, but there is little prospect of reaching Waddell's ideal; nor would it be of value in most Structural development because for economy of material commensurate with a yield stress of 45 Tons/sq. inch, thicknesses would be too small to be robust enough for constructional stability.

CHAPTER I

Development of High Tensile Steels

There are three means of gaining strength in steel:

I. Cold working.
II. Heat treatment.
III. Addition of alloying elements.

For structural purposes, where steel is used in ''As Rolled'' condition, only the third method has general application, although the other methods are used occasionally as, for example, in production of cold drawn wire and heat treated chain links for suspension bridges.

Definitions

In dealing with Structural Steels it is customary in Great Britain to refer either to Mild Steel (M.S.) or to High Tensile Steel (H.T.S.). By the term ''Mild Steel'' is meant a steel essentially free from alloying elements and having an Ultimate Tensile Strength not exceeding 33 tons/sq. inch. In England, such steels comply with one of the Standard Specifications for Mild Steel, for structural purposes, usually B.S.S. No. 15. The term ''High Tensile Steel'' has different meanings to different users, but for structural purposes it is at present limited to steels having an Ultimate Tensile Strength exceeding 33 tons/sq. inch, but not exceeding 45 tons/sq. inch.

Making of H.T. Steel

The simplest and cheapest way of increasing the tensile strength of steel is by raising the carbon content, but if the carbon exceeds about 0,3 %, the ductility and toughness suffer, the steel becomes very ''hardenable'' and consequently it cannot be used in structures. Structural High Tensile Steels are usually obtained by increasing the carbon content and adding small percentages of alloying elements. Such steels have increased strength as well as the physical characteristics of Mild Steel, although simple processes of normalising are required in some qualities.

Special Alloy Steels have often been made for structures of exceptional magnitude and importance, with Silicon or Nickel as main alloying elements, but Si Steel has a yield stress of only about 20 tons/sq. inch, while Ni Steel is expensive. The need for steels superior to Silicon and obtainable at little extra cost has led to the development of modern Low Alloy Structural Steels.

Alloying Elements

Some of the principal alloying elements now used, and their effects on the properties of Steel, are set out below:

Manganese. One of the cheapest of the alloying elements and therefore most commonly used.
After Carbon and Phosphorus is also one of the most effective strengtheners of steel. Powerful hardening agent. Considerably reduces ductility. Does not increase resistance to corrosion.

Chromium. Increases hardenability. May increase Ultimate Strength without correspondingly increasing Yield Stress. Increases resistance to corrosion and oxidation.

Nickel. Increases strength and only slightly increases hardenability or decreases ductility. Increases resistance to corrosion. Relatively large quantity is required to secure marked increase in strength and therefore expensive to use.

Silicon. Strengthens steel and only moderately reduces ductility or increases hardenability. Does not increase resistance to corrosion.

Copper. When used in small quantity (up to 0,6 %) its effect on strength or ductility is very small, but it greatly increases resistance to atmospheric corrosion.

Phosphorus. Now accepted that it increases strength and resistance to corrosion without affecting ductility or having other marked effects.

Molybdenum, Titanium, Vanadium. Reduce hardenability and improve weldability, but are relatively expensive.

By the use of these elements in various proportions, a great variety of Steels, suitable for structural purposes, can be produced.

Variety of Steels

The number of H.T. Proprietary Steels available is very confusing because of the variety of chemical analysis. In a report by D. J. Davies on "The use of H.T. Steel in Britain" given in October 1947 to the International Congress of Steel Development, sixteen different H.T. Structural Steels with Ultimate Tensile Strength of 33 to 45 tons/sq. inch and Yield Stress of 19 to 23 tons/sq. inch are listed. Of these, about half are said to be of weldable quality.

British Standard Specifications for H.T. Steels

Today, Structural H.T. Steels are usually required to comply either with B.S.S. No. 548 (published 1934) or with B.S.S. No. 968 for Weldable Quality (published 1941).

B.S.S. No. 548 describes a Steel with Tensile Breaking Strength of 37 to 43 tons/sq. inch combined with a minimum Yield Stress of 23 tons/sq. inch (for plates and sections up to $1 - {}^1/_4''$ thick) and a minimum Elongation of 18 % on standard test piece *A*, but does not specify the exact chemical composition, only limiting:

Carbon to a maximum of 0,3 % (Reduced to 0,25 % for Rivet Steel)
Sulphur and Phosphorus to a maximum of 0,05 % each.
Copper to a maximum of 0,6 %.

B.S.S. No. 968 specifies smaller Ultimate and Yield Stresses for plates over ${}^1/_2''$ thick and for all sections, but imposes more severe limitations on the chemical composition, limiting:

Carbon to a maximum of 0,23 %.
Silicon ,, ,, ,, ,, 0,35 %.
Nickel ,, ,, ,, ,, 0,5 %.
Copper ,, ,, ,, ,, 0,6 %.

Sulphur and Phosphorus to a maximum of 0,06 % each.

Combined Chromium and Manganese to a maximum of 2,0 %.

Although H.T.S. used for Structural purposes in Great Britain usually comply with one of the above Specifications, they satisfy other requirements, e.g., weldability, resistance to corrosion and fatigue etc., in varying degrees.

CHAPTER II

Main Requirements for a good Structural High Tensile Steel

These can be briefly summarised as follows:

Strength. Yield Stress and Ultimate Breaking Strength sufficiently high to permit a saving in weight commensurate with the increase in cost.

Plasticity. Good plastic range, as plasticity is an essential quality for equalising stresses at all "Stress Raisers" such as holes, notches, etc.

Ductility. High degree of ductility and resistance to impact. The raising of Yield Stress, while preserving ductility is one of the main problems in the production of special steels.

Fatigue. High degree of resistance to fatigue. It is desirable to increase this proportionately to the increase in Yield Stress, as otherwise full advantage of the extra strength cannot be realised in Structures subject to repeated stress.

Workability, etc. It must be workable in fabrication. It should not Air Harden erratically or Flame Cut detrimentally.

Weldability. Today, it may have to be weldable. By Weldability the Structural Engineer means the ability to be welded satisfactorily with normal working conditions.

Resistance to Corrosion. For certain uses increased resistance to corrosion is valuable, as the higher allowable stresses lead to thinner sections.

CHAPTER III

Welding of H.T. Steels

The introduction of Welding methods of fabrication is a very important step in the development of structural design. Unfortunately, welding of H.T. Steels is more difficult than that of M. Steel.

During welding, all conditions of Heat Treatment may be met in the heat affected zone. In all steels, as the Carbon content increases, the hardness developed on ''Quenching'' also increases. The alloys do not usually increase the maximum hardness, but only facilitate its development. The Metallurgical damage in the heat affected zone makes the metal more susceptible to bi-axial and tri-axial stresses, with the consequent tendency to cracking. The amount of ''Damage'' depends principally on:

I. Chemical Analysis of the Steel.
II. Welding Process employed.

Carbon Equivalence

Of the many attempts to develop a method whereby one could predict the type of elements and their quantities which would yield the best increase in strength, accompanied by the least reduction in weldability, the one more commonly used is based on the principle of ''Carbon Equivalence''. This expresses the influence of any element in terms of the amount of Carbon which would have the equivalent effect. Taking the hardening effect of Carbon as Unity, average values for most alloying elements have been determined and the maximum effect on Weld hardness of an Alloy Steel is obtained by adding the relative effects of all the elements it contains. The use of this method is restricted to certain limits of composition and welding conditions.

