HISTORICAL STRUCTURAL STEELWORK HANDBOOK

Properties of U.K. and European Cast Iron, Wrought Iron and Steel Sections including Design, Load and Stress Data since the Mid 19th Century

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PREFACE

One of the most regular questions the BCSA is asked as part of its advisory service to the public is to identify a steel section from its accessible dimensions and suggest ways of determining its load bearing capacity.

This publication has been prepared to enable clients, architects, and engineers to have a comprehensive guide to the various factors that need to be considered in assessing the load bearing capacity of an existing steel framed building. The text is supplemented with advice on how to proceed with such structural investigations and deriving additional data by simple calculation.

The author was the Chief Structural Engineer of Redpath Dorman Long and has had wide experience of this type of work.

This book can be summarised as being a guide to over a century of building in iron and steel sections containing information on properties of materials, profiles, loads and stresses.

ACKNOWLEDGEMENTS

In compiling this work the author has received help and encouragement from sources too numerous to mention in detail. However special reference must be made to:

British Standards Institution
Institution of Structural Engineers
London County Council
British Steel Corporation

to former colleagues and to the very many people with whom he serves on technical committees both in this country, and in Europe. Without their help so freely given this publication could not have been compiled in its present form.

Copies of current British Standards can be obtained from the British Standards Institution, Linford Wood, Milton Keynes MK14 6LE.

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SECTION NO. 1 Introduction and Historical Notes

1.1 Introduction

From time to time it is necessary to refurbish existing buildings of which little is known other than the approximate period when construction took place.

It is possible to ascertain the shape and dimensions of the existing structure by making a careful survey of the premises. Having obtained this information a great deal of extra detail is still required such as:—

(a) Probable material ie Cast Iron, Wrought Iron or Steel.
(b) Technical properties of the different members.
(c) Origin of the members.
(d) Strength of the material from which members were made.
(e) Design loading at period of construction.
(f) Design stresses etc relative to the particular material.

All this information can probably be found by access to various sources of information, though few people would know how to readily locate these sources.

Whilst every care has been taken to ensure that the information given herein is accurate it must be appreciated that gaps exist in some of the records which have been consulted, and the author has attempted to bridge these gaps in the interests of continuity.

1.2 Historical Notes

Requirements regarding quality of material, shapes and sizes, design loads and permissible stresses all developed rapidly after the year 1900 when British Standards Institution as it now is called first came into being, though BSI must not be considered as the only authority as the Institution of Structural Engineers, the Greater London Council and Government departments have made major contributions to regulations controlling construction.

The various ways in which each has played a part are mentioned from time to time in the following text.

It should also be appreciated that many commercial firms have also contributed in the effort to promote the use of their products or of their technical skills. Again references will be made to these firms when necessary.

During the years before 1900 however the engineers designing or constructing using iron or steel products had far more to say regarding design requirements, materials and shapes, factors of safety etc, and hence were required to have a much greater knowledge of all the aspects of construction including the properties of materials and shapes than applies at the present time.

In order to contain this publication within reasonable proportions it has been necessary to condense a great deal of technical information. It can be assumed therefore that recommendations made regarding material qualities, sizes etc are representative rather than inflexible, and the following text should be treated in this way.

SECTION NO. 2 Materials

2.1 Introduction

Iron has been known since very early days. It was probably first discovered by chance by heating iron ore in a charcoal fire.

So much was the value of the metal appreciated, that in the middle ages most of the forests in Britain were destroyed to make charcoal to smelt the iron ore.

It was found that the fire burned more efficiently when the wind was blowing. This led to the use of a forced draft by means of bellows to increase the air supply and produce the iron more rapidly.

Such primitive furnaces are the forerunners of the modern blast furnaces, the charcoal being replaced by coke, a product of coal and not wood.

Iron produced by early primitive methods did not actually become molten and could be forged and shaped by hammering. On the other hand the molten iron produced by the blast furnaces was hard and brittle since it absorbed three to five percent of carbon from the firing medium ie charcoal or coke, both being almost pure carbon.

These are facts which are part of history, and are only repeated in outline. The main purpose is to introduce the three iron products used in building viz:—

(a) Cast Iron
(b) Wrought Iron
(c) Steel

The basic difference chemically of the three is the amount of carbon and other impurities included with the iron, but the mechanical properties are appreciably different.

The various impurities which can be mixed with the pure iron are Carbon, Silicon, Managanese, Sulphur, Phosphorus, Chromium and Copper, though minute quantities of Tin, Tungsten, Antimony etc can be found.

The influence of the main impurities on the quality and characteristics of the material can be briefly summarised as follows:—

(a) Carbon:- Decreases malleability — increases hardness.
(b) Silicon:— Tends to prevent solubility of the carbon in the metal — increases fuseability.
(c) Manganese:— Increases malleability.
(d) Sulphur:— Increases hardness.
(e) Phosphorus:— Makes metal more fusable.
(f) Chromium:— Increases tensile strength.
(g) Copper:— Increases resistance to corrosion.

Acceptable quantities of these various impurities will be specified later. As far as steel is concerned they are of course specified in the various British Standards.

The use of cast iron as a building material probably dates back to about the year 1800, with wrought iron being introduced a few years later. Cast Iron columns were still being made for limited use in the early 1930's though they substantially ceased to be used in any quanitity after the beginning of the century when steel took over as the main structural material.

Wrought iron, probaly because it was costly to produce, began to be replaced by steel about 1850 and very little wrought iron was used after 1890, though there is evidence of some use of wrought iron sections as late as 1910, and also mixtures of wrought iron and steel in identical sizes in the same structure.

Steel structural sections were available in very limited sizes from 1850 onwards but in 1880 they had started to increase quickly in both size and quantity. As will be seen from the next section, in 1887 Dorman Long and Company produced a range of 99 beam sizes as well as a vast range of channel and angle shapes.

The three structural metals will each be examined in detail in separate items in this section.

2.2 Cast Iron as a structural material

Iron castings could be made directly from the molten metal from the blast furnace but these were of inferior quality and it was usual to run the metal into pig beds and manufacture cast iron by remelting pig iron and then running the metal into moulds of the required shape.

Cast Iron contains from 2.0 to 6.0% of carbon. It is brittle, not forgeable or weldable.

There were three types of cast iron used for structural members viz:

Grey Iron
White Iron
Mottled Iron

these depending upon the type of impurities present in the pig iron.

Grey Cast Iron was made from the best quality pig iron and was therefore the most reliable.

White Cast Iron was less subject to rusting than grey but it was harder, more brittle and less reliable.

Mottled Cast Iron had many of the characteristics of the other two. It contained more sulphur and was more prone to cracking during cooling.

Engineers usually specified grey iron for their castings and unless there is evidence to the contrary this type of iron should be assumed as having been used.

The ultimate tensile and compressive strengths of cast iron varied appreciably as will be seen from the figures in table 2.1 published in 1879. Earlier figures, published in 1872 gave somewhat higher average values.

For the purpose of checking the carrying capacity of cast iron beams and columns it is advisable to adopt conservative figures for the ultimate strength, the following being considered as suitable:—

Ultimate strength in tension	6 tons/sq. in.
Ultimate strength in compression	32 tons/sq. in.
Ultimate strength in shear	8 tons/sq. in.

A factor of safety (usually 4) should be used to arrive at working stresses.

Table 2.1 Ultimate Strengths of Cast Iron 1879

Description of Iron		Compressive Strength	Tensile Strength
		tons/sq inch	
Lowmoor Iron	No 1	25.2	5.7
Lowmoor Iron	No 2	41.2	6.9
Clyde Iron	No 1	39.6	7.2
Clyde Iron	No 2	45.5	7.9
Clyde Iron	No 3	46.8	10.5
Blenavon Iron	No 1	35.9	6.2
Blenavon Iron	No 2	30.6	6.3
Calder Iron	No 1	33.9	6.1
Coltness Iron	No 3	45.4	6.8
Brymbo Iron	No 1	33.8	6.4
Brymbo Iron	No 3	34.3	6.9
Bowling Iron	No 2	33.0	6.0
Ystalyfera Iron	No 2 (anthracite)	42.7	6.5
Ynis-cedwyn Iron	No 1	35.1	6.2
Ynis-cedwyn Iron	No 2	33.6	5.9
Average		34.24	6.77

As the use of cast iron as a structural material was on the decline when the BSI was first established little interest was shown in producing a detailed specification for the use of the material in structures. There are however a number of standards for cast iron as a material, and BS1452 1948 defines seven separate grades of cast iron with ultimate tensile strengths of 10, 12, 14, 17, 20, 23 and 26 tons/sq. inch. These grades and strength values can only be considered of general interest.

2.3 Wrought Iron as a structural material

Wrought iron was traditionally produced from cast iron by the puddling process which consisted of raising the iron to a high temperature in a reverberatory furnace where the carbon and other impurities were removed by a strong air blast, the iron being kept from direct contact with the fuel.

The carbon was removed by combining with the oxygen as a gas and the silicon and other impurities forming a fusible slag which could be run off.

Wrought iron is almost pure iron, softer than steel but less liable to corrosion etc. The material being malleable could be forged and bent to shape. It was considered as being of approximately equal strength in both tension and compression, the ultimate tensile strength varying between 18 and 30 tons/sq. inch.

In 1879 the following values were recommended as average for the strength of wrought iron:—

Ultimate strength in tension	21 tons/sq.in.
Ultimate strength in compression	16 tons/sq.in.
Ultimate strength in shear	20 tons/sq.in.

One of the main advantages of wrought iron was its facility to stand reheating and rolling to shape with increased strength resulting from elongating into fibres the cubic crystals which formed the basic metal.

It is stated in 1879 that rolled I beams of depths from 3" to 14" in an endless variety were obtainable from different makers in both this country and abroad, particularly Belgium.

It is of interest to note that the foreign iron joists could be obtained some 20% cheaper than the British!

2.4 Steel as a structural material

Steel has been produced for structural purposes since about 1850, although it took 40/60 years for it to entirely replace wrought iron.

Steel has much less carbon and other impurities than cast iron, although appreciably more than wrought iron.

Originally it could be produced by one of two methods ie

(a) By adding carbon to wrought iron.
(b) By removing carbon etc from pig iron.

The first of these methods is too expensive to be of practical use and therefore the second was the method generally adopted.

The two early methods of steelmaking were

(1) The use of the Bessemer converter
(2) The use of the Siemens Martin open hearth furnace

Two alternatives of each process are

(i) Acid
(ii) Basic

The difference is in the lining of the furnace; in the case of the acid process the lining consists of a material with a high content of silicon, whilst in the case of the basic process the lining contains a high proportion of basic oxides ie calcined dolomite or magnesite.

The use of either acid or basic process is governed by the type of iron ore used since the former is not capable of removing sulphur and phosphorus and the latter is.

There are now several more modern steel making processes all of which are acceptable. These will not be discussed in the publication.

Mild steel has many of the properties of wrought iron, but with ultimate tensile and compressive strengths roughly equal ie between 28 and 32 tons/sq. inch.

In 1879 the following average values for the ultimate strength of mild steel were quoted:—

Ultimate strength in tension	32 tons/sq.in.
Ultimate strength in compression	30 tons/sq.in.
Ultimate strength in shear	24 tons/sq.in.

A factor of safety (usually of four) was adopted to obtain the safe working stresses.

Structural steel quickly replaced wrought iron and by the year 1900 few beams or other structural shapes were rolled in wrought iron.

Developments in the manufacture and in the control of quality and strength of steel are reflected in the British Standard Specifications which are reviewed in 2.5.

2.5 British Standard Specifications for Structural Steel

BS15 1906 **Standard Specification for Structural Steel for Bridges and General Building Construction**

For bridges the steel must be made by the Open Heath process, either acid or basic.

For general buildings the Bessemer process acid or basic was included.

For bridges not more than 0.06% sulphur and no phosphorus was allowed.

For buildings 0.06% sulphur and 0.07% phosphrous was permitted.

The ultimate tensile strength was specified at 28 to 32 tons/sq.in.

BS15 1912 **Standard Specification for Structural Steel for Bridges and General Building Construction**

Same steel making processes as in 1906.

A class steel for bridges not more than 0.06% sulphur or phosphorus.

B Class steel (not for bridges) not more than 0.06% sulphur and not more than 0.08% phosphorus permitted.

Ultimate tensile strength specified at 28 to 33 tons/sq.in.

BS15 1930 **Standard Specification for Structural Steel for Bridges and General Building Construction**

All as 1912 except basic Bessemer process not now permitted.

BS15 1936 **Standard Specification for Structural Steel for Bridges and General Building Construction**

Division of steel into classes A & B omitted.

Not more than 0.06% sulphur or phosphorus.

Ultimate tensile strength specified at 28 to 33 tons/sq.in.

CF(15) 7376 **1941 War Emergency revision to BS15**

Two main qualities of steel

No 1 Quality as BS15 1936; No 2 Quality as BS15 1936 plus

(a) 0.20 to 0.35% copper
(b) 0.35 to 0.50% copper

Otherwise as 1936.

BS15 1948 **Structural Steel**

Steel processes open hearth acid or basic or acid Bessemer.

No 1 Quality not more than 0.06% sulphur

No 2 Quality not more than 0.06% sulphur or phosphorus + 0.20 to 0.50% copper as wartime emergency.

For the first time yield strenth introduced into mechanical properties ie

Up to and including ¾ inch thick	16 tons/sq.in.
Over ¾" up to 1½" thick	15 tons/sq.in.
Over 1½" thick	14.75 tons/sq.in.

Ultimate tensile strength 28 to 33 tons/sq.in.

BS15 1961 Mild Steel for General Structural Purposes

Steel processes as 1948 plus any of the oxygen processes.

Carbon content 0.25% to make suitable for welding.

If oxygen process used nitrogen content not more than 0.008%.

The full chemical content now given against three grades viz:—

	Grade 1	Grade 2	Grade 3
Carbon	0.25%	0 to 0.25%	0 to 0.25%
Copper	0	0.20 to 0.35%	0.35 to 0.5%
Sulphur	0.06%	0 to 0.06%	0 to 0.06%
Phosphorus	0.06%	0 to 0.06%	0 to 0.06%

The carbon content of 0.25% on material up to 2 inches thick, above to be agreed between maker and user.

Yield strength and ultimate strength as 1948.

This was the last issue of BS 15 being replaced by BS 4360: 1968.

Additional specifications for steel before 1968 included the following:—

BS 548 1934 High Tensile Structural Steel for Bridges and General Building Contruction.

Steel processes were similar to BS 15 1930 (which excluded basic Bessemer process).

The chemical properties included

Carbon	maximum of 0.30%
Sulphur	maximum of 0.05%
Phosphorus	maximum of 0.05%
Copper	up to 0.6%

The mechanical properties included:—

Yield Strength

Thickness	up to and including 1¼"	23 tons/sq.in.
Over 1¼"	up to and including 1¾"	22 tons/sq.in.
Over 1¾"	up to and including 2¼"	21 tons/sq.in.
Over 2¼"	up to and including 2¾"	20 tons/sq.in.
Over 2¾"		19 tons/sq.in.

Ultimate tensile strength 37 to 43 tons/sq.in.

War emergency amendment to BS 548 1942

Sulphur and Phosphorus allowance increased to 0.06%.

Note:— This specification was withdrawn in 1965.

BS 968 1941 (War emergency standard) High Tensile (Fusion Welding Quality) Structural Steel for Bridges and General Building Purposes.

The chemical properties included:

Carbon	maximum of 0.23%
Silicon	maximum of 0.35%
Manganese	maximum of 1.8%
Chromium (optional)	maximum of 1.0%
Nickel (optional)	maximum of 0.5%
Sulphur	maximum of 0.06%
Phosphorus	maximum of 0.06%
Copper	maximum of 0.6%

NB. Manganese plus Chromium not more than 2.0%.

The mechanical properties were as BS 548.

War time amendment No 1 to BS 968 1943

The chemical properties were divided into two classes viz:—

		Class (a)	Class (b)
Carbon	maximum of	0.23%	0.23%
Silicon	maximum of	0.35%	0.35%
Manganese	maximum of	1.8%	0.8%
Nickel	maximum of	0.5%	0.5%
Chromium	maximum of	0.35%	0.8%
Sulphur	maximum of	0.06%	0.06%
Phosphorus	maximum of	0.06%	0.06%
Copper	maximum of	0.6%	0.6%

Because chromium was in short supply the Class (b) steel only to be called up in exceptional circumstances.

The mechanical properties included:—

Material up to and including ¾" thick

Yield Strength	21 tons/sq.in.
Ultimate Tensile Strength	35 to 41 tons/sq.in.

Material over ¾" thick

Yield Strength	19 tons/sq.in.
Ultimate Tensile Strength	33 to 39 tons/sq.in.

BS 968 1962 High Tensile (Fusion Welding Quality) Structural Steel for Bridges or General Building Purposes.

A new steelmaking process produced steel with improved yield strength.

Chemical properties (ladle analysis)

Carbon	maximum 0.20% — 0.22% over 5/8" thick
Silicon	maximum 0.35% — increased to 0.5% in 1965
Manganese	maximum 1.5% } Total not to exceed 1.6%
Chromium	maximum 0.5% } Total not to exceed 1.6%
Sulphur	maximum 0.05%
Phosphorus	maximum 0.05%

Mechanical properties —

Yield Strength

Thickness up to and including 5/8"	23 tons/sq.in.
over 5/8" up to and including 1¼"	22.5 tons/sq.in.
over 1¼" up to and including 2"	22 tons/sq.in.
Over 2" to be agreed	
Ultimate Tensile Strength	32 to 39 tons/sq.in.

This specification was also replaced by BS 4360 1968.

BS4360 1968 Weldable Structural Steels

This was the first issue of a comprhensive specification covering steels previously specified in BS15 BS968 BS2762 and BS3706 but appreciably increaing the range of steels.

Four groups of steels were included with ultimate tensile strength with a minimum of 26, 28, 32 and 36 tons/sq.inch and corresponding yield strengths.

The specification was also widened to include tolerances on plates, tolerances on sections being covered elsewhere.

Amendment Slip No 1 to BS4360 1968 was published in September 1969 and as well as correcting minor errors altered the number to BS4360 Part 1 Inch Units.

BS4360 Part 2 1969 Metric Units was issued without any technical alteration to Part 1.

BS4360 1972 Weldable Structural Steels

This revision to the specification cancelled the imperial version hence it reverted to a number without the addition of Part 1 or Part 2.

The scope of the specification was extended to include weathering steels and the whole format was altered and improved.

BS4360 1979 Weldable Structural Steels

At the time of writing this is the current version of the specification and apart from the inclusion of additional steels, flat products are aligned with European practice, and dimensional tolerances introduced to replace weight rolling margins.

The BSI committee concerned has just embarked on a further revision to BS4360.

It is assumed that copies of BS430 and amendments thereto are readily available hence no details of specific items are given.

2.6 General Remarks

This section has been restricted to the developments in iron and steel construction in the United Kingdom. However a great deal of parallel development took place in Europe, especially in Belgium and Luxembourg.