According to Dearden & O'Neil, for good weldability, the maximum Carbon Equivalence should not exceed 0,45 %.

Weldability Tests

Many tests have been developed to compare the weldability of steels, such as: Bend, Single bead, Patch weld, Jamini's and Dr. Reeve's Tests. Of these, the last is perhaps the best known and is fully described in the Transactions of Institute of Welding, 1938, Vol. 1.

It is suggested that for a steel to be considered weldable, the Pyramid Hardness Test Number, developed in Dr. Reeve's Test with a fillet weld of approximately 0,045 sq. inch area, should not exceed 350.

Welding Precautions

There are various methods of improving the welding of H.T. Steels and some of these are listed below:

I. Limitation of Carbon and introduction of special alloying elements, e. g., Titanium, Molybdenum, Vanadium, Cobalt, etc.
II. Adoption of proper welding sequence.
III. Preheating of parent metal (up to about 200°C. is usually sufficient).
IV. Introduction of Annealing runs.
V. Using maximum possible gauge of Electrodes with minimum speed of welding, consistent with the size of weld.
VI. Using special Electrodes:
  a) Soft Mild Steel.
  b) Special H. T.
  c) Austenitic.
VII. Avoiding all Tack Welding and Stray Flashing.

Weldable Steels

Some difficulty is experienced in producing easily weldable H.T. Steel. During the last few years, much research has been carried out. In 1941, B.S.S. No. 968 was produced, giving minimum requirements for the qualities of the steel and in the same year the British Welding Research Association published its recommendation for Welding Technique (Revised 1944).

H.T. Steel has been extensively used for Bailey Bridge Panels, but with this exception, no Welded H.T. Steel Bridge of any size has yet been constructed in Britain, although several have been built on the Continent of Europe.

CHAPTER IV.

Corrosion of H.T. Steels

From the corrosion point of view, Carbon-Silicon-Manganese Group of Steels has no particular merit, but there is improvement with Copper-Nickel-Chromium Alloys. Comprehensive tests show that Copper, in particular, is very effective in atmospheric conditions, but no benefits can be claimed for immersion conditions. This has been fully confirmed by recent tests carried out in the Port of Copenhagen where Mild Steel and Copper Steel samples were subject to immersion tests over a period of 10 years and showed no difference of importance in their resistance to corrosion. On the other hand, the "Corrosion Committee for Steel exposed to Industrial Atmosphere" obtained the following results with plates $^1/_8''$ thick subjected to 10 years exposure in Sheffield:

Steel	Percentage corroded away in 10 years
Mild Steel	66
H.T.S. with Cr = 0,95% and Cu = 0,48%	22

Dr. J. C. Hudson in a paper presented to the Institution of Civil Engineers in February, 1947, writes: "It may be serviceable to emphasise, that one of the most potent methods of combating Rusting in Structural Steel is the choice of an improved material with increased corrosion resistance. Proper Rustless Steels are too expensive for Structural purposes, but Low Alloy Steels of Chrome-Copper type offer very considerable increased resistance to corrosion and far too little use is made of them, so far, for this purpose.

It may be stated that the best Low Alloy Steels now on the market are at least three times as resistant to straightforward atmospheric corrosion as is Mild Steel.

It is true that this does not dispense with the necessity of protective coatings, but it does allow the adoption of smaller thickness with some degree of safety".

CHAPTER V.

Some Examples of the Use of High Tensile (Low Alloy) Steels in Bridges designed and constructed by British Engineers in Recent Years

1. *Sydney Harbour Bridge* (Australia). Built 1924–1932.

Silicon Steel, with a yield of 20 tons/sq. inch was used for the whole of the Trusses, principal Lateral Bracing and Flanges of the Cross Girders of the 1,650 ft. Two Hinged Arch Span. Approximately 26,000 tons of Silicon and 11 000 tons of Mild Steel were required. M. S. Rivets were used throughout. For Silicon Steel, the allowable Stresses were generally 30 % greater than those for Mild Steel as given in B.S.S. No. 153 (1923), giving a Basic Allowable Tensile Stress of 10,5 tons/sq. inch.

2. *Birchenough Bridge* (Rhodesia). Built 1933 – 1935.

A two-hinged Arch Span of 1,080 ft. with a suspended deck. This is the first British Long Span Bridge employing modern H.T. Steel for the construction of all the principal members. Mild Steel Rivets were used throughout, as it was considered undesirable to adopt H.T. Rivets, which are somewhat more difficult to heat and drive and the available labour was native with no experience.

The H.T. Steel used was a new product under the proprietary name of "Chromador" with a guaranteed Yield Stress of 23 tons/sq. inch for thicknesses up to $1-{}^1/_4''$ and approximate chemical composition as follows:

Carbon 0,22 %, Manganese 0,8 %, Chromium 0,9 % and Copper 0,3 %.

At the time of designing this bridge, no Standard Specification, either for the steel or for the allowable stresses, existed, and in deciding the latter the designers proceeded cautiously. The allowable stresses adopted were 33 % higher than those for Mild Steel as given in B.S.S. No. 153 (1933), giving a basic Tensile Stress of 12 tons/sq. inch. The total amount of steel used was 1,600 tons, costing approximately 80 % of the total cost of the work. The saving afforded by the use of H.T. Steel was very considerable, as the cost of transport of material from Great Britain to the site was relatively very high (about £ 12 per ton).

3. *Chelsea Bridge* (London). Built 1934 – 1937

Self-anchored Suspension Bridge of 352 ft. Span with two Anchor Spans of 173 ft. each.

At the time of the design of this bridge, the modern H.T. Steels were in process of development. The web and flanges of the 8′ 10″ deep stiffening girders were built from two kinds of Low Alloy Steel and for the first time H.T. Steel Rivets were used. The H.T. Steels used were new products under proprietary names of "Ducol" and "Atlantes" with the following average characteristics:

Steel	C%	Si%	S%	P%	Cu%	Mn%	Cr%	U.T.S.	Yield Stress	Elongation
Ducol	0,25	0,13	0,03	0,03	0,36	1,52	—	41,5 T/sq. in.	24,8 T/sq. inch	21%
Atlantes	0,25	0,12	0,04	0,03	0,43	0,92	0,44	39,2 T/sq. in.	25,0 T/sq. inch	21%

Both steels have a guaranteed minimum yield of 23 tons/sq. inch. To ensure uniform quality $2-{}^1/_2$ times the usual number of steel tests were made. Basic allowable stresses adopted were 40 % higher than those for Mild Steel as given in B.S.S. No. 153 (1933).

Many tests were carried out to develop suitable H.T. Steel for Rivets, using various alloys and different shapes of rivet heads etc., eventually the following specification was evolved:

Carbon 0,16 to 0,22 %
Silicon 0,1 to 0,2 %
Sulphur and Phosphorus not more than 0,05 % each.
Copper 0,29 to 0,39 %
Manganese 0,75 to 0,85 %
Chromium 0,29 % to 0,39 %

With elongation of 26 % to 19 % on 2″ test piece this Steel gave U.T.S. of 31 to 34,5 tons/sq. inch and Shear Strength after driving of 26 to 31,3 tons/sq. inch.

A Rivet Head similar to the one used for Sydney Harbour Bridge rivets was found to be best and also helped to distinguish H.T. from M.S. Rivets.