For some reason the continental steel makers did not match up to the qualities achieved by the U.K., at least most authorities insisted on the use of lower strength values when the steel was imported.

As far as the design of structures was concerned, the codes of practice and design specifications closely followed upon developments in materials etc. and one must be related to the other.

SECTION NO. 3 Shapes & Sizes

3.1 Introduction

Previous sections have given details of developments in materials, and standardisation. This section will concentrate on shapes and sizes of structural sections over the last 100/150 years.

The subject will be dealt with in three parts corresponding to the three basic materials.

3.2 Cast Iron

During the period 1830 to 1900 cast iron was extensively used as a building material and many important structures, including the Crystal Palace, were constructed using the material.

Because of the method of manufacture ie the casting into moulds of moulten iron, sections were purpose made for the particular application and therefore it is not possible to give details of actual shapes and sizes.

The two main structural elements in cast iron ie beams and columns, were used either separately or together. For instance, cast iron beams were used supported on brickwork or on columns and cast iron columns were used to support timber and wrought iron beams as well as cast iron beams.

Connections between beams and columns were of the simplest form, consisting mainly of direct support on brackets cast on the column with a nominal attachment of beam to column by bolts or coach screws in cored holes.

Because it is impossible to give actual sizes some guide to determining the proportions could be useful.

3.2.1 Cast Iron Beams

It has already been mentioned in Section 2 that cast iron is a brittle material, strong in compression but weak in tension.

For this reason cast iron beams were made of asymmetric shape as shown in Figure 3.1.

It is important to note that such case iron beams must be simply supported at each end. If the beam is used as a cantilever the proportions must be reversed.

Strengthening an existing structure by introducing intermediate props under cast iron beams can be dangerous as this will result in the reversal of stresses. Should such strengthening be required it is best done by inserting a new beam below or alongside the existing cast iron beam to take the full loading.

Being purpose made, many cast iron beams were provided with a curved elevation as shown in Figure 3.2.

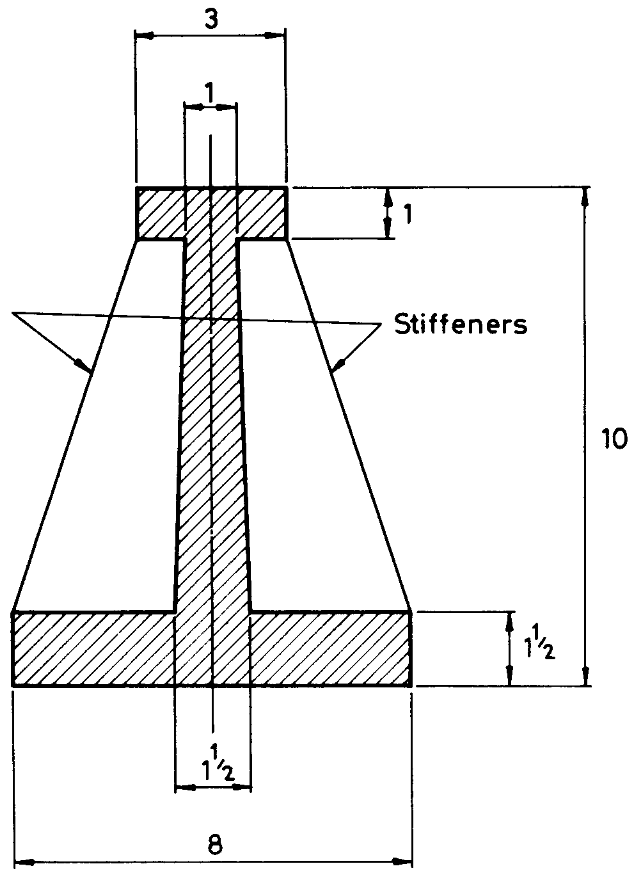


Figure 3.1 Cast Iron Beam.

Note:– The dimensions given on the sketch show the proportions recommended by Professor John Goodman of Leeds University circa 1904 as giving the most economical section. Beams made prior to that date may vary from these proportions.

As cast iron beams were frequently used to support barrel vault floors as indicated in Figure 3.3 care must be taken in examining the construction to avoid damaging the brick arches.

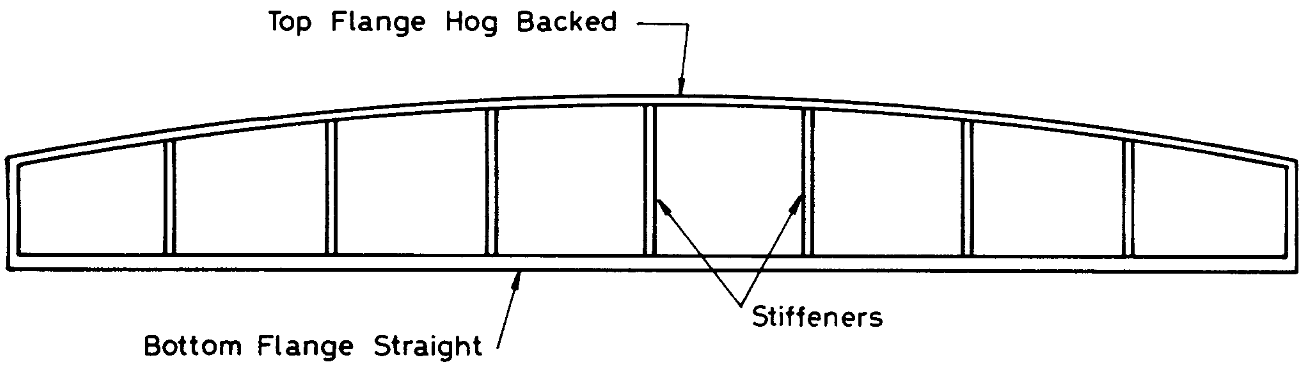


Figure 3.2 Elevation of Cast Iron Beam.

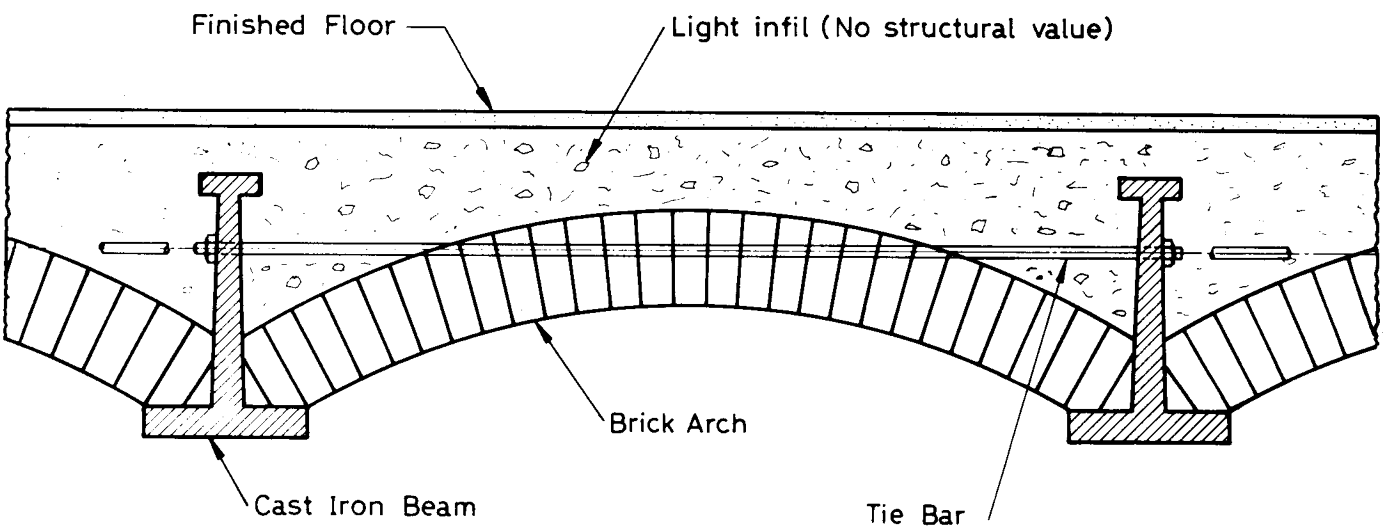


Figure 3.3 Barrel vault construction.

Figure 3.3 Barrel vault construction

3.2.2. Cast Iron Columns

The use of cast iron columns extended well beyond the period when cast iron beams were replaced by mild steel beams, in fact isolated cases of their use were recorded in the early 1930's.

By far the most extensive use of cast iron columns occurred however before the beginning of the twentieth century.

Cast iron columns were usually of hollow circular construction provided with brackets to receive the beams and carried up to receive the column over. Bases were often cast separately with a simple end to the column itself.

In order to ensure adequate contact area for the transmission of load sometimes the ends of the columns were machined but with a good iron foundry sufficient accuracy could be achieved to eliminate the need for machining and often a simple lead pad was introduced between bearing surfaces to improve contact.

Figure 3.4 shows a typical cast iron column assembly.

In examining existing cast iron construction it is necessary to determine the thickness of the metal. Since access to the core will not be possible the thickness should be found by drilling small holes and measuring by means of a piece of wire.

One possible error which can be found in existing cast iron columns is cases where the core is not central on the column. To ensure that this is not the case **three** holes should be drilled in positions as indicated in Figure 3.5 – not of course on the same horizontal line – and the average taken of the thickness measured at each position.

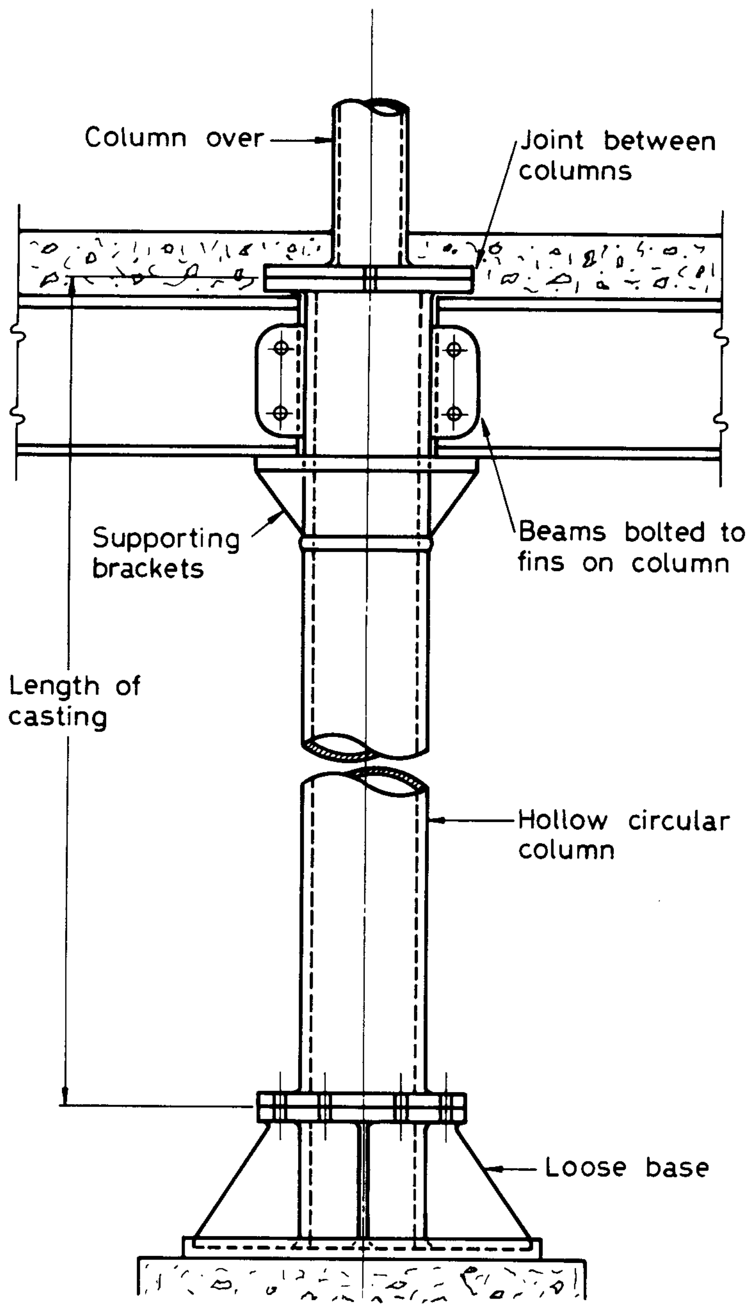


Figure 3.4 Cast Iron Column.

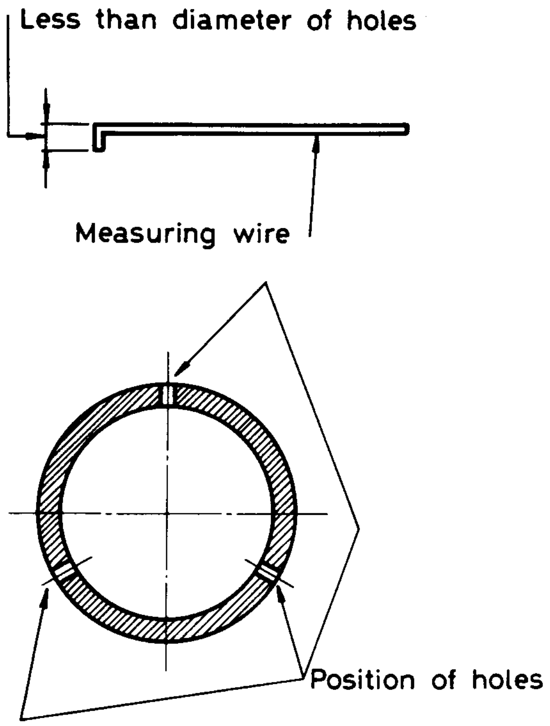


Figure 3. 5 Thickness of Cast Iron Column.

3.3 Wrought Iron

During the period 1850 to 1900 wrought iron was used to replace cast iron for beams in building construction. Some wrought iron joist shapes were produced but of very limited depth, around 8" being considered the limit. Above this size rivetted fabricated girders were used made up of angles and plates or in some instances angles latticed with small plates, see Figure 3.6.

The actual sizes of the angles used in these girders can be determined by measurement. It can be assumed that many of the mild steel sizes given later were originally produced in wrought iron.

It has been reported that the annual production of wrought iron plates and sections in 1870 amounted to around 3 million tons.

During the last quarter of the nineteenth century mild steel became increasingly used on account of its increased strength. It is reputed that by changing from wrought iron to mild steel for the Forth Railway Bridge design stresses were increased from 5.0 to 6.5 tons per square inch.

To conclude on this subject, when considering the strength of any structure built between 1850 and say 1890 when the material is in question, caution should be adopted and the lower stresses for wrought iron assumed.

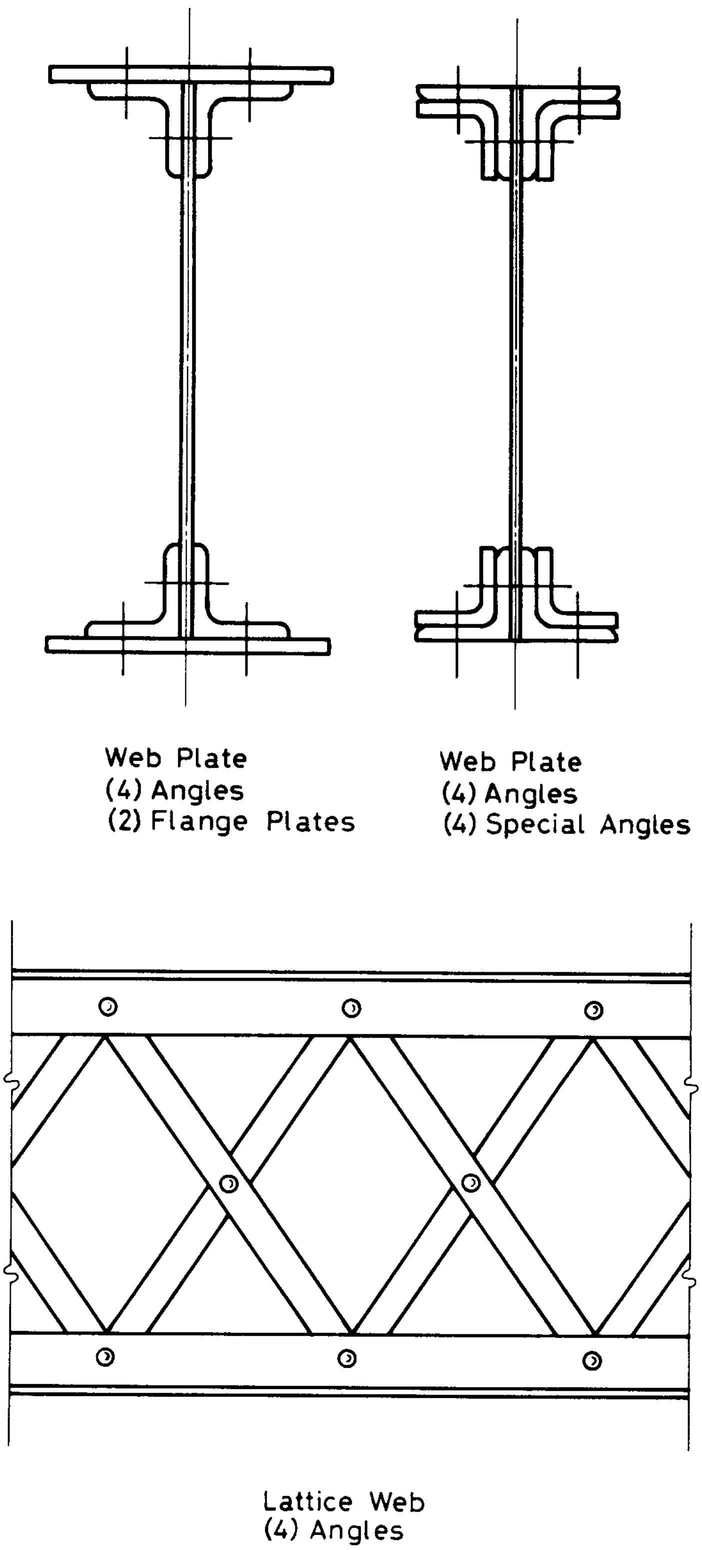


Figure 3. 6 Typical Fabricated Girders.

3.4 Steel

Steel sections were produced in quantity from about 1883 through some of the smaller sections were available in mild steel before that date.

Prior to the formation of the British Standards Institution (as it is now called) in 1900, shapes and sizes were settled by the individual manufacturer, mainly of course to meet their customers requirements. These manufacturers produced catalogues giving dimensions, and in some instances design properties of the various sections which they produced.

The earliest available handbook which has been considered is that published by Dorman Long and Company in 1887. Subsequent copies were published in 1890 and 1895 but showed little variation from the 1887 issue.

Redpath, Brown & Co published their first handbook in 1892 and as this firm manufactured girders etc as opposed to producing steel sections, their handbook was more of a design manual than a catalogue.

As it was considered that only a limited number of engineers could actually design, safe load tables were produced from which, in theory at least, the uninitiated were able to select the right member to meet their requirements.

In part 3.5, numerous tables are given to provide as much design information as possible on steel sizes from 1887 onwards. Notes are included giving details of the various tables.

From 1903, when British Standard 4 was first issued, all the tables refer to British Standard Sections, though at various times since 1903 some steel sections have been imported and used which do not conform to British Standards. The most notable of these are Broad Flange Beams rolled on the continent of Europe. Details of these and other continental sections are given in Section 8.

Since the last of the main section tables given in part 3.5 two major developments have occured. In 1972 British Standard 4848 Part 4 Metric Equal and Unequal angles was issued. These metric sizes replace the imperial sizes in British Standard 4.

Details of metric angles and their properties are contained in the Constrado publication "Structural Steelwork Handbook – Metric Angles to BS4848 Part 4 1972" published in 1973 and which is currently available.

The second major development was the issue of British Standard 4 Part 1. 1980. This updated previous issues of BS4 to correct minor inaccuracies and to cover the properties of Universal Beams which now all have parallel flanges. Again, all the details given in BS4 Part 1 1980 are included in the BCSA/Constrado publication "Structural Steelwork Handbook – Sections to BS4 Part 1" which is currently available and also includes the Safe Load Tables.

Though this was published in 1978, before the last revision to BS4 Part 1. 1980, it anticipated the information given in the latter. Editorial and other minor corrections have been incorporated in subsequent impressions of this publication.

3.5 Tables

In the tables which follow the properties of a wide range of sections are given.

These tables are produced in the units in which the information was originally presented and the equivalent metric or imperial size is given immediately after the original. This is to enable the size to be identified in whichever form of measurement is adopted.

When the section properties are required in the alternative units to those printed conversion factors must be used as Table 3.1.

Table 3.1 Conversion Factors

Item	Imperial to Metric Imp x		= metric	Metric to Imperial x	= Imp.
Depth & Breadth	ins x	25.4	= mm	x 0.03937	= ins
Mass/unit length	lb/ft x	1.48816	= kg/m	x 0.67197	= lb/ft
Thickness	ins x	25.4	= mm	x 0.03937	= ins
Area	ins^2 x	6.4516	= cm^2	x 0.155	= ins^2
Moment of Inertia	ins^4 x	41.6231	= cm^4	x 0.024025	= ins^4
Radius of Gyration	ins x	2.54	= cm	x 0.3937	= ins
Section Modulus	ins^3 x	16.3871	= cm^3	x 0.061024	= ins^3

In order to get the information regarding a section onto a single line in the following tables, fractions of an inch are given as decimals of an inch based on Table 3.2:

The decimal values given are for indentification purposes only and are based on the first two figures of the true values and therefore must not be used for calculation purposes.

Table 3.2 Equivalent decimal values

Fraction	1/32	1/16	3/32	1/8	5/32	3/16	7/32	1/4	9/32	5/16	11/32	3/8	13/32	7/16	15/32	1/2
Decimal	.03	.06	.09	.12	.15	.18	.21	.25	.28	.31	.34	.37	.40	.43	.46	.50
Fraction	17/32	9/16	19/32	5/8	21/32	11/16	23/32	3/4	25/32	13/16	27/32	7/8	29/32	15/16	31/32	1
Decimal	.53	.56	.59	.62	.65	.68	.71	.75	.78	.81	.84	.87	.90	.93	.96	1.00

TABLE NO. 3.3 BEAM SIZES ROLLED BY DORMAN LONG & CO 1887

IMPERIAL UNITS See separate page for notes

Nominal Size D X B	Mass/ft	Metric Equivalent D X B	Metric Equivalent Mass/m	Actual Size D X B	Thickness Web	Thickness Flange	Area	Moment of Inertia X - X	Moment of Inertia Y - Y	Radius of Gyration X - X	Radius of Gyration Y - Y	Section Modulus X - X	Section Modulus Y - Y
ins	lbs	mm	kg	ins	ins	ins	ins2	ins4		ins		ins3	
20x8	100	508x210	149	20 x8.26	0.76	0.97	29.67	1825.10	80.43	7.84	1.65	182.5	19.5
	95	508x208	141	20 x8.18	0.68	0.97	28.24	1774.43	77.99	7.93	1.66	177.4	19.1
	90	508x206	134	20 x8.11	0.61	0.97	26.78	1725.09	75.62	8.02	1.68	172.5	18.6
18x7	90	457x183	134	18 x7.20	0.81	0.94	26.46	1255.72	49.98	6.89	1.37	139.5	13.9
	84	457x180	125	18 x7.10	0.71	0.94	24.67	1207.61	47.59	7.00	1.39	134.2	13.4
	78	457x175	116	18 x6.90	0.61	0.94	22.88	1159.01	45.32	7.12	1.41	128.8	13.1
16x6	68	406x155	101	16 x6.12	0.71	0.82	20.18	753.30	29.32	6.11	1.21	94.2	9.58
	64.5	406x154	96	16 x6.06	0.64	0.82	19.15	731.11	28.22	6.18	1.21	91.4	9.31
	59	406x151	88	16 x5.95	0.54	0.82	17.51	696.30	26.69	6.31	1.23	87.0	8.97
15x6	65	381x157	97	15 x6.17	0.79	0.81	19.34	663.68	30.30	5.86	1.25	88.5	9.82
	61	381x155	91	15 x6.09	0.72	0.81	18.15	641.46	28.98	5.94	1.26	85.5	9.52
	57	381x153	85	15 x6.01	0.64	0.81	16.96	619.24	27.70	6.04	1.28	82.6	9.22
15x5	60	381x134	89	15 x5.26	0.70	0.80	17.85	566.18	18.55	5.63	1.02	75.5	7.05
	55	381x131	82	15 x5.16	0.60	0.80	16.36	538.34	17.35	5.74	1.03	71.8	6.72
	50	381x129	74	15 x5.06	0.50	0.80	14.88	510.21	16.23	5.86	1.04	68.0	6.42
14x6	61	356x154	91	14 x6.05	0.67	0.81	18.15	533.89	28.34	5.42	1.25	76.3	9.37
	57	356x151	85	14 x5.96	0.59	0.81	16.96	514.46	27.07	5.51	1.26	73.5	9.08
	53	356x149	79	14 x5.87	0.50	0.81	15.76	494.56	25.74	5.60	1.28	70.7	8.77
12x6	62	305x158	92	12 x6.23	0.73	0.87	18.45	404.26	30.98	4.68	1.30	67.4	9.95
	57	305x155	85	12 x6.11	0.61	0.87	16.96	386.41	29.02	4.77	1.31	64.4	9.50
	52	305x152	77	12 x5.99	0.49	0.87	15.47	368.55	27.04	4.88	1.32	61.4	9.03
12x5	47	305x131	70	12 x5.17	0.67	0.65	13.98	286.58	14.37	4.53	1.01	47.8	5.56
	43	305x129	64	12 x5.07	0.58	0.65	12.80	272.32	13.44	4.61	1.02	45.4	5.30
	39	305x126	58	12 x4.98	0.48	0.65	11.60	258.14	12.56	4.72	1.04	43.0	5.04
10x6	48	254x157	71	10 x6.16	0.66	0.70	14.27	221.55	25.16	3.94	1.33	44.3	8.17
	45.5	254x154	68	10 x6.08	0.58	0.70	13.54	215.47	24.23	3.99	1.34	43.1	7.97
	43	254x153	64	10 x6.01	0.51	0.70	12.76	209.22	23.21	4.04	1.35	41.8	7.72
10x5	41.5	254x133	62	10 x5.23	0.73	0.66	12.34	190.25	14.25	3.93	1.07	38.1	5.45
	38	254x130	57	10 x5.13	0.63	0.66	11.30	181.58	13.33	4.01	1.09	36.3	5.20
	34.5	254x128	51	10 x5.03	0.52	0.66	10.26	172.91	12.40	4.10	1.10	34.6	4.93
10x4.50	34	254x114	51	10 x4.49	0.49	0.66	10.11	155.32	9.14	3.92	0.95	31.1	4.07
	31.5	254x112	47	10 x4.41	0.41	0.66	9.37	149.07	8.67	3.99	0.96	29.8	3.93
	29	254x111	43	10 x4.38	0.38	0.66	8.63	146.40	8.45	4.12	0.99	29.3	3.86
9x7	62	229x182	92	9 x7.16	0.92	0.81	18.45	226.60	47.62	3.50	1.61	50.4	13.3
	58	229x179	86	9 x7.03	0.79	0.81	17.25	218.52	45.00	3.56	1.62	48.6	12.8
	54	229x175	80	9 x6.90	0.66	0.81	16.06	210.44	42.40	3.62	1.62	46.8	12.3
9x3.75	26	229x 95	39	9 x3.75	0.50	0.50	7.74	89.02	4.38	3.39	0.75	19.8	2.34
	24.25	229x 94	36	9 x3.69	0.44	0.50	7.22	85.50	4.13	3.44	0.76	19.0	2.24
	22.5	229x 92	34	9 x3.63	0.38	0.50	6.70	82.04	3.90	3.50	0.76	18.2	2.15
8x6	38	203x154	57	8 x6.05	0.55	0.62	11.30	117.34	21.93	3.22	1.39	29.3	7.25
	36	203x152	54	8 x5.98	0.48	0.62	10.71	114.14	21.01	3.26	1.40	28.5	7.03
	34	203x150	51	8 x5.90	0.40	0.62	10.12	110.99	20.24	3.31	1.41	27.7	6.86
8x5	34	203x130	51	8 x5.12	0.56	0.62	10.12	100.98	13.71	3.16	1.16	25.2	5.36
	31.25	203x127	47	8 x5.01	0.45	0.62	9.30	96.58	12.87	3.22	1.18	24.1	5.14

8x4	28.5	203x125	42	8 x4.91	0.35	0.62	8.48	92.23	12.07	3.30	1.19	23.1	4.92
	28	203x105	42	8 x4.13	0.53	0.56	8.33	78.93	6.17	3.08	0.86	19.7	2.99
	25	203x102	37	8 x4.02	0.42	0.56	7.44	74.17	5.63	3.16	0.87	18.5	2.80
	22	203x 99	33	8 x3.91	0.31	0.56	6.55	69.40	5.22	3.26	0.89	17.4	2.67
7x3.75	22	178x 98	33	7 x3.87	0.49	0.46	6.55	47.29	4.15	2.69	0.80	13.5	2.14
	20	178x 96	30	7 x3.78	0.41	0.46	5.95	44.89	3.86	2.75	0.81	12.8	2.04
	18	178x 94	27	7 x3.70	0.32	0.46	5.36	42.43	3.57	2.81	0.82	12.1	1.93
6.25x3.50	20	159x 91	30	6.25x3.57	0.45	0.50	5.95	35.07	3.43	2.43	0.76	11.2	1.92
	18	159x 88	27	6.25x3.47	0.36	0.50	5.36	33.11	3.22	2.49	0.78	10.4	1.86
	16	159x 86	24	6.25x3.38	0.26	0.50	4.76	31.18	2.87	2.56	0.78	9.93	1.70
6x5	28	152x131	42	6 x5.14	0.64	0.50	8.33	45.64	10.75	2.34	1.14	15.2	4.18
	26	152x128	39	6 x5.04	0.54	0.50	7.73	43.84	10.07	2.38	1.14	14.6	4.00
	24	152x126	36	6 x4.94	0.44	0.50	7.14	42.04	9.44	2.43	1.15	14.0	3.82
6x3	17	152x 79	25	6 x3.09	0.39	0.50	5.06	27.55	2.21	2.33	0.66	9.18	1.43
	16	152x 77	24	6 x3.04	0.34	0.50	4.76	26.69	2.09	2.37	0.66	8.90	1.38
	15	152x 76	22	6 x2.99	0.29	0.50	4.46	25.77	1.98	2.40	0.67	8.59	1.32
6x2	14	152x 55	21	6 x2.15	0.47	0.38	4.16	18.59	0.67	2.11	0.40	6.20	0.62
	12.25	152x 53	18	6 x2.07	0.39	0.38	3.65	17.12	0.58	2.17	0.40	5.70	0.56
	10.5	152x 51	16	6 x1.99	0.31	0.38	3.12	15.64	0.50	2.24	0.40	5.21	0.50
5.50x2	12	138x 53	18	5.5 x2.10	0.42	0.38	3.57	14.18	0.60	1.99	0.41	5.15	0.57
	11	138x 52	16	5.5 x2.04	0.36	0.38	3.27	13.41	0.55	2.02	0.41	4.88	0.54
	10	138x 51	15	5.5 x1.99	0.31	0.38	2.97	12.65	0.50	2.06	0.41	4.50	0.50
5x5	28	127x132	42	5 x5.20	0.64	0.625	8.33	32.05	11.24	1.96	1.16	12.8	4.32
	25.5	127x128	38	5 x5.05	0.49	0.625	7.58	30.49	10.21	2.01	1.16	12.2	4.04
	23	127x125	34	5 x4.90	0.33	0.625	6.82	28.90	9.20	2.06	1.16	11.6	3.76
5x4.50	26	127x117	39	5 x4.62	0.62	0.58	7.74	29.24	9.35	1.94	1.10	11.7	4.05
	23.75	127x113	35	5 x4.43	0.43	0.58	7.07	27.32	8.53	1.97	1.10	10.9	3.85
	21.5	127x111	32	5 x4.35	0.35	0.58	6.39	26.44	7.77	2.03	1.10	10.6	3.57
5x3	17	127x 83	25	5 x3.25	0.50	0.46	5.06	18.22	2.46	1.90	0.70	7.28	1.51
	15.25	127x 80	23	5 x3.15	0.40	0.46	4.54	17.17	2.22	1.94	0.70	6.87	1.41
	13.5	127x 77	20	5 x3.04	0.30	0.46	4.02	16.09	1.98	2.00	0.70	6.43	1.30
4.75x1.75	10	121x 46	15	4.75x1.82	0.42	0.35	2.98	8.50	0.37	1.69	0.35	3.58	0.41
	9.25	121x 45	14	4.75x1.77	0.37	0.35	2.76	8.08	0.35	1.71	0.36	3.40	0.40
	8.5	121x 44	13	4.75x1.72	0.32	0.35	2.53	7.66	0.33	1.74	0.36	3.23	0.38
4.62x3	16	117x 84	24	4.62x3.30	0.55	0.40	4.76	14.41	2.36	1.74	0.70	6.23	1.43
	14	117x 81	21	4.62x3.17	0.42	0.40	4.17	13.35	2.06	1.79	0.70	5.77	1.30
	12	117x 77	18	4.62x3.04	0.29	0.40	3.57	12.29	1.80	1.86	0.71	5.31	1.18
4x3	14	102x 82	21	4 x3.23	0.48	0.407	4.16	9.82	2.12	1.54	0.71	4.91	1.31
	12.75	102x 80	19	4 x3.14	0.39	0.407	3.79	9.32	1.92	1.57	0.71	4.66	1.22
	11.5	102x 77	17	4 x3.04	0.30	0.407	3.42	8.83	1.74	1.61	0.71	4.42	1.14
4x1.75	10	102x 50	15	4 x1.98	0.48	0.35	2.97	6.07	0.48	1.43	0.40	3.03	0.48
	8.5	102x 48	13	4 x1.87	0.37	0.35	2.53	5.48	0.39	1.47	0.39	2.74	0.42
	7	102x 45	10	4 x1.76	0.26	0.35	2.08	4.88	0.31	1.53	0.39	2.44	0.35
3.50x3	12.5	89x 80	19	3.5 x3.14	0.45	0.30	3.72	6.80	1.93	1.35	0.72	3.88	1.23
	10.75	89x 76	16	3.5 x2.99	0.30	0.30	3.20	6.26	1.65	1.40	0.72	3.58	1.04
	9	89x 72	13	3.5 x2.84	0.15	0.30	2.68	5.73	1.39	1.46	0.72	3.27	0.98
3.50x1.50	7	89x 43	10	3.5 x1.68	0.37	0.30	2.08	3.34	0.25	1.27	0.35	1.91	0.30
	6	89x 41	9	3.5 x1.60	0.28	0.30	1.78	3.04	0.20	1.31	0.34	1.73	0.25
	5	89x 38	7	3.5 x1.51	0.20	0.30	1.49	2.74	0.17	1.36	0.34	1.57	0.23
3x3	12	76x 80	18	3 x3.16	0.47	0.40	3.57	4.73	1.98	1.15	0.74	3.15	1.25
	10.25	76x 76	15	3 x2.99	0.30	0.40	3.05	4.34	1.65	1.19	0.74	2.89	1.10
	8.5	76x 71	13	3 x2.81	0.13	0.40	2.53	3.94	1.36	1.25	0.73	2.63	0.97
3x1.25	6	76x 38	9	3 x1.49	0.40	0.25	1.75	1.94	0.15	1.05	0.29	1.29	0.20
	5	76x 36	7	3 x1.40	0.31	0.25	1.50	1.74	0.12	1.08	0.28	1.16	0.17

Notes relative to Table 3.3

Table 3.3 has been developed from information contained in a Handbook prepared by Dorman Long and Company and published in 1887.

These sections are in groups of threes, the middle section in each group being the basic section and the other two being manufactured by opening or closing the rolls. It is claimed that these two special derived sections in each group would be rolled to order providing that a sufficient quantity was specified.

It is impossible to estimate at this date how often derived sections were supplied, for this reason the properties of all 99 sections are given.

The sections all had taper flanges and were rounded at toe and root, as shown in Figure 3.7.

The properties provided are based on the following sketch:—

Area of section = A

Moment of Inertia = I

Raidus of Gyration = r

Section Modulus = Z

$$\text{Then } r_{xx} = \sqrt{\frac{I_{xx}}{A}} \qquad \text{Then } Z_{xx} = \frac{2 \times I_{xx}}{D}$$

$$r_{yy} = \sqrt{\frac{I_{yy}}{A}} \qquad Z_{yy} = \frac{2 \times I_{xx}}{B}$$

Note Information relative to radii at toe and root has been omitted as of little interest to the user.

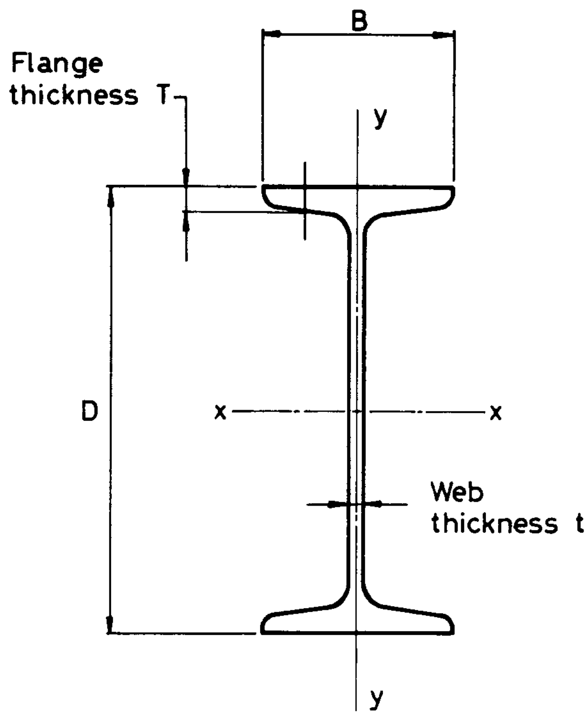


Figure 3.7 Dorman Long Beam.