4. *Storstrom Bridge* (Denmark). Built 1932 – 1937.

This High Level Bridge, one of the longest in Europe, consists of forty-seven plate girder Approach Spans of 197 ft. average length and three Tied Arch Navigation Spans, two of 335 ft. span and one of 447 ft. span.

Three kinds of Steel were used:

I. The whole of the Arch Ribs, Hangers and Stiffening girders and approach main girders were constructed of "Chromador" H.T. Steel with a guaranteed yield stress of 22,8 tons/sq. inch for thicknesses up to 1 – $^1/_4$″.

II. All Deck material etc., was of Manganese Steel with a guaranteed Yield Stress of 18,4 tons/sq. inch.

III. All Packings and lightly stressed parts were of ordinary B.S.S. Mild Steel.

High Tensile Rivets were used with High Tensile material.

The Rivet Steel was generally similar to Mild Steel, but with the addition of about 1,0 % of Chromium, giving a shear strength after driving of not less than 27,5 tons/sq. inch.

Allowable Basic Stresses for Dead Load + Live Load + Impact were 9,85 tons/sq. inch and 12,7 tons/sq. inch for the Manganese and Chromador Steels respectively, increased to a maximum of 11,75 tons/sq. inch and 14,6 tons/sq. inch for the most unfavourable combination of service loads and to 12,7 tons/sq. inch and 15,85 tons/sq. inch during erection.

Allowable Shear Stresses in Webs of Plate Girders were 0,8 of the Allowable Tensile Stress.

5. *Chien Tang River Bridge* (China). Built 1935 – 1938.

A double deck Rail and Road Bridge consisting of 16 Main Spans of 220 ft. each and approach Viaducts, requiring in all 4,135 tons of Steel. Main Trusses, Plate Girders, Railway Stringers and Cross Girders were of H.T. Steel (Chromador) generally conforming to B.S.S. No. 548.

Allowable stresses adopted were 50 % above those for Mild Steel as given in B.S.S. No. 153 (1923) giving a Basic Tensile Stress of 12 tons/sq. inch.

The saving in weight of plate girder stringers (27 ft. span) and cross girders (34 ft. span) obtained by using H.T. Steel instead of Mild Steel was approximately 26 % and that for 220 ft. Trusses 24 %. The high cost of transport from England to China particularly favoured the use of H.T. Steel and resulted in substantial economies.

6. *Story Bridge over Brisbane River* (Australia). Built 1935 – 1939.

A Cantilever Bridge, consisting of Main Span opening of 924 ft. with two anchor arms of 270 ft. each.

All main members were of H.T. Steel produced and fabricated in Australia. The steel had the following main characteristics:

Carbon 0,3 to 0,4 %
Manganese 0,6 to 1,2 %
Silicon 0,15 to 0,35 %
Sulphur and Phosphorus not more than 0,05 % each.
Ultimate Tensile Strength 36 to 42 tons/sq. inch.
Minimum guaranteed Yield Stress 20 tons/sq. inch.

Mild Steel Rivets were used throughout.

Basic Allowable Stresses for H.T. Steel were 16 % above those for M.S., giving a basic Tensile Stress of 10,5 tons/sq. inch.

The weight of steelwork in the Main Span was 11 000 tons and comprised about two-thirds of the total Dead Load.

7. *Krustpils Bridge* (over River Daugava, Latvia). Built 1936.

Consists of three simple Spans of approximately 270 ft. each.

H.T. Steel complying with B.S.S. No. 548 was used for main material of main trusses and cross girders, but M.S. Rivets were used throughout.

Approximately 545 tons of H.T. and 300 tons of M. Steel were used.

The Bridge was designed to a Latvian Specification with the basic Tensile Stress for H.T. Steel of 12,45 tons/sq. inch. The main Trusses were "Prestressed" during erection.

8. *Wandsworth Bridge* (London). Built 1936 – 1940.

A Cantilever Deck type Bridge, having a Central Span of 300 ft. and two side spans of 185 ft. each.

High Tensile Steel conforming to B.S.S. No. 548 was used wherever found economical, resulting in a structure with H.T. and Mild Steels freely intermixed.

In general, lattice portions of Main girders and the greater part of webs and flanges of all plate girders were of H.T. Steel, while all details and bracing were of M. Steel.

High Tensile Rivets were used for H.T. Steel connections.

H.T. Steels were approximately of the following composition:

Steel	C%	Mn%	Cu%	Si%	S%	P%
					not more than	
H.T. Structural Steel	not more than 0,3	1,3 to 1,5	0,6 max.	—	0,05	0,05
H.T. Rivet Steel	0,24	1,1	—	0,18	0,04	0,025

For H.T. Rivets, the Ultimate Shear, when driven, was 26 tons/sq. inch, otherwise they complied with B.S.S. No. 15.

The number of Tests specified for H.T. Steel was double that usually required for Mild Steel. All web plates, joint covers and gussets were normalised after rolling. Approximately 1,700 tons of H.T. and 1,100 tons of M.S. were used. As the Bridge was designed in the early days of H.T. Steel development, the Basic Allowable Tensile Stress of 12 tons/sq. inch was adopted, but the Allowable Shear for H.T. Rivets was 50 % greater than that given in B.S.S. No. 153 (1933) for M.S. Rivets. The girders were "prestressed" during erection and some of the joints were completed only when full Dead Load was operative.

9. *Howrah Bridge* (Calcutta). Built 1936 – 1942.

The third largest Cantilever Bridge in the world, furnishes an inspiring example of Indian and British co-operation, as it was designed and constructed by English firms, but practically all the steel (over 23,000 tons), including most of the High Tensile, was made in India.

The Bridge consists of Main Span of 1,500 ft. with two Anchor Arms of 325 ft. each.

High Tensile Steel and H.T. Rivets, conforming closely to B.S.S. No. 548 were used wherever this effected economy.

17,500 tons of High Tensile, 6,300 tons of Mild and 1,500 tons of Cast and

Forged Steel were used in the Main Span. The cost of steelwork amounted to nearly 70 % of the cost of the span.

It is estimated that the use of H.T. Steel effected a saving in weight of steel in Main Trusses of the order of 25 %. Allowable Basic Stresses for H.T. Steel were approximately 40 % above those for M.S. as given in B.S.S. No. 153 (1933), giving a Basic Tensile Stress of 12,65 tons/sq. inch, while allowable shear in H.T. Rivets was 50 % higher than for M.S., with progressive reduction for grips over 4 diameters. Butt joints in permanent compression members were only covered and riveted to a value of 50 %, the remaining stress being transferred in direct bearing.

For Stress combinations, including Wind, etc., the allowable Stresses were 18 % higher, giving a Tensile Stress of 15 tons/sq. inch and for the most unfavourable stress combination, including Secondary Stresses, the Allowable Stresses were further increased, giving maximum Tensile Stress of 17 tons/sq. inch. To reduce Secondary Stresses to a minimum, the Trusses were "Prestressed" during erection.

All main gussets and Pin Plates were normalised after rolling. It may be of interest to note that different kinds of H.T. Steel were used, as some was made in England and some in India. The Indian steel formed the bulk and its chemical composition was as follows:

Carbon	0,23 to 0,28 %
Manganese	1,0 to 1,3 %
Chromium	0,5 to 0,6 %
Copper	0,3 to 0,6 %
Silicon	not more than 0,2 %
Sulphur and Phosphorus	not more than 0,05 % each.