Note:— It is interesting to note that the makers name is rolled into these sections.

TABLE NO.3.4 DORMAN LONG CHANNELS 1887

IMPERIAL UNITS

Size in inches DepthxBreadthxThickness	Metric Equivalent D x B x t mm	Approximate Mass/ft	Inertia on axis YY	Area
ins	mm	lbs	ins4	ins2
12.00x3.00x0.44	305x76x11	22.44	4.51	6.60
12.00x3.00x0.56	305x76x14	27.54	5.35	8.10
10.00x3.00x0.37	254x76x10	20.91*	4.24	6.15*
10.00x3.00x0.50	254x76x13	24.14	4.94	7.10
9.00x3.00x0.37	229x76x10	18.60	4.29	5.47
9.00x3.00x0.50	229x76x13	22.44	4.82	6.60
9.00x2.50x0.37	229x64x10	17.78	2.49	5.23
9.00x2.50x0.50	229x64x13	21.62	2.72	6.36
7.00x3.00x0.37	178x76x10	16.42	4.16	4.83
7.00x3.00x0.50	178x76x13	19.41	4.83	5.71
6.00x3.87x0.50	152x98x13	23.80	10.27	7.00
6.00x3.87x0.62	152x98x16	26.52	13.07	7.80
6.00x2.87x0.44	152x73x11	16.25	3.62	4.78
6.00x2.87x0.56	152x73x14	18.80	4.17	5.53
5.12x2.87x0.44	130x73x11	16.49	4.04	4.85
5.12x2.87x0.56	130x73x14	18.02	4.43	5.30
4.50x2.00x0.56	114x51x14	14.96	1.61	4.40
4.50x2.00x0.69	114x51x17	16.93	2.11	4.98
4.50x1.75x0.44	114x44x11	10.64	0.75	3.13
4.50x1.75x0.56	114x44x14	12.75	0.93	3.75
4.00x3.00x0.37	102x76x10	17.00	4.44	5.00
4.00x3.00x0.50	102x76x13	18.70	5.47	5.50
3.50x1.50x0.37	89x38x10	6.46*	0.62	1.90*
3.50x1.50x0.50	89x38x13	9.93	0.77	2.92

Note:- * Assumed values as information in handbook appears incorrect!
Mass/unit length based on 1 sq.in. of steel weighing 3.4 lbs/ft.
No details are available of Ixx for these sections

TABLE NO. 3.5	LIST OF DORMAN LONG EQUAL ANGLES	1887
IMPERIAL UNITS	See separate page for notes	L
Normal Size in ins A x B x Thickness	Normal Size in ins A x B x Thickness	Special Size in ins A x B x Thickness
8.00x8.00x1.00	3.00x3.00x0.68	4.37x4.37x0.75
8.00x8.00x0.75	3.00x3.00x0.43	4.37x4.37x0.56
8.00x8.00x0.50	3.00x3.00x0.25	4.37x4.37x0.37
6.00x6.00x1.00	2.75x2.75x0.62	4.00x4.00x0.75
6.00x6.00x0.75	2.75x2.75x0.43	4.00x4.00x0.56
6.00x6.00x0.50	2.75x2.75x0.25	4.00x4.00x0.37
5.50x5.50x1.00	2.50x2.50x0.62	3.50x3.50x0.75
5.50x5.50x0.75	2.50x2.50x0.43	3.50x3.50x0.56
5.50x5.50x0.50	2.50x2.50x0.25	3.50x3.50x0.37
5.00x5.00x0.87	2.25x2.25x0.50	3.00x3.00x0.62
5.00x5.00x0.62	2.25x2.25x0.37	3.00x3.00x0.46
5.00x5.00x0.43	2.25x2.25x0.25	3.00x3.00x0.31
4.75x4.75x0.87	2.00x2.00x0.37	2.75x2.75x0.56
4.75x4.75x0.62	2.00x2.00x0.28	2.75x2.75x0.31
4.75x4.75x0.37	2.00x2.00x0.18	2.50x2.50x0.62
4.50x4.50x0.87	1.75x1.75x0.37	2.50x2.50x0.50
4.50x4.50x0.62	1.75x1.75x0.28	
4.50x4.50x0.37	1.75x1.75x0.18	
4.00x4.00x0.68	1.50x1.50x0.31	
4.00x4.00x0.50	1.50x1.50x0.21	
4.00x4.00x0.31	1.50x1.50x0.12	
3.50x3.50x0.75	1.25x1.25x0.31	
3.50x3.50x0.50	1.25x1.25x0.21	
3.50x3.50x0.31	1.25x1.25x0.12	
3.25x3.25x0.75	1.00x1.00x0.25	
3.25x3.25x0.50	1.00x1.00x0.14	
3.25x3.25x0.31	1.00x1.00x0.09	

Note:- Normal sizes have sharp external corner as (1) in Fig.3.8 whilst special sizes have rounded external corner as (2) in Fig.3.8. This enables special section to nest in normal section.

Figure 3.8 Angle Sections.

TABLE NO. 3.6	LIST OF DORMAN LONG UNEQUAL ANGLES	1887
IMPERIAL UNITS	See separate page for notes	L
Size in ins A x B x Thickness	Size in ins A x B x Thickness	Size in ins A x B x Thickness
10.00x6.00x1.00	6.00x3.00x0.75	4.00x3.50 x0.87
10.00x6.00x0.62	6.00x3.00x0.56	4.00x3.50 x0.62
10.00x6.00x0.56	6.00x3.00x0.37	4.00x3.50 x0.37
8.00x4.75x1.00	5.50x4.00x0.87	4.00x3.00 x0.75
8.00x4.75x0.75	5.50x4.00x0.62	4.00x3.00 x0.53
8.00x4.75x0.50	5.50x4.00x0.37	4.00x3.00 x0.31
7.00x4.00x0.87	5.50x3.50x0.81	3.50x3.00 x0.68
7.00x4.00x0.65	5.50x3.50x0.59	3.50x3.00 x0.50
7.00x4.00x0.43	5.50x3.50x0.37	3.50x3.00 x0.31
7.00x3.00x0.75	5.50x3.00x0.75	3.50x2.50 x0.62
7.00x3.00x0.56	5.50x3.00x0.56	3.50x2.50 x0.46
7.00x3.00x0.37	5.50x3.00x0.37	3.50x2.50 x0.31
6.50x4.50x1.00	5.00x4.00x0.81	3.50x0.43x1.75x0.37
6.50x4.50x0.68	5.00x4.00x0.59	3.50x0.37x1.75x0.31
6.50x4.50x0.43	5.00x4.00x0.37	3.50x0.31x1.75x0.25
6.50x4.00x0.81	5.00x3.50x0.75	3.00x2.75 x0.68
6.50x4.00x0.62	5.00x3.50x0.53	3.00x2.75 x0.46
6.50x4.00x0.43	5.00x3.50x0.31	3.00x2.75 x0.25
6.50x3.00x0.75	5.00x3.00x0.75	3.00x2.50 x0.62
6.50x3.00x0.56	5.00x3.00x0.53	3.00x2.50 x0.43
6.50x3.00x0.37	5.00x3.00x0.31	3.00x2.50 x0.25
6.00x5.00x1.00	4.50x4.00x0.87	3.00x2.00 x0.56
6.00x5.00x0.68	4.50x4.00x0.62	3.00x2.00 x0.40
6.00x5.00x0.43	4.50x4.00x0.37	3.00x2.00 x0.25
6.00x4.00x0.87	4.50x3.50x0.87	2.50x2.00 x0.50
6.00x4.00x0.62	4.50x3.50x0.62	2.50x2.00 x0.37
6.00x4.00x0.37	4.50x3.50x0.37	2.50x2.00 x0.25
6.00x3.50x0.87	4.50x3.00x0.75	2.00x1.50 x0.37
6.00x3.50x0.62	4.50x3.00x0.53	2.00x1.50 x0.28
6.00x3.50x0.37	4.50x3.00x0.31	2.00x1.50 x0.18

Notes relative to Tables 3.5 and 3.6

These tables list the imperial sizes of equal and unequal angles given in the Dorman Long & Co 1887 handbook.

It can be assumed that many of these sections were available in both iron or steel and that they must have been in use for some time prior to 1887.

The design properties of these angles are not given in the handbook. Many sizes however were included in the 1962 British Standard 4 and the properties can be obtained from Table Nos 3.26 and 3.27 given later. The properties of other sizes can be approximated from these tables or calculated as follows:— (ignoring the root and toe radii). Note:— A size in BS4 1962 has been selected so that the approximation can be compared with the listed.

6" x 4" x 3/8" unequal angle

Area = (a1) + (a2)

$A = 5.625 \times 0.375 + 4 \times 0.375$

$= 2.11 + 1.5 = 3.61\ in^2$

$C_x = {}^1/_{3.61}\ [2.11 \times 3.1875 + 1.5 \times 0.1875]$

$= {}^1/_{3.61}\ [6.73 + 0.28] = {}^1/_{3.61}\ [7.01] = 1.94$ ins

$C_y = {}^1/_{3.61}\ [2.11 \times 0.1875 + 1.5 \times 2]$

$= {}^1/_{3.61}\ [0.40 + 3.0] = {}^1/_{3.61}\ [3.40] = 0.94$ ins

$I == bd^3/12 + Ay^2$

$$\therefore\ I_{xx} = \left[\frac{0.375 \times 5.625^3}{12} + 2.11 \times 1.25^2\right] + \left[\frac{4.0 \times 0.375^3}{12} + 1.5 \times 1.75^2\right]$$

$$= [\ 5.56 + 3.30 + 0.02 + 4.59\ ] = 13.47\text{ins}^4$$

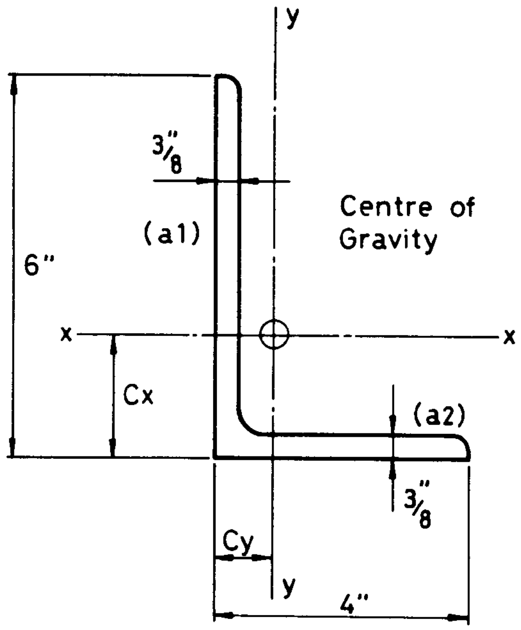
$$\therefore\ I_{yy} = \left[\frac{0.375 \times 4.0^3}{12} + 1.5 \times 1.06^2\right] + \left[\frac{5.625 \times 0.375^3}{12} + 2.11 \times 0.75^2\right]$$

$$= [2.0 + 1.68 + 0.02 + 1.19] = 4.89\text{ins}^4$$

$$r_{xx} = \sqrt{\frac{I_{xx}}{A}} = 1.93\text{ins}$$

$$r_{yy} = \sqrt{\frac{I_{yy}}{A}} = 1.16\text{ins}$$

Note:— Approximation within 1% of listed values.



6" x 4" x 3/8" unequal angle.
Properties.

A	=	3·61 ins.^{2}			
Ixx	=	13·34 ins.^{4}			
Iyy	=	4·82 ins.^{4}			
rxx	=	1·92"	ryy	=	1·15"
Cx	=	1·92"	cy	=	0·93"

Figure 3.9 Example of Angle.

TABLE NO. 3.7 PROPERTIES OF BEAMS TO BRITISH STANDARD 4. 1903

IMPERIAL UNITS See separate page for notes

Ref No.	Size D x B	Approximate Mass/ft	Metric Equivalent D x B	Metric Equivalent Mass/m	Thickness Web	Thickness Flange	Area	Mom. of Inert. X - X	Mom. of Inert. Y - Y	Rad. of Gyr. X - X	Rad. of Gyr. Y - Y	Sec. Mod. X - X	Sec. Mod. Y - Y
	ins	lbs	mm	kg	ins	ins	ins2	ins4	ins4	ins	ins	ins3	ins3
BSB 1	3 x1.50	4.0	76x 38	6	0.16	0.25	1.18	1.66	0.12	1.19	0.33	1.11	0.17
BSB 2	3 x3	8.5	76x 76	13	0.20	0.33	2.50	3.79	1.26	1.23	0.71	2.53	0.84
BSB 3	4 x1.75	5.0	102x 44	7	0.17	0.24	1.47	3.67	0.19	1.58	0.36	1.84	0.22
BSB 4	4 x3	9.5	102x 76	14	0.22	0.34	2.80	7.53	1.28	1.64	0.68	3.76	0.85
BSB 5	4.75x1.75	6.5	121x 44	10	0.18	0.33	1.91	6.77	0.26	1.88	0.37	2.85	0.30
BSB 6	5 x3	11.0	127x 76	16	0.22	0.38	3.24	13.6	1.46	2.05	0.67	5.45	0.97
BSB 7	5 x4.50	18.0	127x114	27	0.29	0.45	5.29	22.7	5.66	2.07	1.03	9.08	2.51
BSB 8	6 x3	12.0	152x 76	18	0.26	0.35	3.53	20.2	1.34	2.40	0.62	6.74	0.89
BSB 9	6 x4.50	20.0	152x114	30	0.37	0.43	5.88	34.7	5.41	2.43	0.96	11.6	2.40
BSB 10	6 x5	25.0	152x127	37	0.41	0.52	7.35	43.6	9.11	2.44	1.11	14.5	3.64
BSB 11	7 x4	16.0	178x102	24	0.25	0.39	4.71	39.2	3.41	2.89	0.85	11.2	1.71
BSB 12	8 x4	18.0	203x102	27	0.28	0.40	5.30	55.7	3.57	3.24	0.82	13.9	1.79
BSB 13	8 x5	28.0	203x127	42	0.35	0.58	8.24	89.4	10.3	3.29	1.12	22.3	4.10
BSB 14	8 x6	35.0	203x152	52	0.44	0.60	10.29	110.6	17.9	3.28	1.32	27.6	5.98
BSB 15	9 x4	21.0	229x102	31	0.30	0.46	6.18	81.1	4.20	3.62	0.82	18.0	2.10
BSB 16	9 x7	58.0	229x178	86	0.55	0.92	17.06	229.7	46.3	3.67	1.65	51.05	13.20
BSB 17	10 x5	30.0	254x127	45	0.36	0.55	8.82	145.7	9.78	4.06	1.05	29.14	3.91
BSB 18	10 x6	42.0	254x152	63	0.40	0.74	12.36	211.6	22.9	4.14	1.36	42.32	7.64
BSB 19	10 x8	70.0	254x203	104	0.60	0.97	20.58	345.0	71.6	4.09	1.87	69.01	17.9
BSB 20	12 x5	32.0	305x127	48	0.35	0.55	9.41	220.1	9.74	4.84	1.02	36.69	3.90
BSB 21	12 x6	44.0	305x152	66	0.40	0.72	12.95	315.4	22.3	4.94	1.31	52.57	7.42
BSB 22	12 x6	54.0	305x152	80	0.50	0.88	15.88	375.6	28.3	4.86	1.33	62.60	9.43
BSB 23	14 x6	46.0	356x152	69	0.40	0.70	13.53	440.6	21.6	5.71	1.26	62.95	7.20
BSB 24	14 x6	57.0	356x152	85	0.50	0.87	16.77	533.1	27.9	5.64	1.29	76.16	9.31
BSB 25	15 x5	42.0	381x127	63	0.42	0.65	12.35	428.2	11.9	5.89	0.98	57.09	4.78
BSB 26	15 x6	59.0	381x152	88	0.50	0.88	17.35	629.1	28.2	6.02	1.28	83.88	9.40
BSB 27	16 x6	62.0	406x152	92	0.55	0.85	18.23	726.0	27.1	6.31	1.22	90.74	9.02
BSB 28	18 x7	75.0	457x178	112	0.55	0.93	22.07	1150.0	46.6	7.22	1.45	127.7	13.30
BSB 29	20 x7.50	89.0	508x191	132	0.60	1.01	26.16	1671.0	62.6	7.99	1.55	167.1	16.70
BSB 30	24 x7.50	100.0	610x191	149	0.60	1.07	29.39	2655.0	66.9	9.50	1.51	221.2	17.80