The inclusion of not less than 0,3 % of Copper was specified for all H.T. Steel to increase its resistance to corrosion.

Extensive tests were carried out on the driving qualities of H.T. Rivets, which showed that the percentage of Carbon and Manganese should be carefully controlled and that Ultimate Tensile Strength should be kept within 30 to 35 tons/sq. inch, giving driven shear values of 25,5 to 27,7 tons/sq. inch. Much stronger Rivets were easily obtainable, but their driving qualities proved unsatisfactory.

10. *Otto Beit Bridge* (Rhodesia). Built 1938 – 1939.

Stiffened Suspension Bridge of 1,050 ft. Span.

Stiffening Trusses and Main Deck members were of H.T. Steel (Chromador) conforming to B.S.S. No. 548. As in Birchenough Bridge, M.S. Rivets were used throughout and for the same reasons.

11. *Menai Straits Bridge* (British Isles). Built 1938 – 1940.

In the reconstruction of this famous Suspension Bridge of 580 ft. span, the new chain links and the stiffening trusses and deck were made of H.T. Steel (Chromador) conforming to B.S.S. No. 548. The links were originally intended to be forged, but it was found that the output was too slow and approximately half the links were flame cut, machined all over, (removing about $^1/_4''$ of metal affected by the heat) and subsequently normalised. These links were more expensive to make than the forged ones, but this was more than compensated for by the saving of time.

12. *Bailey Bridges.* Made 1941 – 1944.

This Military Bridging equipment, now spanning over many rivers of Western Europe, has been developed and made during the war years. It gives an excellent example of the use of H.T. Steel where economy in the commercial sense is subjugated to other requirements. Undoubtedly a "cheaper" Bailey Bridge panel could have been constructed in Mild Steel, but for the same strength its weight would be some 30 % greater. Special H.T. Steel was used throughout in the making of the Standard, all Welded, panel-units, approximately 10 ft. long · 5 ft. deep · 7 ins. wide.

The Steel was a development of the Weldable B.S.S. No. 968 quality, with a yield stress raised to 23 tons/sq. inch instead of 21 tons/sq. inch for the sections used. With regard to the chemical composition, the specification read as follows:

a) A plain Carbon-Manganese Steel is preferred, the Carbon to be between 0,2 to 0,26 % and the Manganese not to exceed 1,7 %, or,

b) If Chromium and/or Molybdenum are added, the sum of the alloying elements not to exceed 2,0 % and in that case Carbon to be limited to 0,23 %.

A delicate balance had to be struck between obtaining required strength and avoiding welding troubles. Strict welding procedure had to be observed throughout, involving the control of: type and gauge of electrodes, current, protection from weather, welding sequences, jigging and periodical testing of welders. All Tack Welding was absolutely forbidden.

A working stress of 15 tons/sq. inch was adopted.

The total production of panels, in England alone, amounted to 496,544, of which 71,3 % were tested and only 469 failed to pass the tests.

13. *Baghdad Rail and Road Bridge* (Iraq). Being built now.

Main River crossing of approximately 1,500 ft. is made up of 3 Anchor Spans of 340 ft. and 4 suspended spans of 122 ft. each, giving maximum openings of 268 ft.

The Railway approaches are about 1 mile long and consist of plate girder stringers on steel trestles.

H.T. Structural Steel and Rivets, complying with B.S.S. No. 548 were used wherever found economical. The saving of weight is of particular advantage as the cost of transport is exceptionally heavy.

Main Trusses of Anchor and Suspended Spans, bottom laterals, plate girder railway stringers (24′ 4″ span) and cross girders (37′ 6″ span) are of H.T. Steel.

Allowable stresses adopted are as for Howrah Bridge, i.e., Basic Tensile Stress for H.T. Steel of 12,65 tons/sq. inch.

Approximately 2,100 tons of H.T. Steel and 1,250 tons of M.S. will be used in the Superstructure of the Main Spans.

14. *Lesser Zab and Euphrates Railway Bridges* (Iraq). Being built now.

These bridges consist of 5 and 6 identical spans of 166 ft. each respectively. The very high cost of transport to remote parts of the country favoured adoption of H.T. Steel.

Main Trusses, top and bottom laterals, plate girder railway stringers (20′ 9″ span) and cross girders (17′ 0″ span) were made of H.T. Steel complying with B.S.S. No. 548. Mild Steel is used only in sway bracing and minor details. Allowable stresses as for Howrah Bridge. Approximately 1,100 tons of H.T. Steel will be used in the two bridges.

CHAPTER VI.

Allowable Stresses

Existing British Standard Specifications

B.S.S. No. 153 (1937) deals with the design of Bridges, only in Mild Steel (B.S.S. No. 15).

B.S.S. Nos. 548 (1934) and 968 (1941) cover the physical properties of H.T. Steels, without specifying any working stresses.

B.S.S. No. 449 (1937) deals with the design of Buildings in Mild and H.T. Steels, but is not intended for Bridges.

British designers, therefore, have to exercise their own individual judgement in deciding the allowable stresses for H.T. Steel in Bridgework and, consequently, a variety of different values and rules have been used, of which those noted below are characteristic:

Table of Basic Allowable Stresses for H.T. Steel complying with B.S.S. No. 548.

Nature of Stress (All stresses in Tons/sq. inch)	Birchenough and Otto Beit Bridges	Wandsworth Bridge	Storstrøm Bridge	Howrah and Iraq Bridges
Axial Tension (Basic)	12,0	12,0	12,7	12,65
Axial Tension (Max.)	16,0	16,0	15,85	17,00
Axial Compression in Pin Ended Struts of length 1 and rad. of gyration r.	$12\,(1-0{,}0054)\,\frac{1}{r}$ Max. 10,0	$12{,}3(1-0{,}0054)\frac{1}{r}$ Max. 10,0	Ostenfeld Parabollic Max. 12,7	$13{,}8\,(1-0{,}0057\frac{1}{r})$ Max. 10,75
Bending-Tension Flange	12,0	12,0	12,7	12,65
Bending Unstiffened Compression flange of length 1 and width b	$12\,(1-0{,}01\frac{1}{b})$	$12\,(1-0{,}01\frac{1}{b})$	As struts	12,65 (1–0,0112F)
Shear in Web (Average)	7,0	7,0	10,0	7,5
Shear in Shop Rivets	(M.S.) 6,0	9,0	10,0	9,0
Bearing on Shop Rivets	(M.S.) 15,0	18,0	20,0	18,0

Factor of Safety

The adequacy of a structure should be considered with regard to strength and elastic stability.

I. Strength is related either to the Ultimate Strength or to the Yield Stress of the material, which vary for different steels.

Although in some forms of structure stresses in excess of the yield stress may be allowed to occur without endangering the permanent reliability of the framework, knowledge of the conditions under which these deformations occur is not yet sufficiently advanced to justify design of bridge structures for stresses which may cause permanent distortion.

Allowable stresses must, therefore, under any conditions which can be foreseen, be less than those which can produce permanent distortion. Allowance must be made for such possibilities as variation in quality of material, errors of manufacture, imperfect erection and unintended excessive loading.

Although in the past in Great Britain it has been customary to speak of a "Factor of Safety" which expresses the ratio of Ultimate Strength to normal maximum working stress, usually about 3 to 4, this definition is obviously misleading and has ceased to have any useful significance. The only ratio that need be considered is the ratio of the yield stress of the material under consideration to the actual stress which is imposed; this ratio in practice for frequent and probable combinations of applied loads is 2 to 1½, for highly improbable and infrequent combinations it is reduced to 1,5 or 1,33. In this connection, it is noteworthy that Bailey Bridge panels were designed for a ratio of 1,5 and were, no doubt, frequently overloaded, but no case of failure has been recorded.

As it is the yield stress of the steel which is important, it is essential that the specification of the steel should define this and tests should be made to ensure that the steel conforms to the specification.

II. Elastic stability is related to the Modulus of Elasticity of the material, which is approximately the same for all steels.

As the slenderness ratio of any element liable to buckle (e. g. struts, compression flanges of beams, webs in shear, etc.) increases, the allowable stresses for H. T. Steel have to be decreased proportionately more than those for Mild Steel, the two gradually merging at high slenderness ratios. What might be termed the law of decrease associating working stresses with slenderness ratio varies with the conditions of support, accuracy of fabrication, etc., and may follow a variety of different curves, but ultimately when slenderness ratio is high and true buckling becomes the criterion for failure, the factor of safety should be related only to the Modulus of Elasticity of the material and, in this case, H. T. Steel has no advantage over Mild Steel.

In order to provide equal reliability, Allowable Stresses for all steels should be chosen on a common basis of equal ability to resist deformation from whatever causes, i.e., a common Factor of Safety should be adopted for a specified combination of loadings (say, 1,75 for Basic Stresses), then:

I. For steels of different qualities, the allowable stresses are rationally comparable and,

II. For any particular steel, maximum allowable stresses for tension and compression (Axial or due to Bending) are the same, while that for Shear is about 25% less.

Although this principle is commonly applied on the Continent of Europe, in Britain it is more usual to increase the Safety Factor for the allowable stresses in compression and shear.

Allowable stresses should, of course, also take into account such factors as fatigue and corrosion, but the appropriate allowances for these should be made separately.

Basic Allowable Stresses for Steel to B.S.S. No. 548

H.T. Steel complying with B.S.S. No. 548 has a yield stress at least 50 % greater than that of Mild Steel, and the Basic Allowable Stresses therefore, could be taken at 50 % above those for Mild Steel.

However, the quality and reliability of Mild Steel has been proved by many years of use, whereas H. T. Steels are a comparatively new product and in the past, most designers preferred to have a somewhat greater Factor of Safety than the one allowed for Mild Steel. Consequently, in Bridgework, basic maximum stresses usually were increased by only 40 %.

It is reasonable to expect that, as the qualities and behaviour of H.T. Steels become more fully established, full advantage of its strength will be taken and the basic allowable stresses will be increased in the ratio of the yield stresses.

Riveted Joints

With H.T. Rivets, the allowable shear and bearing values can be increased in the same proportion as the yield stresses in the parent metal, producing a great economy of jointing material.

If ordinary M.S. Rivets are used, they can be stressed only to normal M.S. Stresses and the joints become disproportionately large.

Welded Joints

For welded joints in H.T. Steel, as yet, there is no established practice, no general specification and very little precedent, but the whole subject is now under review and it is hoped that an appropriate B.S. Specification will be available soon.

At present, weldable steels produced to B.S.S. No. 968 for plates over $^1/_2$″ thick and for all sections, have approximately 10 % lower yield stresses than the non-weldable steels produced to B.S.S. No. 548 and, consequently, lower allowable stresses must be adopted in welded designs, thereby somewhat limiting its usefulness.

If, in order to reduce liability to cracking, M.S. electrodes are used, the size of joints must be increased accordingly, as the "Alloy Pick-up" is found to vary with the different chemical compositions of the parent metal and cannot be relied upon in all cases.

For full strength Butt Welds, the use of large gauge H.T. Electrodes has been found advisable.

Effect of Fatigue

Another Factor influencing the allowable stresses is "Fatigue". There is now no doubt that the Fatigue resistance of fabricated H.T. Steels does not increase proportionately to the increase in their static strength. Prof. W. M. Wilson found that Fatigue Strength of plates with riveted joints is independent of the Ultimate Tensile Strength of Steel. He tested steels of 28, 36 and 44 tons/sq. inch U.T.S. Fatigue Strength is defined by him as the maximum stress to which the specimen can be subjected 2 000 000 times without failure, the range being from 0 to maximum. Much other experimental work has been done on this subject. Plain material and riveted and welded joints of all descriptions, both of H.T. and Mild Steel, have been tested for Fatigue by many investigators. The following general conclusions can be drawn:

I. The resistance to fatigue of plain steels, when tested as polished specimens, is nearly proportional to their respective ultimate strengths.

II. The reduction in fatigue resistance caused by any "Stress Raiser" (e. g. Notches, Holes, Welds) is increased with the increase in Static Tensile Strength. No advantage is gained by using steels with high U.T.S. if significant stress raisers are present and the steel is subjected to a large number of stress reversals.

III. Periods of rest and frequency of load application do not affect fatigue strength appreciably.

IV. There appears to be little difference in fatigue strength between designed and well executed riveted and butt welded joints, but fillet welds are distinctly inferior. The shape of joint is of great importance in all cases. The principal advantage of the riveted connection over the welded one, from the fatigue point of view, lies in its ability to yield internally, resulting in the adjustment of stresses.

V. The fatigue strength of riveted joints appears to be affected by the Clamping Force of the rivets and, as H. T. Rivets generally exercise smaller clamping forces than the M. S. ones, the use of M. S. Rivets with H. T. members improves the fatigue strength of the joint. This is further improved by the greater relative yield of the softer rivet.

VI. Both riveted and butt welded joints in Low Alloy Steels do not offer much advantage over the M. S. joints in resistance to fatigue due to Reversing Stresses, but develop increased strength when subject to pulsating loads, especially when a prestress is present.

Allowances for Fatigue

In making allowances for fatigue it must be remembered that fatigue depends on two factors:

a) Range and intensity of stress.
b) Number of repetitions.

If one factor is decreased, the other can be increased, thus M. Freudenthal has shown that for both pulsating and reversing stresses the fatigue resistance at 100,000 repetitions is about twice that at 2 000 000 repetitions and therefore probable frequency of occurrence of the maximum intensity of stress must be considered in ensuring that effective provision is made for fatigue.

In the latest American Welding Society Specification for M.S. Bridges (published 1947) a classification is made of the probable incidence of maximum live load in the life of different types of bridge, roughly as follows:

Loading producing maximum Stress	Number of repetitions
Short critical loading 100 ft. or less on single track of Railway	2 000 000
Railway loading on single track of more than 100 ft. length Railway loading on double track of any length. Highway loading on not more than 2 panels or 60 ft. of single lane	600 000
Normally not considered for railway bridges. Highway loading on more than 2 panels or 60 ft. of single lane, but not more than 2 panels or 60 ft. of double lane	100 000
Never for a railway bridge Highway loading on more than 2 panels or 60 ft. of multiple lanes	Less than 100 000

Dealing only with first class riveted and butt welded connections, designed with minimum amount of "Stress Raisers", for 100 000 or less repetitions the fatigue effects are negligible and full advantage of H.T. Steel can, therefore, be taken. When subjected to 600 000 and more repetitions, the fatigue effects come into play and reductions in the allowable stresses for H.T. Steel should be proportionately greater than the corresponding ones for Mild Steel.