TABLE NO. 3.8 PROPERTIES OF BEAMS TO BRITISH STANDARD 4 1921

IMPERIAL UNITS See separate page for notes

Ref No.	Size D x B	Approximate Mass/ft	Metric Equivalent D x B	Mass/m	Thickness Web	Flange	Area	Mom. of Inert. X - X	Y - Y	Rad. of Gyr. X - X	Y - Y	Sec. Mod. X - X	Y - Y
	ins	lbs	mm	kg	ins		ins2	ins4		ins		ins3	
NBSB 1	3 x1.50	4	76x38	6	0.16	0.25	1.18	1.66	0.13	1.19	0.33	1.11	0.17
NBSB 2	4 x1.75	5	102x44	7	0.17	0.24	1.47	3.66	0.19	1.58	0.36	1.83	0.21
NBSHB 1	4 x3	10	102x76	15	0.24	0.35	2.94	7.79	1.33	1.63	0.67	3.89	0.88
NBSB 3	4.50x2	7	114x51	10	0.19	0.32	2.06	6.65	0.38	1.80	0.43	2.96	0.38
NBSB 4	5 x2.50	9	127x64	13	0.20	0.35	2.65	10.9	0.79	2.03	0.55	4.36	0.63
NBSHB 2	5 x4.50	20	127x114	30	0.29	0.51	5.88	25.0	6.59	2.06	1.06	10.0	2.93
NBSB 5	6 x3	12	152x76	18	0.23	0.38	3.53	21.0	1.46	2.44	0.64	7.00	0.97
NBSHB 3	6 x5	25	152x127	37	0.33	0.56	7.35	45.2	9.88	2.48	1.16	15.1	3.95
NBSB 6	7 x3.50	15	178x89	22	0.25	0.40	4.42	35.9	2.41	2.85	0.74	10.3	1.38
NBSB 7	8 x4	18	203x102	37	0.28	0.40	5.30	55.9	3.51	3.24	0.81	13.9	1.75
NBSHB 4	8 x6	35	203x152	52	0.35	0.65	10.30	115.1	19.54	3.34	1.38	28.8	6.51
NBSB 8	9 x4	21	229x102	31	0.30	0.46	6.18	81.1	4.15	3.62	0.82	18.0	2.07
NBSHB 5	9 x7	50	229x178	74	0.40	0.83	14.71	208.1	40.17	3.76	1.65	46.25	11.48
NBSB 9	10 x4.50	25	254x114	37	0.30	0.51	7.35	122.3	6.49	4.08	0.94	24.47	2.88
NBSHB 6	10 x6	40	254x152	60	0.36	0.71	11.77	204.8	21.76	4.17	1.36	40.96	7.25
NBSHB 7	10 x8	55	254x203	82	0.40	0.78	16.18	288.7	54.74	4.22	1.84	57.74	13.69
NBSB 10	12 x5	30	305x127	45	0.33	0.51	8.83	206.9	8.77	4.84	1.00	34.49	3.51
NBSHB 8	12 x8	65	305x203	97	0.43	0.90	19.12	487.8	65.18	5.05	1.85	81.30	16.30
NBSB 11	13 x5	35	330x127	52	0.35	0.60	10.30	283.5	10.80	5.25	1.03	43.62	4.33
NBSB 12	14 x5.50	40	356x140	60	0.37	0.63	11.77	377.1	14.80	5.66	1.12	53.87	5.38
NBSHB 9	14 x8	70	356x203	104	0.46	0.92	20.59	705.6	66.70	5.85	1.80	100.80	16.70
NBSB 13	15 x6	45	381x152	67	0.38	0.66	13.24	491.9	19.90	6.10	1.23	65.59	6.62
NBSB 14	16 x6	50	406x152	74	0.40	0.73	14.71	618.1	22.50	6.48	1.24	77.26	7.49
NBSHB 10	16 x8	75	406x203	112	0.48	0.94	22.06	973.9	68.30	6.64	1.76	121.70	17.10
NBSB 15	18 x6	55	457x152	82	0.42	0.76	16.18	841.8	23.60	7.21	1.21	93.53	7.88
NBSHB 11	18 x8	80	457x203	119	0.50	0.95	23.53	1292.0	69.40	7.41	1.72	143.60	17.40
NBSB 16	20 x6.50	65	508x165	97	0.45	0.82	19.12	1226.0	32.60	8.01	1.31	122.60	10.00
NBSB 17	22 x7	75	559x178	112	0.50	0.83	22.06	1677.0	41.10	8.72	1.36	152.40	11.70
NBSB 18	24 x7.50	90	610x191	140	0.52	0.98	26.47	2443.0	60.40	9.61	1.51	203.60	16.10

TABLE NO.3.10 PROPERTIES OF SPECIAL BEAM TO BRITISH STANDARD 4 1932

IMPERIAL UNITS See separate page for notes

Reference No.	Size D x B	Approx. Mass/ft	Metric Equivalent D x B	Mass/m	Thickness Web	Flange	Area	Mom. of Int. X - X	Y - Y	Rad. of Gyr. X - X	Y - Y	Sec. Mod. X - X	Y - Y
	ins	lbs	mm	kg	ins		ins2	ins4		ins		ins3	
BSB 140	24x7.50	95	610x191	141	0.57	1.01	27.94	2533.0	62.5	9.52	1.50	211.1	16.7

TABLE NO. 3.9 PROPERTIES OF BEAMS TO BRITISH STANDARD 4. 1932 I

IMPERIAL UNITS See separate page for notes

Ref No.	Size D x B	Approximate Mass/ft	Metric Equivalent D x B	Mass/m	Obtain Properties from table no:-
	ins	lbs	mm	kg	
BSB 101	3 x1.50	4	76x38	6	3.7 or 3.8
BSB 102	3 x3	8.5	76x76	13	3.7
BSB 103	4 x1.75	5	102x44	7	3.7 or 3.8
BSB 104	4 x3	10	102x76	15	3.8
BSB 105	4.75x1.75	6.5	121x44	10	3.7
BSB 106	5 x3	11	127x76	16	3.7
BSB 107	5 x4.50	20	127x114	30	3.8
BSB 108	6 x3	12	152x76	18	3.7 or 3.8
BSB 109	6 x4.50	20	152x114	30	3.7
BSB 110	6 x5	25	152x127	37	3.7 or 3.8
BSB 111	7 x4	16	178x102	24	3.7
BSB 112	8 x4	18	203x102	27	3.7 or 3.8
BSB 113	8 x5	28	203x127	42	3.7
BSB 114	8 x6	35	203x152	52	3.7 or 3.8
BSB 115	9 x4	21	229x102	31	3.7 or 3.8
BSB 116	9 x7	50	229x178	74	3.8
BSB 117	10 x4.50	25	254x114	37	3.8
BSB 118	10 x5	30	254x127	45	3.7
BSB 119	10 x6	40	254x152	60	3.8
BSB 120	10 x8	55	254x203	82	3.8
BSB 121	12 x5	32	305x127	48	3.7
BSB 122	12 x6	44	305x152	66	3.7
BSB 123	12 x6	54	305x152	69	3.7
BSB 124	12 x8	65	305x203	97	3.8
BSB 125	13 x5	35	330x127	52	3.8
BSB 126	14 x6	46	356x152	69	3.7
BSB 127	14 x6	57	356x152	85	3.7
BSB 128	14 x8	70	356x203	104	3.8
BSB 129	15 x5	42	381x127	63	3.7
BSB 130	15 x6	45	381x152	67	3.8
BSB 131	16 x6	50	406x152	74	3.8
BSB 132	16 x6	62	406x152	92	3.7
BSB 133	16 x8	75	406x203	112	3.8
BSB 134	18 x6	55	457x152	82	3.8
BSB 135	18 x7	75	457x178	112	3.7
BSB 136	18 x8	80	457x203	119	3.8
BSB 137	20 x6.50	65	508x165	97	3.8
BSB 138	20 x7.50	89	508x191	132	3.7
BSB 139	22 x7	75	559x178	112	3.8
BSB 140	24 x7.50	95	610x191	141	3.10

Notes relative to Tables 3.7 to 3.10 inclusive

These tables list most of the properties of British Standard Beams over the period 1903 to 1959 when these sections were replaced by Universal Beam and Column sections.

Three separate issues of British Standard 4 are relevant viz:—

BS4 1903

British Standard Beams with reference BSB [later classed as *old* British Standard Beams] shown in Table 3.7.

BS4 1921

British Standard Beams with reference NBSB and British Standard Heavy Beams and Pillars with reference NBSHB [commonly classed as *new* British Standard Beams] shown in Table 3.8.

BS4 1932

British Standard Beams with reference BSB101 to BSB140. This consisted of a list of sizes taken from both the 1903 and 1921 ranges with *one* new section only, namely BSB140 — 24 inches x 7½ inches x 95lbs/ft.

These are shown in Table 3.9 and rather than repeat section properties reference is made to the previous tables. However, since the section reference BSB140 is new the properties are given in Table 3.10.

British Standard 4, 1903, 1921 and 1932 were of course issued before the adoption of the metric system in the United Kingdom and all properties were provided in Imperial units.

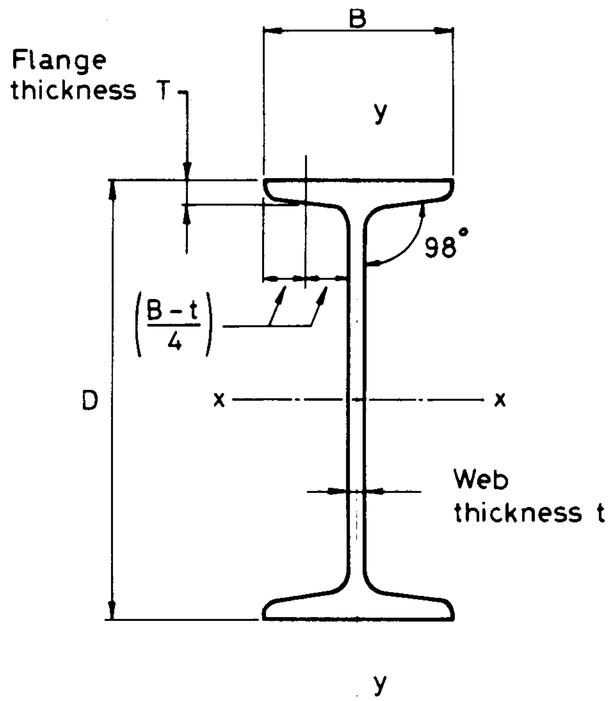


Figure 3.10 British Standard Beam.

TABLE NO. 3.11 PROPERTIES OF UNIVERSAL BEAMS TO BS4 PART 1 1962/1963

Serial Size	Mass/ft	Depth D	Breadth B	Metric Equivalent D x B	Mass/m	Thickness Web	Flange	Area	Mom. of Inert. X - X	Y - Y	Rad. of Gyr. X - X	Y - Y	Sec. Mod. X - X	Y - Y	D/T
	lbs	ins	ins	mm	kg	ins		ins2	ins4		ins		ins3		
36x16.50	260	36.24	16.56	920x421	388	0.85	1.44	76.8	17230	1021	15.0	3.7	951	123	25
	230	35.88	16.48	911x419	343	0.77	1.26	67.7	14990	870.9	14.9	3.6	836	106	29
36x12	194	36.48	12.12	927x308	289	0.77	1.26	57.1	12100	355.4	14.6	2.5	664	58.7	29
	170	36.16	12.03	919x306	253	0.68	1.10	50.0	10470	300.6	14.5	2.5	579	50.0	33
	150	35.84	11.97	910x304	224	0.63	0.94	44.2	9012	250.4	14.3	2.4	503	41.8	38
*	135	35.55	11.94	903x303	201	0.60	0.80	39.7	7801	207.4	14.0	2.3	439	34.7	45
33x11.50	152	33.50	11.57	851x294	226	0.64	1.06	44.7	8148	256.1	13.5	2.4	486	44.3	32
	130	33.10	11.51	841x292	194	0.58	0.86	38.3	6699	201.4	13.2	2.3	405	35.0	39
*	118	32.87	11.48	835x292	176	0.55	0.74	34.7	5896	178.8	13.0	2.2	359	29.8	44
30x10.50	132	30.30	10.55	770x268	197	0.62	1.00	38.8	5753	185.0	12.2	2.2	380	35.1	30
	116	30.00	10.50	762x267	173	0.56	0.88	34.1	4919	153.2	12.0	2.1	328	29.2	35
*	99	29.68	10.44	754x265	147	0.51	0.69	29.1	4049	120.2	11.8	2.0	273	23.0	43
27x10	114	27.28	10.07	693x256	170	0.57	0.93	33.5	4081	149.6	11.0	2.1	299	29.7	29
	102	27.07	10.02	688x255	152	0.52	0.83	30.0	3604	129.5	11.0	2.1	266	25.9	33
	94	26.91	9.99	684x254	140	0.49	0.75	27.7	3267	115.1	10.9	2.0	243	23.0	36
*	84	26.69	9.96	678x253	125	0.46	0.64	24.7	2828	95.9	10.7	2.0	212	19.3	42
24x12	160	24.92	12.26	633x312	238	0.73	1.24	47.1	4979	359.7	10.3	2.8	400	58.7	20
	120	24.31	12.09	618x307	179	0.56	0.93	35.3	3635	254.0	10.2	2.7	299	42.0	26
	100	24.00	12.00	610x305	149	0.47	0.78	29.4	2987	203.6	10.1	2.6	249	33.9	31
24x9	94	24.29	9.06	617x230	140	0.52	0.87	27.6	2683	102.2	9.9	1.9	221	22.6	28
	84	24.09	9.02	612x229	125	0.47	0.77	24.7	2364	88.3	9.8	1.9	196	19.6	31
	76	23.91	8.99	607x228	113	0.44	0.68	22.4	2096	76.5	9.7	1.9	175	17.0	35
*	68	23.71	8.96	602x228	101	0.42	0.58	20.0	1815	63.9	9.5	1.8	153	14.3	41
21x13	142	21.46	13.13	545x334	212	0.66	1.10	41.8	3404	386.0	9.0	3.0	317	58.8	20
	127	21.24	13.06	540x332	189	0.59	0.99	37.4	3018	338.6	9.0	3.0	284	51.8	22
	112	21.00	13.00	533x330	167	0.53	0.87	33.0	2621	289.7	8.9	3.0	250	44.6	24
21x8.25	82	21.44	8.34	545x212	122	0.50	0.84	24.1	1828	77.1	8.7	1.8	171	18.5	26
	73	21.24	8.30	540x211	109	0.46	0.74	21.5	1600	66.2	8.6	1.8	151	16.0	29
	68	21.13	8.27	537x210	101	0.43	0.69	20.0	1478	60.4	8.6	1.7	140	14.6	31
	62	20.99	8.24	533x209	92	0.40	0.62	18.2	1327	53.1	8.5	1.7	126	12.9	34
*	55	20.80	8.22	528x209	82	0.38	0.52	16.2	1138	43.9	8.4	1.7	109	10.7	40
18x7.50	66	18.40	7.59	467x193	98	0.45	0.77	19.4	1097	53.2	7.5	1.7	119	14.0	24
	60	18.25	7.56	464x192	89	0.42	0.70	17.6	984.0	47.1	7.5	1.6	108	12.5	26
	55	18.12	7.53	460x191	82	0.39	0.63	16.2	889.9	42.0	7.4	1.6	98.2	11.1	29
	50	18.00	7.50	457x191	74	0.36	0.57	14.7	800.6	37.2	7.4	1.6	89.0	9.9	32
*	45	17.86	7.48	454x190	67	0.33	0.50	13.2	704.8	31.9	7.3	1.6	78.9	8.5	36
18x6	55	18.31	6.04	465x154	82	0.42	0.74	16.2	868.7	26.3	7.3	1.3	94.9	8.7	25
	50	18.16	6.01	461x153	74	0.39	0.67	14.7	777.9	23.1	7.3	1.3	85.7	7.7	27
	45	18.00	5.98	457x152	67	0.36	0.59	13.2	685.2	19.9	7.2	1.2	76.1	6.7	31
16x7	50	16.25	7.07	413x180	74	0.38	0.63	14.7	655.4	34.8	6.7	1.5	80.7	9.8	26
	45	16.12	7.04	409x179	67	0.35	0.56	13.2	583.3	30.5	6.6	1.5	72.4	8.7	29
	40	16.00	7.00	406x178	60	0.31	0.50	11.8	515.5	26.5	6.6	1.5	64.4	7.6	32
	36	15.85	6.99	403x178	54	0.30	0.43	10.6	446.3	22.1	6.5	1.5	56.3	6.3	37
16x6	50	16.39	6.05	416x154	74	0.40	0.71	14.7	647.2	25.1	6.6	1.3	79.0	8.3	23
	45	16.23	6.02	412x153	67	0.37	0.63	13.2	571.8	21.8	6.6	1.3	70.5	7.3	26
	40	16.06	5.99	408x152	60	0.34	0.55	11.8	495.4	18.5	6.5	1.3	61.7	6.2	29
16x5.50*	31	15.84	5.61	402x142	46	0.27	0.44	9.1	374.9	12.0	6.4	1.2	47.3	4.3	36

	*	26	15.64	5.58	397x142	39	0.25	0.34	7.6	298.1	9.0	6.3	1.1	38.1	3.2	46
15x6		45	15.30	6.08	389x154	67	0.38	0.64	13.2	511.2	22.7	6.2	1.3	66.8	7.5	24
		40	15.15	6.04	385x153	60	0.34	0.57	11.8	447.6	19.6	6.2	1.3	59.1	6.5	27
		35	15.00	6.00	381x152	52	0.31	0.49	10.3	385.5	16.5	6.1	1.3	51.4	5.5	31
14x6.75		45	14.33	6.82	364x173	67	0.36	0.62	13.2	468.1	30.7	6.0	1.5	65.3	9.0	23
		38	14.12	6.78	359x172	57	0.31	0.51	11.2	385.3	24.6	5.9	1.5	54.6	7.3	28
		34	14.00	6.75	356x172	51	0.29	0.45	10.0	339.2	21.3	5.8	1.5	48.5	6.3	31
		30	13.86	6.73	352x171	45	0.27	0.38	8.8	289.6	17.5	5.7	1.4	41.8	5.2	36
14x5	*	26	13.89	4.96	353x126	39	0.26	0.42	7.6	241.6	8.0	5.6	1.0	34.8	3.2	33
	*	22	13.72	4.94	349x125	33	0.23	0.34	6.5	196.2	6.2	5.5	1.0	28.6	2.5	41
12x6.50		36	12.24	6.57	311x167	54	0.31	0.54	10.6	280.8	23.7	5.2	1.5	45.9	7.2	23
		31	12.09	6.53	307x166	46	0.27	0.47	9.1	238.4	19.8	5.1	1.5	39.4	6.1	26
		27	11.96	6.50	304x165	40	0.24	0.40	8.0	204.2	18.6	5.1	1.4	34.1	5.1	30
12x5		32	12.22	4.93	310x125	48	0.35	0.55	9.4	227.9	10.5	4.9	1.1	37.3	4.3	22
		28	12.07	4.89	307x124	42	0.31	0.48	8.2	195.2	8.8	4.9	1.0	32.3	3.6	25
		25	11.96	4.86	304x124	37	0.28	0.42	7.4	171.6	7.6	4.8	1.0	28.7	3.1	28
12x4	*	22	12.31	4.03	313x102	33	0.26	0.42	6.5	155.7	4.6	4.9	0.84	25.3	2.3	29
	*	19	12.16	4.01	309x102	28	0.24	0.35	5.6	130.1	3.7	4.8	0.81	21.4	1.8	35
	*	16.5	12.00	4.00	305x102	25	0.23	0.27	4.9	105.3	2.8	4.7	0.76	17.5	1.4	45
10x5.75		29	10.22	5.80	260x147	43	0.29	0.50	8.5	138.1	15.2	4.3	1.3	30.8	5.3	20
		25	10.08	5.76	256x146	37	0.25	0.43	7.4	133.2	12.7	4.3	1.3	26.4	4.4	23
		21	9.90	5.75	252x146	31	0.24	0.34	6.2	106.3	9.7	4.1	1.3	21.5	3.4	29
10x4	*	19	10.25	4.02	260x102	28	0.25	0.39	5.6	96.2	4.2	4.1	0.86	18.8	2.1	26
	*	17	10.12	4.01	257x102	25	0.24	0.33	5.0	81.8	3.5	4.1	0.83	16.2	1.7	31
	*	15	10.00	4.00	254x102	22	0.23	0.27	4.4	68.8	2.8	4.0	0.80	13.8	1.4	37
8x5.25		20	8.14	5.27	207x134	30	0.25	0.38	5.9	69.2	8.5	3.4	1.2	17.0	3.2	22
		17	8.00	5.25	203x133	25	0.23	0.31	5.0	56.4	6.7	3.4	1.2	14.1	2.6	26