Ultimately, when subjected to a large number of complete reversals the allowable stresses for the two steels should be the same.

The following approximate guiding rules are suggested for a H.T. Steel with yield stress of 23 tons/sq. inch:

Nature of Stress		Ratio $= \dfrac{\text{Allowable Stress in H.T.S.}}{\text{,, ,, M.S.}}$
Static		1,5
Up to	100 000 repetitions (0 to Max.)	1,5
	100 000 full reversals	1,5
	600 000 pulsations (Min. Stress not less than 0,2 Max.)	1,5
	600 000 repetitions (0 to Max.)	1,3
	600 000 full reversals	1,2
	2 000 000 pulsations (Min. Stress not less than 0,2 Max.)	1,5
	2 000 000 repetitions (0 to Max.)	1,1
	2 000 000 full reversals	1,0

In view of the effect of repetition of a varying stress it becomes important to classify bridges or bridge members from the standpoint of the probable number of repetitions of a critical varying stress.

In Great Britain road bridges must be designed for possible combinations of loading and for maximum axle loads which rarely occur in service and it may confidently be assumed that unless very low loadings are used as the basis of design, repetition of stress as a cause of fatigue failure can be entirely disregarded.

Railway bridges are designed for locomotive axle loads which, although provision is made for future increase, are frequently reached in actual service and therefore variations of stress intensity liable to cause fatigue failure may occur and appropriate provisions for fatigue should be made.

Effect of Reduction in Size of Structure and Members

The adoption of higher working stress intensities generally results in shallower structures, smaller individual members and thinner individual parts, with consequent increase of elastic deformations (deflections) and decrease of reserve against corrosion.

With regard to deflections, the increase due to the use of H.T.S. appears to be of no practical importance. Secondary stresses may be increased, but should of course be allowed for in the design.

With regard to corrosion, it must be remembered that all Structural Steels are subject to it, if unprotected, but have an indefinitely long life when completely protected. A good design should leave no inaccessible positions then, with modern surface treatment and painting technique, it is possible to ensure almost complete protection of the steel and use minimum practicable thicknesses with safety.

As a further precaution in exceptional circumstances, a small percentage of Copper or Chromium or other suitable Alloy can be added as an alloying element. This will increase the resistance to atmospheric corrosion of H.T. Steel at least proportionately to the increase in strength.

CHAPTER VII.

Economic Use of H.T. Steel

The Problem of Selection of Steel

The problem of selection of the most suitable steel for any given structure is governed by two main considerations:

1. Technical – either when lightness is of primary importance and the construction becomes practicable only with the use of the superior steel (as in the case of very long span bridges or bridges for military use, etc.)
   or, when exceptional anti-corrosive qualities are required.
2. Commercial – when the use of superior steel results in a cheaper structure.

A given material may be economical under certain conditions and uneconomical under others. If, as a result of the improved properties, the net cost of a substituted material is less than that of the material replaced, there is no economic problem to be solved, as obviously, despite the higher cost per ton, the improved material would be used, as far as it is available.

This is usually the case with all long span bridges, in fact it may be justly claimed that modern Low Alloy Steels have been developed and commercially established largely in response to the needs of designers of long span bridges. For medium spans and certain parts of long span bridges, however, it is necessary to compare the probable cost of the lighter H.T.S. structure with that of the heavier M.S. one, before the selection can be made.

For small structures and in all cases where the sizes of members are controlled by other than stress considerations, there is no advantage in substituting the more expensive for the cheaper material.

Comparative costs of Steelwork

The first cost of steelwork in any structure is made up of seven main items:

I. Cost of plain material.
II. ,, ,, fabrication.
III. ,, ,, transport.
IV. ,, ,, erection.
V. ,, ,, painting.
VI. Overheads and establishment charges.
VII. Profit and return on Capital Investment.

I. Plain Material. H.T. Structural Steel requires the addition of alloying elements involving additional costs, not only in the supply of the alloys, but also in the increased difficulties in production: The Carbon in the steel-making bath must be taken down to a low figure, thus requiring extra steelmaking time and consequent additional wear and tear of the furnaces. In the case of some alloys, there is a tendency to produce excessive "Piping" and this involves additional precautions in casting and the inevitable cropping to a greater degree than for M. Steel. The higher tensile properties of the steel give rise to the necessity for increased care in processing and, in general, the yield of finished material is smaller than for ordinary M. Steel. In addition, there is a greater risk of the finished material being outside the specification, which means that the incidence of misfit casts must be catered for. Necessity of additional testing also involves extra costs.

At present, September 1948, the average "Extra cost" per ton as charged by the Steel makers for B.S.S. Nos. 548 and 968 Steels amounts to about 10 % increase on the price of Mild Steel.

II. Fabrication. Cost of fabrication is higher for Low Alloy Steels. The material is harder to work on, requiring either more powerful machines or reduced speed of operation. Roughly speaking, the capacities of shearing, punching and straightening machines and the operating speeds of drilling and milling machines are rated down about 25 %. At the same time, the areas, thicknesses and number of holes are proportionately reduced so that the net cost of the actual operations does not increase by much more than 5 % to 10 %.

In April 1949 this has been increased to abt. 15%.

However, for H.T. riveted structures, provided all joints and lacing, etc., are carefully proportioned, the amount of fabrication per structure should be 5 % to 10 % less than that for Mild Steel one and, therefore, it may be said that the net fabrication cost of H.T. Steel increases proportionately to the saving in weight.

III. Transport. Cost of transport per ton is about the same for both steels.

IV. and V. Erection and Painting. About half of the cost of erection, riveting (H.T.) and painting is constant per ton and the other half increases proportionately to the saving in weight.

VI. Overheads. The cost of supervision, fabricating and erection plant and drawings is approximately constant for any given structure; therefore, the cost per ton of steel varies inversely with the weight of structure.

VII. Profit. This is usually expressed as percentage of the net cost of the work.

Cost per ton.

If the gross cost of plain material, delivered to fabricating works, be taken as = Unity and the percentage saving in weight resulting from the use of H.T. instead of M. Steel as = p, then the following approximate cost comparisons, at present day prices, can be made for average riveted steelwork:

Item	Cost per ton	
	M.S.	H.T.S.
Plain material delivered to works	1,0	1,1
Net fabrication	0,5	$0{,}5 \cdot \frac{100}{100-p}$
Average transport (in British Isles)	0,2	0,2
Erection, riveting and painting	0,6	$0{,}3 + 0{,}3 \cdot \frac{100}{100-p}$
Overheads, etc.	1,0	$1{,}0 \cdot \frac{100}{100-p}$
Total net Cost	3,3	$1{,}6 + 1{,}8 \cdot \frac{100}{100-p}$
Profit at, say, 10%	0,33	$0{,}16 + 0{,}18 \cdot \frac{100}{100-p}$
Total gross Cost	3,63	$1{,}76 + 1{,}98 \cdot \frac{100}{100-p}$

Percentage Saving in Cost

$$\text{Total \% saving in Cost of steelwork} = \frac{\left[3{,}63 - \left(1{,}76 + 1{,}98\frac{100}{100-p}\right)\frac{100-p}{100}\right] 100\,\%}{3{,}63}$$

$$= \frac{1{,}76\,p - 11}{3{,}63}\,\% = \text{approx. } (p/2 \cdot 3)\,\%. \text{ For 1949 Prices}$$

$$\%\ \text{Saving in cost} = \text{approx.} (p/2 \cdot 4^1/_2)\,\%.$$

From above, for percentage saving in weight of 6,2, 10, 20, 30 and 40 %, the corresponding saving in cost = 0, 1,8, 6,7, 11,5 and 16,3 %.

If transport costs for an Overseas job are assumed at, say, 1,2 Units (instead of 0,2) then the saving in cost will increase to 3,3, 9,8, 15,8 and 21,9 % respectively.

Effect of using Welding

A considerable saving in weight can usually be effected by welding, but at present, there is not sufficient data available to arrive at any general conclusions as to the relative cost of welded and riveted construction in H.T.S. bridgework, particularly as regards field welding.

There is no doubt that in Great Britain there is serious disinclination to use welding in association with H.T. Steel. In many structures, welded construction in Mild Steel will compare favourably with riveted construction in H.T. Steel.

Also, "Weldable H.T. Steel" to B.S.S. No. 968 has Yield and Ultimate Tensile Stresses approximately 10 % lower than those of H.T. Steel to B.S.S. No. 548, thus reducing the possible saving in weight due to the adoption of welding. Weldable steels with higher Yield Stress are obtainable, but at a cost which in ordinary conditions is prohibitive.

Practicable saving in Weight

Taking Basic working stresses for H.T. Steel at 40 % above those for M. Steel, maximum saving in weight of main material in members will be approximately as follows:

Tension members about 30 %.
Compression members, liable to buckle,
  with l/r varying from 0 to 50, average about 25 %
and with l/r varying from 50 to 100, average about 20 %.

Webs of plate girders, which are seldom controlled by pure strength considerations, about 10 to 15 %.

The following data indicates possible savings in weight of structures:

I. Plain Joists used as Beams

With l/b of Compression Flange limited to about 20 and no limit on vertical deflections, the comparative strengths and weights of a few typical R.S. Joists are listed below.

From the table it is seen that an average saving in weight of about 15 % is obtained by using H.T. Joists instead of M.S. Joists.

As the current prices, September 1948, of plain H.T.S. Joists are only 10 % above those of M.S. Joists and the cost of fabrication is about the same for each individual joist, it follows that it is almost always economic to use H.T.S. Joists as beams.

M.S. Joists			Nearest Equivalent H.T.S. Joists			% Saving in Weight
Size	Wt/ft lbs	Modulus of Section in^3	Size	Wt/ft lbs	Modulus of Section in^3	
24 · 7–$^1/_2$	95	211	22 · 7	75	152	21,0
22 · 7	75	152	20 . 6–$^1/_2$	65	122	13,3
20 · 6–$^1/_2$	65	122	18 · 6	55	93	15,4
18 · 6	55	93	15 · 6	45	66	18,2
16 · 6	50	77	15 · 5	42	57	16,0
15 · 5	42	57	13 · 5	35	44	16,7
13 · 5	35	44	12 · 5	30	34	14,3
12 · 5	30	35	10 · 4–$^1/_2$	25	24	16,7
10 · 5	30	29	10 · 4–$^1/_2$	25	24	16,7
10 · 4–$^1/_2$	25	24	9 · 4	21	18	16,0
9 · 4	21	. 18	8 · 4	18	14	14,3

When M.S. Compound beams can be replaced by H.T.S. plain ones, the saving in costs is greater, as the saving in weight is increased, while fabrication costs are decreased.

II. Plate Girders

Table of approximate savings in Weight for Riveted Plate Girders.

Total Equivalent Load in tons/ft	Span Ft	$^0/_0$Saving in Weight $= \frac{\text{M.S.Wt.} - \text{H.T.Wt.}}{\text{M.S.Wt.}} \times 100$
2	40	6
	80	14
	120	22
3	40	12
	80	18
	120	24
4	40	17
	80	21
	120	25
5	40	23
	80	25
	120	27

Generally, short plate girders carrying heavy loads (members of deck system) or long plate girders carrying heavy to medium loads are approximately from 15 to 25 % lighter in H.T. than in Mild Steel.

III. Trusses

With regard to main Trusses of Bridges, generally speaking, their weights vary in a somewhat complex manner with the total loading, the square of the span and the Unit Stresses. Various formulae have been published for estimating weights of Trusses for any given set of conditions, but for accurate comparisons a complete design has to be made for each case.

If the loading is relatively heavy and the panel lengths small, a considerable saving in weight can be achieved by the use of H.T. Steel even for relatively short spans. The author compared the weights of 80 ft. Trusses of fixed depth and carrying a load of $2^{1}/_{2}$ tons/ft., designed in H.T. and Mild Steels, (Allowable Stress Ratio = 1,4) with riveted and welded joints and found that, taking M.S. all riveted Truss as basis.

H.T. all riveted Truss gives a saving in weight of 25 %.
M.S. ,, welded ,, ,, ,, ,, ,, ,, ,, 30 % and
H.T. ,, welded ,, ,, ,, ,, ,, ,, ,, 48 %.

In each case the riveted trusses were somewhat more robust.

For normal loading there is rarely any significant saving in weight of Main Trusses for spans of less than 150 ft.

If the Basic Allowable Stresses are increased by 40 %, a saving in weight of approximately 10 % can be obtained with a 150 ft. single span Truss, carrying a total equivalent load of 2 tons/ft.

For Trusses of longer spans and/or carrying greater loads, the saving increases up to a maximum of about 25 % for a defined total loading, giving a saving in the cost of steelwork of about 9 %. Furthermore, the weight of a Truss of given span varies with the loading and the saving in its own weight produces a reduction of the total loading and consequently a further saving in weight of the Truss. This consequential saving is of small importance with medium spans, but in long span bridges, where the weight of the truss forms a considerable proportion of the total "Design load", it increases the possible saving in weight of Main Trusses to about 40 % resulting, with current prices, in a saving in cost of Trusses of about 15 % to 20 %.

For medium span bridges, the cost of Main Trusses forms only a moderate percentage of the total cost of the work and consequently a saving in cost of steelwork of about 9 % would give a saving of only a few % in the total cost. In the case of long span bridges, the cost of steelwork may amount to as much as 80 % of the total cost of the work and a saving of 20 % in the cost of steelwork would give a saving about 15 % in the total cost of the work.

In addition, there is often a considerable consequential saving in the cost of foundations.

Also, it must be remembered that, although the area of painting per ton of H.T. Steel is generally larger than that per ton of Mild Steel, the total area of painting of a H.T. Steel structure is usually smaller than that of an equivalent M.S. structure and that, therefore, the cost of maintenance of H.T. Steel structures is less than that of Mild Steel structures of the same strength.

Use of H.T.S. for Deck and Laterals

To obtain maximum economy, structural members of Deck and Lateral systems, particularly of long span bridges, should in many cases be made of H.T.S. The consequential effect of the saving in weight may justify increased cost of the particular members.

Conclusions

It must be emphasised that although the more general adoption of H.T. Steel may result in only a small saving of cost, the saving in the total weight of steel required to meet the demand for Structural Work is sufficiently large to justify closer attention.

By employing H. T. steels wherever they offer economic advantages, a saving of at least 10 % of the total consumption of structural steel would be made, with the consequent saving of Labour, Transport, Coal, Ore, etc., or else at least 10 % more structures could be built for the same output of steel.