See separate page for notes   Sections with * in 1963 addendum

TABLE NO. 3.12 PROPERTIES OF UNIVERSAL COLUMNS TO BS4 PART 1 1962

See separate page for notes

Serial Size	Mass/ft	Depth D	Breadth B	Metric Equivalent D x B	Metric Equivalent Mass/m	Thickness Web	Thickness Flange	Area	Mom. of Inert. X - X	Mom. of Inert. Y - Y	Rad. of Gyr. X - X	Rad. of Gyr. Y - Y	Sec. Mod. X - X	Sec. Mod. Y - Y	D/T
	lbs	ins	ins	mm	kg	ins	ins	ins2	ins4	ins4	ins	ins	ins3	ins3	
14x16	426	18.69	16.70	475x424	634	1.88	3.03	125.3	6610	2360	7.3	4.3	707	283	6
	370	17.94	16.48	456x419	551	1.66	2.66	108.8	5454	1986	7.1	4.3	608	241	7
	314	17.19	16.24	437x412	467	1.42	2.28	92.3	4399	1631	6.9	4.2	512	201	8
	264	16.50	16.03	419x407	393	1.21	1.94	77.6	3526	1331	6.7	4.1	427	166	9
	228	16.00	15.87	406x403	340	1.05	1.69	67.1	2942	1125	6.6	4.1	368	142	10
	193	15.50	15.71	394x399	287	0.89	1.44	56.7	2402	930.1	6.5	4.1	310	118	11
	158	15.00	15.55	381x395	235	0.73	1.19	46.5	1901	745.0	6.4	4.0	253	95.8	13
Column Core	320	16.81	16.71	427x424	477	1.89	2.09	94.1	3714	1635	6.6	4.2	493	196	8
14x14.50	136	14.75	14.74	375x374	202	0.66	1.06	40.0	1593	567.8	6.3	3.8	216	77.0	14
	119	14.50	14.65	368x372	177	0.57	0.94	35.0	1373	491.8	6.3	3.8	189	67.1	16
	103	14.25	14.58	362x370	153	0.50	0.81	30.3	1166	419.7	6.2	3.7	164	57.6	18
	87	14.00	14.50	356x368	129	0.42	0.69	25.6	966.9	349.7	6.2	3.7	138	48.2	20
12x12	190	14.38	12.67	365x322	283	1.06	1.74	55.9	1893	589.7	5.8	3.3	263	93.1	8
	161	13.88	12.52	353x318	240	0.91	1.49	47.4	1542	486.3	5.7	3.2	222	77.7	9
	133	13.38	12.37	340x314	198	0.76	1.24	39.1	1221	389.9	5.6	3.2	183	63.1	11
	106	12.88	12.23	327x311	158	0.62	0.99	31.2	930.7	300.9	5.5	3.1	145	49.2	13
	92	12.62	12.16	321x309	137	0.55	0.86	27.1	788.9	256.4	5.4	3.1	125	42.2	15
	79	12.38	12.08	315x307	118	0.47	0.74	23.3	663.1	216.4	5.3	3.1	107	35.8	17
	65	12.12	12.00	308x305	97	0.39	0.61	19.1	533.4	174.6	5.3	3.0	88.0	29.1	20
10x10	112	11.38	10.42	289x265	167	0.76	1.25	32.9	718.7	235.4	4.7	2.7	126	45.2	9
	89	10.88	10.28	276x261	132	0.62	1.00	26.2	542.4	180.6	4.6	2.6	99.7	35.2	11
	72	10.50	10.17	267x258	107	0.51	0.81	21.2	420.7	141.8	4.5	2.6	80.1	27.9	13
	60	10.25	10.08	260x256	89	0.42	0.68	17.7	343.7	116.5	4.4	2.6	67.1	23.1	15
	49	10.00	10.00	254x254	73	0.34	0.56	14.4	272.9	93.0	4.4	2.5	54.6	18.6	18
8x8	58	8.75	8.22	222x209	86	0.51	0.81	17.1	227.3	74.9	3.7	2.1	52.0	18.2	11
	48	8.50	8.12	216x206	71	0.41	0.68	14.1	183.7	60.9	3.6	2.1	43.2	15.0	12
	40	8.25	8.08	210x205	60	0.37	0.56	11.8	146.3	49.0	3.5	2.0	35.5	12.1	15
	35	8.12	8.03	206x204	52	0.32	0.49	10.3	126.5	42.5	3.5	2.0	31.1	10.6	17
	31	8.00	8.00	203x203	46	0.29	0.43	9.1	109.7	37.0	3.5	2.0	27.4	9.2	19
6x6	25	6.37	6.08	162x154	37	0.32	0.45	7.4	53.3	17.0	2.7	1.5	16.7	5.6	14
	20	6.20	6.02	158x153	30	0.26	0.37	5.9	41.9	13.4	2.7	1.5	13.5	4.5	17
	15.7	6.00	6.00	152x152	23	0.24	0.27	4.6	30.3	9.7	2.6	1.5	10.1	3.2	22

TABLE NO.3.13 IMPERIAL PROPERTIES OF EXTRA BEAMS TO BS4 PART 1 1962/1972

Serial Size	Mass/ft	Depth D	Breadth B	Metric Equivalent D x B	Metric Equivalent Mass/m	Thickness Web	Thickness Flange	Area	Mom. of Inert. X - X	Mom. of Inert. Y - Y	Rad. of Gyr. X - X	Rad. of Gyr. Y - Y	Sec. Mod. X - X	Sec. Mod. Y - Y	D/T
	lbs	ins	ins	mm	kg	ins	ins	ins2	ins4	ins4	ins	ins	ins3	ins3	
24x7	61	23.72	7.02	603x178	91	0.42	0.59	18.0	1537	34.3	9.3	1.4	129.6	9.8	40
	55	23.55	7.00	598x178	82	0.40	0.50	16.2	1340	28.9	9.1	1.3	113.8	8.3	47
21x6.50	49	20.82	6.52	529x166	73	0.37	0.53	14.4	970.9	24.7	8.2	1.3	93.3	7.6	39
	44	20.66	6.50	525x165	66	0.35	0.45	13.0	842.9	20.7	8.1	1.3	81.6	6.4	46
18x6	40	17.90	6.02	455x153	60	0.32	0.52	11.8	611.8	19.1	7.2	1.3	68.4	6.3	34
	35	17.71	6.00	450x152	52	0.30	0.43	10.3	512.8	15.5	7.1	1.2	57.9	5.2	41

TABLE NO.3.16 AMENDMENT No 1 TO BS4 1975

Imperial Serial Size & Mass	Delete from Table No.	Metric Serial Size & Mass
24x 7 x 61 lbs/ft	3.13 and 3.14	610x178x 91 kg/m
24x 7 x 55 lbs/ft	3.13 and 3.14	610x178x 82 kg/m
21x13 x142 lbs/ft	3.11 and 3.14	533x330x212 kg/m
21x13 x127 lbs/ft	3.11 and 3.14	533x330x189 kg/m
21x13 x112 lbs/ft	3.11 and 3.14	533x330x167 kg/m
21x 6.50x 49 lbs/ft	3.13 and 3.14	533x165x 73 kg/m
21x 6.50x 44 lbs/ft	3.13 and 3.14	533x165x 66 kg/m
16x 6 x 50 lbs/ft	3.11 and 3.14	406x152x 74 kg/m
16x 6 x 45 lbs/ft	3.11 and 3.14	406x152x 67 kg/m
16x 6 x 40 lbs/ft	3.11 and 3.14	406x152x 60 kg/m
15x 6 x 45 lbs/ft	3.11 and 3.14	381x152x 67 kg/m
15x 6 x 40 lbs/ft	3.11 and 3.14	381x152x 60 kg/m
15x 6 x 35 lbs/ft	3.11 and 3.14	381x152x 52 kg/m

TABLE NO. 3.14 PROPERTIES OF UNIVERSAL BEAMS TO BS4 PART 1 1972

See separate page for notes

Serial Size	Mass/m	Depth D	Breadth B	Imperial Equivalent D x B	Imperial Equivalent Mass/ft	Thickness Web	Thickness Flange	Area	Mom. of Inert. X - X	Mom. of Inert. Y - Y	Rad. of Gyr. X - X	Rad. of Gyr. Y - Y	Sec. Mod. X - X	Sec. Mod. Y - Y	D/T
	kg	mm	mm	ins	lbs	mm		cm2	cm4		cm		cm3		
914x419	388	920.5	420.5	36.2x16.6	260	21.5	36.6	494	717300	42480	38.1	9.3	15590	2021	25
	343	911.4	418.5	35.9x16.5	230	19.4	32.0	437	623900	36250	37.8	9.1	13690	1733	29
914x305	289	926.6	307.8	36.5x12.1	194	19.6	32.0	369	503800	14790	37.0	6.3	10870	961.3	29
	253	918.5	305.5	36.2x12.0	170	17.3	27.9	323	435800	12510	36.8	6.2	9490	819.2	33
	224	910.3	304.1	35.8x12.0	150	15.9	23.9	285	375100	10430	36.3	6.1	8241	685.6	38
	201	903.0	303.4	35.6x11.9	135	15.2	20.2	256	324700	8632	35.6	5.8	7192	569.1	45
838x292	226	850.9	293.8	33.5x11.6	152	16.1	26.8	288	339100	10660	34.3	6.1	7971	725.9	32
	194	840.7	292.4	33.1x11.5	130	14.7	21.7	247	278800	8384	33.6	5.8	6633	573.6	39
	176	834.9	291.6	32.9x11.5	118	14.0	18.8	224	245400	7111	33.1	5.6	5879	487.6	44
762x267	197	769.6	268.0	30.3x10.6	132	15.6	25.4	251	239500	7699	30.9	5.5	6223	574.6	30
	173	762.0	266.7	30.0x10.5	116	14.3	21.6	220	204700	6376	30.5	5.4	5374	478.1	35
	147	753.9	265.3	29.7x10.4	99	12.9	17.5	188	168500	5002	30.0	5.2	4471	377.1	43
686x254	170	692.9	255.8	27.3x10.1	114	14.5	23.7	216	169800	6225	28.0	5.4	4902	486.8	29
	152	687.6	254.5	27.1x10.0	102	13.2	21.0	194	150000	5391	27.8	5.3	4364	423.7	33
	140	683.5	253.7	26.9x10.0	94	12.4	19.0	178	136000	4789	27.6	5.2	3979	577.5	36
	125	677.9	253.0	26.7x10.0	84	11.7	16.2	159	117700	3992	27.2	5.0	3472	515.5	42
610x305	238	633.0	311.5	24.9x12.3	160	18.6	31.4	304	207300	14970	26.1	7.0	6549	961.3	20
	179	617.5	307.0	24.3x12.1	120	14.1	23.6	228	151300	10570	25.8	6.8	4901	688.6	26
	149	609.6	304.8	24.0x12.0	100	11.9	19.7	190	124300	8471	25.6	6.7	4079	555.9	31
610x229	140	617.0	230.1	24.3x 9.1	94	13.1	22.1	178	111700	4253	25.0	4.9	3620	369.6	28
	125	611.9	229.0	24.1x 9.0	84	11.9	19.6	159	98410	3676	24.8	4.8	3217	321.1	31
	113	607.3	228.2	23.9x 9.0	76	11.2	17.3	144	87260	3184	24.6	4.7	2874	279.1	35
	101	602.2	227.6	23.7x 9.0	68	10.6	14.8	129	75550	2658	24.2	4.5	2509	233.6	41
610x178	91	602.5	178.4	23.7x 7.0	61	10.6	15.0	116	63970	1427	23.5	3.5	2124	160.0	40
	82	598.2	177.8	23.6x 7.0	55	10.1	12.8	104	55780	1203	23.1	3.4	1865	135.3	47
533x330	212	545.1	333.6	21.5x13.1	142	16.7	27.8	270	141700	16060	22.9	7.7	5199	963.2	20
	189	539.5	331.7	21.2x13.1	127	14.9	25.0	241	125600	14090	22.8	7.6	4657	849.6	22
	167	533.4	330.2	21.0x13.0	112	13.4	22.0	213	109100	12060	22.6	7.5	4091	730.3	24
533x210	122	544.6	211.9	21.4x 8.3	82	12.8	21.3	156	76080	3208	22.1	4.5	2794	302.8	26
	109	539.5	210.7	21.2x 8.3	73	11.6	18.8	138	66610	2755	21.9	4.5	2469	261.5	29
	101	536.7	210.1	21.1x 8.3	68	10.9	17.4	129	61530	2512	21.8	4.4	2293	239.2	31
	92	533.1	209.3	21.0x 8.2	62	10.2	15.6	118	55230	2212	21.7	4.3	2072	211.3	24
	82	528.3	208.7	20.8x 8.2	55	9.6	13.2	104	47360	1826	21.3	4.2	1793	175.0	40
533x165	73	528.8	165.6	20.8x 6.5	49	9.3	13.5	93.0	40410	1027	20.8	3.3	1528	124.1	39
	66	524.8	165.1	20.7x 6.5	44	8.8	11.5	83.6	35080	863	20.5	3.2	1337	104.5	46
457x191	98	467.4	192.8	18.4x 7.6	66	11.4	19.6	125	45650	2216	19.1	4.2	1954	229.9	24
	89	463.6	192.0	18.3x 7.6	60	10.6	17.7	114	40960	1960	19.0	4.2	1767	204.2	26
	82	460.2	191.3	18.1x 7.5	55	9.9	16.0	104	37040	1746	18.8	4.1	1610	182.6	29
	74	457.2	190.5	18.0x 7.5	50	9.1	14.5	94.9	33320	1547	18.7	4.0	1458	162.4	32
	67	453.6	189.9	17.9x 7.5	45	8.5	12.7	85.4	29340	1328	18.5	4.0	1293	139.9	36
457x152	82	465.1	153.5	18.6x 6.0	55	10.7	18.9	104.4	36160	1093	18.6	3.2	1555	142.5	85
	74	461.3	152.7	18.2x 6.0	50	9.9	17.0	94.9	32380	963	18.5	3.2	1404	126.1	27
	67	457.2	151.9	18.0x 6.0	45	9.1	15.0	85.3	28520	829	18.3	3.1	1248	109.1	31
	60	454.7	152.9	17.9x 6.0	40	8.0	13.3	75.9	25460	794	18.3	3.2	1120	104.0	34
	52	449.8	162.4	17.7x 6.0	35	7.6	10.9	66.5	21350	645	17.9	3.1	949.0	84.6	41
406x178	74	412.8	179.7	16.3x 7.1	50	9.7	16.0	94.9	27280	1448	17.0	3.9	1322	161.2	26

	67	409.4	178.8	16.1x 7.0	45	8.8	14.3	85.4	24280	1869	16.9	3.9	1186	141.9	29
	60	406.4	177.8	16.0x 7.0	40	7.8	12.8	76.1	21520	1108	16.8	3.8	1059	124.7	32
	54	402.6	177.6	15.9x 7.0	36	7.6	10.9	68.3	18580	922	16.5	3.7	922.8	103.8	37
406x152	74	416.3	153.7	16.4x 6.1	50	10.1	18.1	94.8	26940	1047	16.9	3.3	1294	136.2	23
	67	412.2	152.9	16.2x 6.0	45	9.3	16.0	85.3	23800	908	16.7	3.3	1155	118.8	26
	60	407.9	152.2	16.1x 6.0	40	8.6	13.9	75.8	20520	768	16.5	3.2	1011	100.9	29
406x140	46	402.3	142.4	15.8x 5.6	31	6.9	11.2	58.9	15600	500	16.3	2.9	775.6	70.3	36
	39	397.3	141.8	15.6x 5.6	26	6.3	8.6	49.3	12410	373	15.9	2.8	624.7	52.6	46
381x152	67	388.6	154.3	15.3x 6.1	45	9.7	16.3	85.4	21280	947	15.5	3.3	1095	122.7	24
	60	384.8	153.4	15.2x 6.0	40	8.7	14.4	75.9	18630	814	15.7	3.3	968.4	106.2	27
	52	381.0	152.4	15.0x 6.0	35	7.8	12.4	66.4	16050	685	15.8	3.2	842.3	90.0	31
356x171	67	364.0	173.2	14.3x 6.8	45	9.1	15.7	85.3	19480	1278	15.1	3.9	1071	147.6	23
	57	358.6	172.1	14.1x 6.8	38	8.0	13.0	72.1	16040	1026	14.9	3.8	894.3	119.2	28
	51	355.6	171.5	14.0x 6.8	34	7.3	11.5	64.5	14120	885	14.8	3.7	794.0	103.3	31
	45	352.0	171.0	13.9x 6.7	30	6.9	9.7	56.9	12050	730	14.6	3.6	684.7	85.4	36
356x127	39	352.8	126.0	13.9x 5.0	26	6.5	10.7	49.3	10050	333	14.3	2.6	570.0	52.9	33
	33	348.5	125.4	13.7x 4.9	22	5.9	8.5	41.7	8167	257	14.0	2.5	468.7	41.0	41
305x165	54	310.9	166.8	12.2x 6.6	36	7.7	13.7	68.3	11690	988	13.1	3.8	751.8	118.5	23
	46	307.1	165.7	12.1x 6.5	31	6.7	11.8	58.8	9924	825	13.0	3.7	646.4	99.5	26
	40	303.8	165.1	12.0x 6.5	27	6.1	10.2	51.4	8500	691	12.9	3.7	559.6	83.7	30
305x127	48	310.4	125.2	12.2x 4.9	32	8.9	14.0	60.8	9485	438	12.5	2.7	611.1	69.9	22
	42	306.6	124.3	12.1x 4.9	28	8.0	12.1	53.1	8124	367	12.4	2.6	530.0	59.0	25
	37	303.8	123.5	12.0x 4.9	25	7.2	10.7	47.4	7143	316	12.3	2.6	470.3	51.1	28
305x102	33	312.7	102.4	12.3x 4.0	22	6.6	10.8	41.8	6482	189	12.5	2.1	414.6	37.0	29
	28	308.9	101.9	12.2x 4.0	19	6.1	8.9	36.3	5415	153	12.2	2.1	350.7	30.0	35
	25	304.8	101.6	12.0x 4.0	16.5	5.8	6.8	31.4	4381	116	11.8	1.9	287.5	22.9	45
254x146	43	259.6	147.3	10.2x 5.8	29	7.3	12.7	55.0	6546	633	10.9	3.4	504.3	86.0	20
	37	256.0	146.4	10.1x 5.8	25	6.4	10.9	47.4	5544	528	10.8	3.3	433.1	72.1	23
	31	251.5	146.1	9.9x 5.8	21	6.1	8.6	39.9	4427	406	10.5	3.2	352.1	55.5	29
254x102	28	260.4	102.1	10.3x 4.0	19	6.4	10.0	36.2	4004	174	10.3	2.2	307.6	34.1	26
	25	257.0	101.9	10.1x 4.0	17	6.1	8.4	32.1	3404	144	10.3	2.1	264.9	28.2	31
	22	254.0	101.6	10.0x 4.0	15	5.8	6.8	28.4	2863	116	10.0	2.0	225.4	22.8	37
203x133	30	206.8	133.8	8.1x 5.3	20	6.3	9.6	38.0	2880	354	8.7	3.1	278.5	52.9	22
	25	203.2	133.4	8.0x 5.3	17	5.8	7.8	32.3	2348	280	8.5	2.9	231.1	41.9	26

TABLE NO. 3.15 · PROPERTIES OF UNIVERSAL COLUMNS TO BS4 PART 1 1972

See separate page for notes

Serial Size	Mass/m	Depth D	Breadth B	Imperial D x B	Equivalent Mass/ft	Thickness Web	Thickness Flange	Area	Mom. of Inert. X - X	Mom. of Inert. Y - Y	Rad. of Gyr. X - X	Rad. of Gyr. Y - Y	Sec. Mod. X - X	Sec. Mod. Y - Y	D/T
	kg	mm	mm	ins	lbs	mm		cm2	cm4		cm		cm3		
356x406	634	474.7	424.1	18.7x16.7	426	47.6	77.0	808.1	275100	98210	18.5	11.0	11590	4632	6
	551	455.7	418.5	17.9x16.5	370	42.0	67.5	701.8	227000	82670	18.0	10.9	9964	3951	7
	467	436.6	412.4	17.2x16.2	314	35.9	58.0	595.5	183100	67910	17.5	10.7	8388	3293	8
	393	419.1	407.0	16.5x16.0	264	30.6	49.2	500.9	146800	55410	17.1	10.5	7004	2723	9
	340	406.4	403.0	16.0x15.9	228	26.5	42.9	432.7	122500	46820	16.8	10.4	6027	2324	10
	287	393.7	399.0	15.5x15.7	193	22.6	36.5	366.0	99990	38710	16.5	10.3	5080	1940	11
	235	381.0	395.0	15.0x15.6	158	18.5	30.2	299.8	79110	38000	16.2	10.2	4153	1570	13
Column Core	477	427.0	424.4	16.8x16.7	320	48.0	53.2	607.2	172400	68060	16.8	10.6	8075	3207	8
356x368	202	374.7	374.4	14.8x14.7	136	16.8	27.0	257.9	66310	23630	16.0	9.6	3540	1262	14
	177	368.3	372.1	14.5x14.7	119	14.5	23.8	225.7	57150	20470	15.9	9.5	2104	1100	16
	153	362.0	370.2	14.3x14.6	103	12.6	20.7	195.2	48530	17470	15.8	9.5	2681	943.8	18
	129	355.6	368.3	14.0x14.5	87	10.7	17.5	164.9	40250	14560	15.6	9.4	2264	790.4	20
305x305	283	365.3	321.8	14.4x12.7	190	26.9	44.1	360.4	78780	24550	14.8	8.3	4314	1525	8
	240	352.6	317.9	13.9x12.5	161	23.0	37.7	305.6	64180	20240	14.5	8.1	3641	1273	9
	198	339.9	314.1	13.4x12.4	133	19.2	31.4	252.3	50830	16230	14.2	8.0	2991	1034	11
	158	327.2	310.6	12.9x12.2	106	15.7	25.0	201.2	38740	12520	13.9	7.9	2368	806.3	13
	137	320.5	308.7	12.6x12.2	92	13.8	21.7	174.6	32840	10670	13.7	7.8	2049	691.4	15
	118	314.5	306.8	12.4x12.1	79	11.9	18.7	149.8	27600	9006	13.6	7.8	1755	587.0	17
	97	307.8	304.8	12.1x12.0	65	9.9	15.4	123.3	22200	7268	13.4	7.7	1442	476.9	20
254x254	167	289.1	264.5	11.4x10.4	112	19.2	31.7	212.4	29910	9796	11.9	6.8	2070	740.6	9
	132	276.4	261.0	10.9x10.3	89	15.6	25.1	167.7	22420	7444	11.6	6.7	1622	570.4	11
	107	266.7	258.3	10.5x10.2	72	13.0	20.5	136.6	17510	5901	11.3	6.6	1313	456.9	13
	89	260.4	255.9	10.3x10.1	60	10.5	17.3	114.0	14310	4849	11.2	6.5	1099	378.9	15
	73	254.0	254.0	10.0x10.0	49	8.6	14.2	92.9	11360	3873	11.1	6.5	894.5	305.0	18
203x203	86	222.3	208.8	8.8x 8.2	58	13.0	20.5	110.1	9462	3119	9.3	5.3	851.5	298.7	11
	71	215.9	206.2	8.5x 8.1	48	10.3	17.3	91.1	7647	2536	9.2	5.3	708.4	246.0	12
	60	209.6	205.2	8.3x 8.1	40	9.3	14.2	75.8	6088	2041	9.0	5.2	581.1	199.0	15
	52	206.2	203.9	8.1x 8.0	35	8.0	12.5	66.4	5263	1770	8.9	5.2	510.4	173.6	17
	46	203.2	203.2	8.0x 8.0	31	7.3	11.0	58.8	4564	1539	8.8	5.1	449.2	151.5	19
152x152	37	161.8	154.4	6.4x 6.1	25	8.1	11.5	47.4	2218	709	6.8	3.9	274.2	91.8	14
	30	157.5	152.9	6.2x 6.0	20	6.6	9.4	38.2	1742	558	6.8	3.8	221.2	73.1	17
	23	152.4	152.4	6.0x 6.0	15.7	6.1	6.8	29.8	1263	403	6.5	3.7	165.7	53.0	22

Notes relative to Tables 3.11 to 3.16 inclusive

Following upon the introduction of Universal Beam and Column sections in 1959, BS4 was amended to cover these sections and the specification split into two parts. Hence BS4 Part A, 1959 covered angles and tees etc whilst BS4 Part B, 1959 covered Universal Beam and Column sections together with a limited range of Broad Flange Beams.

In 1962 BS4 Part 1 was issued to cover the range of Universal Beam and Column sections which were considered, after initial use of the sections, to meet the then known requirements. [With an addendum in 1963 listing extra sizes].

Tables 3.11 and 3.12 give the imperial properties of the BS4 Part 1 1962/63 sections, and whilst there were a number of further minor additions – which are given in Table 3.13 metric equivalents of the imperial properties were given in a subsequent amendment ie BS4 Part 1 1972. These properties are given in Tables 3.14 and 3.15.

The Universal Beams given in these tables are shaped as Fig.3.11. except for 12 x 4 and 10 x 4 where the angle is 91°–9′.

Note:- over a period the flanges of UBs have been made parallel but in no cases are the properties reduced from those listed.

Universal Columns were made from the outset with parallel flanges and the properties given in Tables 3.12 and 3.15 are based on this shape.

In 1975 an amendment to BS4 Part 1, 1972 was issued deleting a number of beams. These are shown in Table 3.16.

Notes relative to Tables 3.17 to 3.20 inc

Table 3.17 lists the essential design properties for single joist compound column sections as sketch a below.

Table 3.18 lists the same design properties for double joist compound column sections as sketch a below.

In compiling the properties of compound column sections gross values of area and inertia have been used with no deduction for rivet holes.

Table 3.19 lists the essential design properties for single joist compound girder sections as sketch a below.

Table 3.20 lists the same properties for double joist compound girder sections as sketch b below.

In compiling the properties of compound girder sections gross area without deduction for rivet holes is given but in calculating the section modulus deduction has been made for rivet holes.

The mass per unit length for *all* compound sections includes an allowance for rivet heads.

It must be noted that the compounds listed in the four tables are only a selection from the full possible range which is too extensive to present in this publication.

Since rivetted compounds are a form of construction related to the period before the introduction of Universal Beam and Column sections, and were substantially obsolete before the change to metric in the industry, no attempt has been made to tabulate metric conversions of the data, except to list the overall size and mass/m.

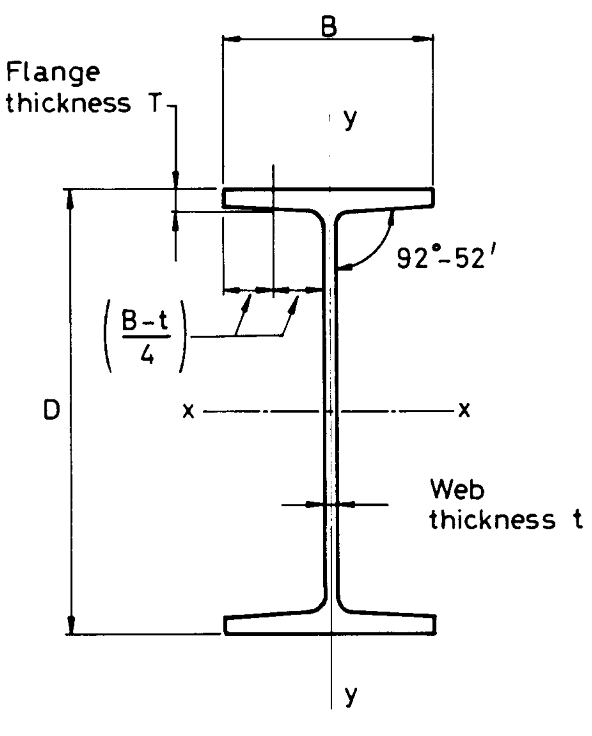


Figure 3.11 Universal Beam.

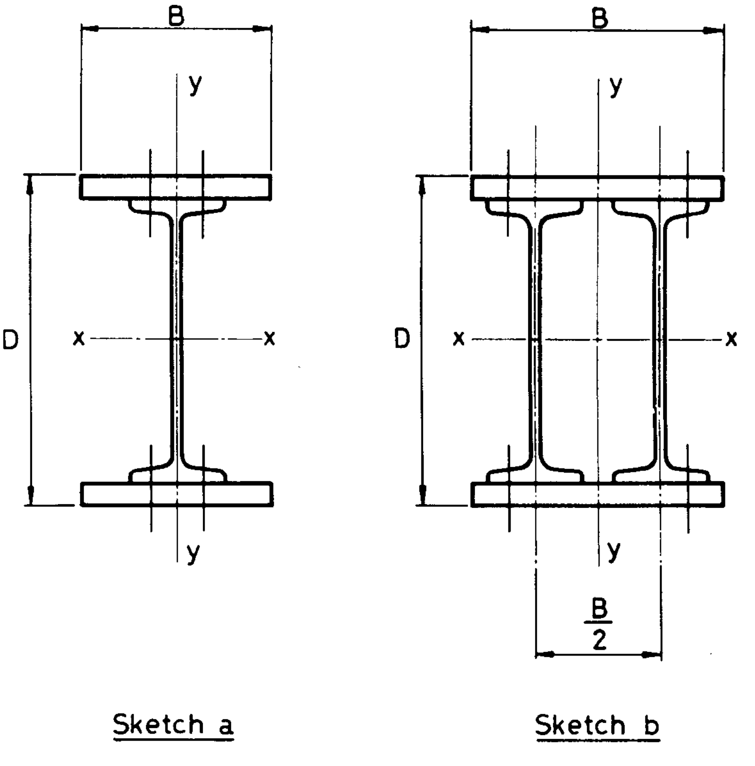


Figure 3.12 Compound Girders and Columns.

TABLE NO.3.17 PROPERTIES OF COMPOUND STANCHION SIZES USING 1932 BEAMS
IMPERIAL UNITS See separate page for notes

Size D x B		Composed of One joist	Plates ea flange	Mass/ft	Metric Equivalent D x B	Mass/m	Area	Rad. of Gyr. Y - Y	X - X	Sec. Mod. Y - Y	X - X
ins			ins	lbs	mm	kg	ins2	ins		ins3	
22	x14	18x8x50	14x2	274.0	559x356	408	79.5	3.5	9.3	140.6	628.2
21	x14		14x1.50	226.4	533x356	337	65.5	3.4	9.0	107.9	504.1
20	x14		14x1	178.8	508x356	266	51.5	3.2	8.6	75.3	382.1
19.50	x14		14x0.75	155.0	495x356	231	44.5	3.0	8.4	58.9	321.9
19	x14		14x0.50	131.2	483x356	195	37.5	2.8	8.2	42.6	262.1
22	x12	18x6x55	12x2	220.5	559x305	328	64.2	3.1	9.4	99.9	514.3
21	x12		12x1.50	179.7	533x305	267	52.2	3.0	9.1	75.9	406.7
20	x12		12x1	138.9	508x305	207	40.2	2.8	8.7	51.9	301.0
19.50	x12		12x0.75	118.5	495x305	176	34.2	2.7	8.4	39.9	248.7
19	x12		12x0.50	98.1	483x305	146	28.2	2.4	8.1	27.9	196.7
20	x14	16x8x75	14x2	269.0	508x356	400	78.1	3.6	8.4	140.4	552.9
19	x14		14x1.50	221.4	483x356	329	64.1	3.4	8.1	107.8	441.8
18	x14		14x1	173.8	457x356	259	50.1	3.2	7.7	75.1	333.2
17.50	x14		14x0.75	150.0	445x356	223	43.1	3.1	7.5	58.8	279.8
17	x14		14x0.50	126.2	432x356	188	36.1	2.9	7.3	42.4	226.7
20	x12	16x6x62	12x2	227.4	508x305	338	66.2	3.0	8.4	100.5	462.9
19	x12		12x1.50	186.6	483x305	278	54.2	2.9	8.0	76.5	367.2
18	x12		12x1	145.8	457x305	217	42.2	2.7	7.6	52.5	273.5
17.50	x12		12x0.75	125.4	445x305	187	36.2	2.6	7.4	40.5	227.2
17	x12		12x0.50	105.0	432x305	156	30.2	2.4	7.1	28.5	181.4
20	x12	16x6x50	12x2	215.5	508x305	321	62.7	3.1	8.5	99.7	452.2
19	x12		12x1.50	174.7	483x305	260	50.7	3.0	8.2	75.7	355.9
18	x12		12x1	133.9	457x305	199	38.7	2.8	7.8	51.7	261.6
17.50	x12		12x0.75	113.5	445x305	169	32.7	2.7	7.6	39.7	215.0
17	x12		12x0.50	93.1	432x305	139	26.7	2.5	7.3	27.7	168.8
19	x12	15x6x45	12x2	210.5	483x305	313	61.2	3.1	8.1	99.3	418.5
18	x12		12x1.50	169.7	457x305	253	49.2	3.0	7.7	75.3	327.7
17	x12		12x1	128.9	432x305	192	37.2	2.9	7.4	51.3	238.8
16.50	x12		12x0.75	108.5	419x305	161	31.2	2.8	7.2	39.3	195.0
16	x12		12x0.50	88.1	406x305	131	25.2	2.6	6.9	27.3	151.6
18	x14	14x8x70	14x2	264.0	457x356	393	76.6	3.6	7.5	140.2	478.7
17	x12		14x1.50	216.4	432x356	322	62.6	3.5	7.2	107.5	380.7
16	x14		14x1	168.8	406x356	251	48.6	3.3	6.9	74.9	285.4
15.50	x14		14x0.75	145.0	394x356	216	41.6	3.1	6.7	58.5	238.6
15	x14		14x0.50	121.2	381x356	180	34.6	2.9	6.5	42.2	192.2
18	x12	14x6x57	12x2	222.5	457x305	331	64.8	3.1	7.5	100.7	402.4
17	x12		12x1.50	181.7	432x305	270	52.8	3.0	7.2	76.7	317.9
16	x12		12x1	140.9	406x305	210	40.8	2.8	6.8	52.7	235.7
15.50	x12		12x0.75	120.5	394x305	179	34.8	2.7	6.6	40.7	195.3
15	x12		12x0.50	100.1	381x305	149	28.8	2.4	6.4	28.7	155.2
18	x12	14x6x46	12x2	211.7	457x305	315	61.6	3.1	7.6	99.6	392.3
17	x12		12x1.50	170.9	432x305	254	49.6	3.0	7.3	75.6	307.2
16	x12		12x1	130.1	406x305	194	37.6	2.9	6.9	51.6	224.3
15.50	x12		12x0.75	109.7	394x305	163	31.6	2.7	6.7	39.6	183.5
15	x12		12x0.50	89.3	381x305	133	25.6	2.5	6.5	27.6	143.1
15	x14	12x8x65	14x1.50	211.4	381x356	315	61.1	3.5	6.3	107.3	321.2
14	x14		14x1	163.8	356x356	244	47.1	3.3	6.0	74.6	239.0
13.50	x14		14x0.75	140.0	343x356	208	40.1	3.2	5.8	58.3	198.8
13	x14		14x0.50	116.2	330x356	173	33.1	3.0	5.6	42.0	159.2
15	x12	12x6x54	12x1.50	178.7	381x305	266	51.9	3.0	6.2	76.7	269.7
14	x12		12x1	137.9	356x305	205	39.9	2.8	5.9	52.7	198.8
13.50	x12		12x0.75	117.5	343x305	175	33.9	2.7	5.7	40.7	164.2
13	x12		12x0.50	97.1	330x305	145	27.9	2.5	5.5	28.7	130.0
15	x12	12x6x44	12x1.50	168.9	381x305	251	49.0	3.0	6.3	75.7	261.8
14	x12		12x1	128.1	356x305	190	37.0	2.9	6.0	51.7	190.4
13.50	x12		12x0.75	107.7	343x305	160	31.0	2.8	5.8	39.7	155.4
13	x12		12x0.50	87.3	330x305	130	25.0	2.6	5.6	27.7	120.9
13	x14	10x8x55	14x1.50	201.4	330x356	300	58.2	3.6	5.4	105.8	259.3
12	x14		14x1	153.8	305x356	229	44.2	3.4	5.1	73.2	189.7
11.50	x14		14x0.75	130.0	292x356	193	37.2	3.3	4.9	56.8	155.9
11	x14		14x0.50	106.2	279x356	158	30.2	3.1	4.7	40.5	122.7
13	x12	10x6x40	12x1.50	164.7	330x305	245	47.8	3.1	5.4	75.6	215.7
12	x12		12x1	123.9	305x305	184	35.8	2.9	5.1	51.6	155.5
11.50	x12		12x0.75	103.5	292x305	154	29.8	2.8	4.9	39.6	126.2
11	x12		12x0.50	83.1	279x305	124	23.8	2.6	4.8	27.6	97.4
11	x12	8x6x35	12x1.50	159.7	279x305	238	46.3	3.1	4.5	75.3	169.8
10	x12		12x1	118.9	254x305	177	34.3	3.0	4.2	51.3	120.6
9.50	x12		12x0.75	98.5	241x305	147	28.3	2.9	4.0	39.3	96.9
9	x12		12x0.50	78.1	227x305	116	22.3	2.7	3.9	27.3	73.8

TABLE NO.3.18 IMPERIAL UNITS

PROPERTIES OF COMPOUND STANCHION SIZES USING 1932 BEAMS
See separate page for notes