In the days of Buyers' Markets before the war, the demand for higher grade steel was reinforced by the pressure of commercial competition. Several British firms took the lead in producing a variety of Low Alloy Steels at prices very little above those of Mild Steel, which enabled them to compete successfully with other firms, in this and other countries, by offering designs in H.T. Steel at lower prices. During the war, Military requirements compelled the designers to take full advantage of the reduced weight/strength ratio offered by H.T. Steel. Nearly 400 000 tons of Welded H.T. Steel were used for Bailey Bridges alone, and it appeared that both H.T. Steel and Welded construction had become established.

The post-war conditions, however, have led the Rolling Mills and Fabricating firms to confine their productions principally to ordinary Mild Steel and the designers have been reluctant to specify H.T. Steel, as it is difficult to obtain. Consequently, many structures that should be of H.T. Steel are being built in Mild Steel, but only a persistent demand will make it worth while for the Rolling Mills to produce the Special material.

At a time like the present, when supply of steel falls far short of the demand, the use of H.T. Steel provides an opportunity for a substantial reduction of consumption, of which little advantage has been taken. There can be no doubt that, to a large extent, this is due to a lack of realisation, on the part of all concerned, that economies both in weight of steel and cost of production are at their command.

Summary

The development of High Tensile Steels, illustrated by a brief description of some of the major structures built in England and elsewhere in recent years.

Characteristic qualities of Modern H.T. Steels.

Allowable stresses and other factors influencing the design.

Economic advantages and limitations in the use of High Tensile Steel, with particular reference to long span bridges.

Zusammenfassung

Die Entwicklung der Stähle mit hoher Streckgrenze, illustriert durch eine kurze Beschreibung von einigen der wichtigeren Bauten, die in England und anderen Ländern in den letzten Jahren ausgeführt wurden.

Charakteristische Eigenschaften der modernen hochwertigen Stähle.

Zulässige Spannungen und andere Faktoren, die den Entwurf beeinflussen.

Wirtschaftliche Vorteile und Grenzen der Anwendungsmöglichkeit von hochwertigen Stählen mit besonderer Berücksichtigung weitgespannter Brücken.

Résumé

Progrès réalisés récemment en matière d'aciers à haute limite d'écoulement, mis en évidence par une courte description de quelques-uns des plus importants ouvrages qui aient été construits en Angleterre et dans d'autres pays au cours de ces dernières années.

Propriétés caractéristiques des aciers modernes à haute résistance.

Contraintes admissibles et autres facteurs intervenant dans l'étude des projets.

Avantages économiques et limites des possibilités d'emploi des aciers à hautes caractéristiques, tout particulièrement du point de vue des ponts de grande portée.

Bibliography

ROLFE R. T.: Steels for the User. London 1942.

BARR W. and HONEYMAN, A. J. K.: Steel and its Practical Application. London 1945.

British Welding Research Association: Publication T 2 on Welding of H. T. Steels. 1944.

Report of Sub-committee No. 2 on Structural Alloy and Heat Treated Steels (U.S.A.) 1936.

Report of British Steelwork Association on the use of H. T. Steels in Britain. 1947.

American Welding Society Specification for Welded Highway and Railway Bridges in M. S. 1947.

ROBERTS G.: A new High Tensile Steel for Structural Work; The Structural Engineer (London). July 1934.

WADDELL J. A. L.: The Possibilities in Bridge Construction by the Use of High Alloy Steels. Transactions of A. Soc. C. E. April 1914.

KARPOV A. V.: Modern Stress Theories. Transactions of A. Soc. C. E. October 1936.

BEARD V. D.: Actual Application of Special Structural Steels. Transactions of A. Soc. C. E. October 1936.

Bain E. C. and Llewellyn F. T.: Low Alloy Structural Steels. Transactions of A. Soc. C. E. October 1936.

Moisseiff L. S.: Evolution of High Strength Steels in Structural Engineering. Transactions of A. Soc. C. E. Oct. 1936.

Freudenthal A. M.: Reflections on Standard Specifications for Structural Design. Transactions of A. Soc. C. E. February 1947.

Kommerell O.: The Influence of frequently Alternating Loads on Welded Structures. 2nd Congress of the International Association for Bridge and Structural Engineering. Berlin 1936.

Wilson W. M.: Fatigue Tests of Riveted Joints. Civil Engineering, New York, Vol. 8, No. 8. 1938.

Swinden T. and Reeve L.: Metallurgical Aspects of the Welding of Low Alloy Structural Steels. Proceedings of Institution of Welding (London). November 1937.

Wilkinson T. B. and O'Neil H.: Observations on the Arc Welding and Gas Cutting of H. T. Low Alloy Structural Steels. Proceedings — Inst. of. Mech. Engineers (London). October 1939.

Dearden J. and O'Neil H.: A Guide to the Selection and Welding of Low Alloy Structural Steels. Transactions of Inst. of Welding (London). Vol. 3. 1940.

Spraragen W. and Rosenthal D.: Fatigue Strengths of Welded Joints. Welding Research Committee U.S.A. July 1942.

Spraragen W. and Chiswick H. H.: Welding Low Alloy High Strength Steels. Welding Research Committee U.S.A. June 1943.

Report No. 1 of Committee F on: The Effect of Periods of Rest on the Fatigue Strength of Welded Joints. Welding Research Committee U.S.A. September 1946.

Zanetti J. K.: Characteristics of Low Alloy H. T. Steels. Materials and Methods (U.S.A.). August 1946.

Honeyman A. J. K. and Erskine J.: Development of Low Alloy Steels for Welding Construction. Metalurgia (Great Britain). July 1946.

Tremlett H. F.: The Arc Welding of H. T. Steels. Welding (London). October, November, December 1944.

Waller W. D.: Chose the right Electrode. Welding (London) October, November 1947.

Times Review of Industry: High Tensile Structural Steel. Welding (London) November 1947.

Bradfield J. J. C.: Story Bridge. Civil Engineering (London). February 1938.

Pain J. F. and Upstone T. J.: Some considerations affecting the Minimum Deflections of small Highway Bridge Girders. Proceedings of Inst. of C. E. (London). April 1943.

Fawcett F. and Hudson J. C.: The Prevention of Corrosion in Structural Steelwork. Proceedings of Inst. of C. E. (London). February 1947.

Freeman Ralph: Sydney Harbour Bridge — Design of Structure and Foundations. Proceedings of Inst. of C. E. (London). April 1934.

Buckton E. J. and Fereday H. J.: The Reconstruction of Chelsea Bridge. Proceedings of Inst. C. E. (London). December 1937.

Maunsell G. A. and Pain J. F.: The Storstrom Bridge. Proceedings of Inst. of C. E. (London). April 1939.

Shirley Smith H. and Freeman R. (Jnr.): The Design and Erection of Birchenough and Otto Beit Bridges. Proceedings of Inst. of C. E. (London). May 1945

Maunsell G. A.: Menai Bridge Reconstruction. Proceedings of Inst. of C. E. (London). December 1945.

Ward A. M. and Bateson E.: The New Howrah Bridge. Proceedings of Inst. of C. E. (London). May 1947.

Sir Donald C. Bailey and Foulkes R. A.: The Bailey Bridge and its Developments. Proceedings of Inst. of C. E. (London). June 1947.