II

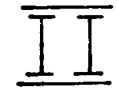
Size D x B	Composed of Two joists	Plates (ea) flange	Mass/ft	Metric Equivalent D x B	Mass/m	Area	Rad. of Gyr. Y - Y	X - X	Sec. Mod. Y - Y	X - X
ins		ins	lbs	mm	kg	ins2	ins		ins3	
22 x18	18x7x75	18x2	398.6	559x457	593	116.2	5.0	9.1	325.8	866.0
21 x18		18x1.50	337.4	533x457	502	98.2	5.0	8.7	271.8	709.1
20 x18		18x1	276.2	508x457	411	80.2	4.9	8.3	217.8	555.4
19.50x18		18x0.75	245.6	495x457	365	71.2	4.9	8.1	190.8	479.7
19 x18		18x0.50	215.0	483x457	320	62.2	4.9	7.9	163.8	404.5
22 x16	18x6x55	16x2	329.9	559x406	491	96.4	4.5	9.2	241.3	736.8
21 x16		16x1.50	275.5	533x406	410	80.4	4.5	8.8	198.6	595.8
20 x16		16x1	221.1	508x406	329	64.4	4.4	8.4	156.0	457.4
19.50x16		16x0.75	193.9	495x406	289	56.4	4.4	8.2	134.6	389.1
19 x16		16x0.50	166.7	483x406	248	48.4	4.3	8.0	113.3	321.4
20 x20	16x8x75	20x2	425.6	508x508	633	124.1	5.6	8.3	390.6	845.4
19 x20		20x1.50	357.6	483x508	532	104.1	5.6	7.9	324.0	689.8
18 x20		20x1	289.6	457x508	431	84.1	5.5	7.6	257.3	537.9
17.50x20		20x0.75	255.6	445x508	380	74.1	5.5	7.4	224.0	463.3
17 x20		20x0.50	221.6	432x508	330	64.1	5.5	7.2	190.6	389.4
20 x16	16x6x62	16x2	343.7	508x406	511	100.4	4.5	8.1	250.3	665.5
19 x16		16x1.50	289.3	483x406	431	84.4	4.4	7.8	207.6	540.4
18 x16		16x1	234.9	457x406	350	68.4	4.4	7.4	165.0	418.3
17.50x16		16x0.75	207.7	445x406	309	60.4	4.4	7.2	143.6	358.2
17 x16		16x0.50	180.5	432x406	269	52.4	4.3	7.0	122.3	298.8
20 x16	16x6x50	16x2	319.9	508x406	476	93.4	4.5	8.3	235.1	644.2
19 x16		16x1.50	265.5	483x406	395	77.4	4.5	8.0	192.5	517.9
18 x16		16x1	211.1	457x406	314	61.4	4.4	7.6	149.8	394.5
17.50x16		16x0.75	183.9	445x406	274	53.4	4.4	7.4	128.5	333.8
17 x16		16x0.50	156.7	432x406	233	45.4	4.3	7.2	107.1	273.6
19 x16	15x6x45	16x2	309.9	483x406	461	90.5	4.5	7.9	228.6	592.5
18 x16		16x1.50	255.5	457x406	380	74.5	4.5	7.6	185.9	473.3
17 x16		16x1	201.1	432x406	299	58.5	4.4	7.2	143.3	357.0
16.50x16		16x0.75	173.9	419x406	259	50.5	4.4	7.0	121.9	299.8
16 x16		16x0.50	146.7	406x406	218	42.5	4.4	6.8	100.6	243.1
18 x20	14x8x70	20x2	415.5	457x508	618	121.2	5.6	7.4	383.0	728.6
17 x20		20x1.50	347.6	432x508	517	101.2	5.6	7.1	316.3	591.3
16 x20		20x1	279.6	406x508	416	81.2	5.6	6.7	249.6	458.1
15.50x20		20x0.75	245.6	394x508	265	71.2	5.5	6.5	216.3	392.8
15 x20		20x0.50	211.6	381x508	315	61.2	5.5	6.3	183.0	328.4
18 x16	14x6x57	16x2	334.0	457x406	497	97.6	4.5	7.3	244.8	576.0
17 x16		16x1.50	279.6	432x406	416	81.6	4.5	7.0	202.1	465.7
16 x16		16x1	225.2	406x406	335	65.6	4.4	6.6	159.4	358.7
15.50x16		16x0.75	198.0	394x406	295	57.6	4.4	6.4	138.1	306.2
15 x16		16x0.50	170.8	381x406	254	49.6	4.3	6.2	116.8	254.4
18 x16	14x6x46	16x2	312.3	457x406	465	91.2	4.5	7.4	230.4	555.8
17 x16		16x1.50	257.9	432x406	384	75.2	4.5	7.1	187.7	444.4
16 x16		16x1	203.5	406x406	303	59.2	4.4	6.7	145.1	336.0
15.50x16		16x0.75	176.3	394x406	262	51.2	4.4	6.5	123.7	282.8
15 x16		16x0.50	149.1	381x406	222	43.2	4.4	6.3	102.4	230.2
15 x20	12x8x65	20x1.50	337.6	381x508	502	98.2	5.6	6.2	308.6	496.1
14 x20		20x1	269.6	356x508	401	78.2	5.6	5.8	242.0	381.3
13.50x20		20x0.75	235.6	343x508	351	68.2	5.5	5.7	208.6	325.4
13 x20		20x0.50	201.6	330x508	300	58.2	5.5	5.5	175.3	270.3
15 x14	12x6x54	14x1.50	253.1	381x356	377	73.8	3.9	6.0	151.7	356.4
14 x14		14x1	205.5	356x356	306	59.8	3.9	5.7	129.0	276.7
13.50x14		14x0.75	181.7	343x356	270	52.8	3.9	5.5	112.7	237.9
13 x14		14x0.50	157.9	330x356	235	45.8	3.8	5.3	96.4	199.8
15 x14	12x6x44	14x1.50	233.5	381x356	347	68.0	3.9	6.1	149.8	340.7
14 x14		14x1	185.9	356x356	277	54.0	3.9	5.8	117.2	259.8
13.50x14		14x0.75	162.1	343x356	241	47.0	3.9	5.6	100.8	220.4
13 x14		14x0.50	138.3	330x356	206	40.0	3.9	5.4	84.5	181.6
13 x18	10x8x55	18x1.50	297.2	330x457	442	86.4	5.1	5.2	247.0	365.1
12 x18		18x1	236.0	305x457	351	68.4	5.0	4.9	193.0	278.2
11.50x18		18x0.75	205.4	292x457	306	59.4	5.0	4.8	166.0	236.3
11 x18		18x0.50	174.8	279x457	260	50.4	5.0	4.6	139.0	195.3
13 x14	10x6x40	14x1.50	225.1	330x356	335	65.5	3.9	5.3	145.4	277.9
12 x14		14x1	177.5	305x356	264	51.5	3.9	4.9	112.7	209.8
11.50x14		14x0.75	153.7	292x356	229	44.5	3.9	4.8	96.4	176.9
11 x14		14x0.50	129.9	279x356	193	37.5	3.9	4.6	80.1	144.7
11 x14	8x6x35	14x1.50	215.1	279x356	320	62.6	4.0	4.4	139.6	215.6
10 x14		14x1	167.5	254x356	249	48.6	3.9	4.1	107.0	159.9
9.50x14		14x0.75	143.7	241x356	214	41.6	3.9	3.9	90.5	133.3
9 x14		14x0.50	119.9	227x356	178	34.6	2.7	3.9	74.3	107.4

TABLE NO.3.19 PROPERTIES OF COMPOUND GIRDER SIZES USING 1932 BEAMS
IMPERIAL UNITS See separate page for notes

Size D x B	Composed of One joist	Plates @ea flange	Mass/ft	Metric Equivalent D X B	Mass/m	Area	Net Inertia X - X	Section Modulus X - X Girder	1" extra plate width
ins		ins	lbs	mm	kg	ins2	ins4	ins3	
28 x12	24x7.50x95	12x2	261.8	711x305	390	75.9	9783	698.8	48.4
27 x12		12x1.50	221.0	686x305	329	63.9	7691	569.7	36.2
26 x12		12x1	180.2	660x305	268	51.9	5749	442.2	24.1
25.50x12		12x0.75	159.8	648x305	238	45.9	4832	379.0	18.0
25 x12		12x0.50	139.4	635x305	207	39.9	3950	316.0	12.0
26 x12	22x7 x75	12x2	241.8	660x305	360	70.1	7892	607.1	44.4
25 x12		12x1.50	201.0	635x305	299	58.1	6093	487.5	33.2
24 x12		12x1	160.2	610x305	238	46.1	4433	369.4	22.1
23.50x12		12x0.75	139.8	597x305	208	40.1	3653	310.9	16.5
23 x12		12x0.50	119.4	584x305	178	34.1	2905	252.6	11.0
24 x12	20x7.50x89	12x2	255.8	610x305	381	74.2	6876	573.0	40.4
23 x12		12x1.50	215.0	584x305	320	62.2	5348	465.1	30.2
22 x12		12x1	174.2	559x305	259	50.2	3948	358.9	20.1
21.50x12		12x0.75	153.8	546x305	229	44.2	3294	306.4	15.0
21 x12		12x0.50	133.4	533x305	199	38.2	2669	254.2	10.0
24 x10	20x6.50x65	10x2	204.6	610x254	304	59.1	5486	457.2	40.4
23 x10		10x1.50	170.6	584x254	254	49.1	4235	368.2	30.2
22 x10		10x1	136.6	559x254	203	39.1	3088	280.7	20.1
21.50x10		10x0.75	119.6	546x254	178	34.1	2552	237.4	15.0
21 x10		10x0.50	102.6	533x254	153	29.1	2040	194.3	10.0
22 x12	18x7 x75	12x2	241.9	559x305	360	70.1	5466	496.9	36.5
21 x1		12x1.50	201.1	533x305	299	58.1	4187	398.8	27.2
20 x12		12x1	160.3	508x305	238	46.1	3025	302.5	18.1
19.50x12		12x0.75	139.9	495x305	208	40.1	2485	254.9	13.5
19 x12		12x0.50	119.5	483x305	178	34.1	1973	207.7	9.0
21 x10	18x6 x55	10x1.50	159.3	533x254	237	46.2	3378	321.7	27.2
20 x10		10x1	125.3	508x254	186	36.2	2412	241.2	18.1
19.50x10		10x0.75	108.3	495x254	161	31.2	1964	201.5	13.5
19 x10		10x0.50	91.3	483x254	136	26.2	1539	162.0	9.0
19 x10	16x6 x62	10x1.50	166.2	483x254	247	48.2	2763	290.8	24.2
18 x10		10x1	132.2	457x254	197	38.2	1976	219.6	16.1
17.50x10		10x0.75	115.2	445x254	171	33.2	1615	184.5	12.0
17 x10		10x0.50	98.2	432x254	146	28.2	1273	149.7	8.0

19 x10	16x6	x50	10x1.50	154.3	483x254	230	44.7	2666	280.7	24.2
18 x10			10x1	120.3	457x254	179	34.7	1880	208.9	16.1
17.50x10			10x0.75	103.3	445x254	154	29.7	1518	173.5	12.0
17 x10			10x0.50	86.3	432x254	128	24.7	1177	138.4	8.0
18 x10	15x6	x45	10x1.50	149.3	457x254	222	43.2	2320	257.8	22.8
17 x10			10x1	115.3	432x254	172	33.2	1616	190.2	15.1
16.50x10			10x0.75	98.3	419x254	146	28.2	1294	156.2	11.3
16 x10			10x0.50	81.3	406x254	121	23.2	991	123.8	7.5
18 x9	15x5	x42	9x1.50	136.1	457x227	203	39.4	2051	227.9	22.8
17 x9			9x1	105.5	432x227	157	30.4	1424	167.5	15.1
16.50x9			9x0.75	90.2	419x227	134	25.9	1137	137.8	11.3
16 x9			9x0.50	74.9	406x227	111	21.4	866	103.3	7.5
17 x10	14x6	x57	10x1.50	161.3	432x254	240	46.8	2134	251.0	21.3
16 x10			10x1	127.3	406x254	189	36.8	1508	188.5	14.1
15.50x10			10x0.75	110.3	394x254	164	31.8	1223	157.9	10.5
15 x10			10x0.50	93.3	381x254	139	26.8	956	127.5	7.0
17 x10	14x6	x46	10x1.50	150.5	432x254	224	43.6	2054	241.7	21.3
16 x10			10x1	116.5	406x254	173	33.6	1429	178.6	14.1
15.50x10			10x0.75	99.5	394x254	148	28.6	1144	147.6	10.5
15 x10			10x0.50	82.5	381x254	123	23.6	877	116.9	7.0
16 x9	13x5	x35	9x1.50	129.1	406x227	192	37.3	1542	192.7	19.8
15 x9			9x1	98.5	381x227	147	28.3	1050	140.0	13.1
14.50x9			9x0.75	83.2	368x227	124	23.8	827	114.1	9.8
14 x9			9x0.50	67.9	356x227	101	19.3	619	88.5	6.5
15 x10	12x6	x54	10x1.50	158.3	381x254	236	45.9	1593	212.4	18.3
14 x10			10x1	124.3	356x254	185	35.9	1110	158.6	12.1
13.50x10			10x0.75	107.3	343x254	160	30.9	893	132.3	9.0
13 x10			10x0.50	90.3	330x254	134	25.9	691	106.3	6.0
15 x10	12x6	x44	10x1.50	148.5	381x254	221	43.0	1542	205.5	18.3
14 x10			10x1	114.5	356x254	170	33.0	1058	151.2	12.1
13.50x10			10x0.75	97.5	343x254	145	28.0	841	124.6	9.0
13 x10			10x0.50	80.5	330x254	120	23.0	640	98.4	6.0
15 x9	12x5	x32	9x1.50	126.2	381x227	188	36.5	1316	175.4	18.3
14 x9			9x1	95.6	356x227	142	27.5	885	126.5	12.1
13.50x9			9x0.75	80.3	343x227	119	23.0	692	102.5	9.0
13 x9			9x0.50	65.0	330x227	97	18.5	512	78.8	6.0

TABLE NO 3.20 PROPERTIES OF COMPOUND GIRDER SIZES USING 1932 BEAMS
IMPERIAL UNITS See separate page for notes



Size D x B	Composed of Two joists	Plates @ea flange	Mass/ft	Metric Equivalent D x B	Metric Equivalent Mass/m	Area	Net Inertia X - X	Section Modulus X - X Girder	Section Modulus X - X 1" extra plate width
ins		ins	lbs	mm	kg	ins2	ins4	ins3	
28 x18	24x7.50x95	18x2	438.4	711x457	652	127.9	15500	1107	48.4
27 x18		18x1.50	377.2	686x457	561	109.9	12450	922.4	36.2
26 x18		18x1	316.0	660x457	470	91.9	9621	740.1	24.1
25.50x18		18x0.75	285.4	648x457	425	82.9	8285	649.8	18.0
25 x18		18x0.50	254.8	635x457	379	73.9	7000	560.0	12.0
26 x18	22x7 x75	18x2	398.4	660x457	593	116.1	12320	947.6	44.4
25 x18		18x1.50	337.2	635x457	502	98.1	9698	775.8	33.2
24 x18		18x1	276.0	610x457	411	80.1	7278	606.5	22.1
23.50x18		18x0.75	245.4	597x457	365	71.1	6141	522.6	16.5
23 x18		18x0.50	214.8	584x457	320	52.1	5051	439.2	11.0
24 x18	20x7.50x89	18x2	426.5	610x457	635	124.4	10840	903.3	40.4
23 x18		18x1.50	365.3	584x457	544	106.4	8613	749.0	30.2
22 x18		18x1	304.1	559x457	453	88.4	6572	597.4	20.1
21.50x18		18x0.75	273.5	546x457	407	79.4	5618	522.6	15.0
21 x18		18x0.50	242.9	533x457	361	70.4	4708	448.4	10.0
24 x16	20x6.50x65	16x2	351.2	610x406	523	102.2	9031	752.6	40.4
23 x16		16x1.50	296.8	584x406	442	86.2	7080	615.7	30.2
22 x16		16x1	242.4	559x406	361	70.2	5292	481.1	20.1
21.50x16		16x0.75	215.2	546x406	320	62.2	4457	414.6	15.0
21 x16		16x0.50	188.0	533x406	280	54.2	3660	348.6	10.0
22 x18	18x7 x75	18x2	398.6	559x457	593	116.2	8524	774.9	36.5
21 x18		18x1.50	337.4	533x457	502	98.2	6660	634.3	27.2
20 x18		18x1	276.2	508x457	411	80.2	4966	496.6	18.1
19.50x18		18x0.75	245.6	495x457	365	71.2	4179	428.7	13.5
19 x18		18x0.50	215.0	483x457	320	62.2	3432	361.3	9.0
22 x16	18x6 x55	16x2	329.9	559x406	491	96.4	7274	661.3	36.5
21 x16		16x1.50	275.5	533x406	410	80.4	5613	534.5	27.2
20 x16		16x1	221.1	508x406	329	64.4	4102	410.2	18.1
19.50x16		16x0.75	193.9	495x406	289	56.4	3401	348.8	13.5
19 x16		16x0.50	166.7	483x406	248	48.4	2735	287.9	9.0
19 x14	16x6 x62	14x1.50	268.9	483x356	400	78.4	4144	436.2	24.2
18 x14		14x1	221.3	457x356	329	64.4	3085	342.8	16.1
17.50x14		14x0.75	197.5	445x356	294	57.4	2597	296.8	12.0
17 x14		14x0.50	173.7	432x356	258	50.4	2137	251.4	8.0

19 x14	16x6	x50	14x1.50	245.1	483x356	365	71.4	3951	415.9	24.2
18 x14			14x1	197.5	457x356	294	57.4	2892	321.4	16.1
17.50x14			14x0.75	173.7	445x356	258	50.4	2405	274.9	12.0
17 x14			14x0.50	149.9	432x356	223	43.4	1945	228.8	8.0
18 x14	15x6	x45	14x1.50	235.1	457x356	350	68.5	3411	379.0	22.8
17 x14			14x1	187.5	432x356	279	54.5	2464	289.8	15.1
16.50x14			14x0.75	163.7	419x356	244	47.5	2030	246.0	11.3
16 x14			14x0.50	139.9	406x356	208	40.5	1621	202.6	7.5
18 x12	15x5	x42	12x1.50	208.7	457x305	311	60.7	2873	319.3	22.8
17 x12			12x1	167.9	432x305	250	48.7	2079	244.6	15.1
16.50x12			12x0.75	147.5	419x305	220	42.7	1715	207.9	11.3
16 x12			12x0.50	127.1	406x305	189	36.7	1372	171.6	7.5
17 x14	14x6	x57	14x1.50	259.2	432x356	386	75.6	3183	374.5	21.3
16 x14			14x1	211.6	406x356	315	61.6	2341	292.6	14.1
15.50x14			14x0.75	187.8	394x356	279	54.6	1957	252.5	10.5
15 x14			14x0.50	164.0	381x356	244	47.6	1597	213.0	7.0
17 x14	14x6	x46	14x1.50	237.5	432x356	353	69.2	3024	355.8	21.3
16 x14			14x1	189.9	406x356	283	55.2	2182	272.7	14.1
15.50x14			14x0.75	166.1	394x356	247	48.2	1798	232.0	10.5
15 x14			14x0.50	142.3	381x356	212	41.2	1438	191.8	7.0
16 x12	13x5	x35	12x1.50	194.7	406x305	290	56.6	2134	266.7	19.8
15 x12			12x1	153.9	381x305	229	44.6	1511	201.4	13.1
14.50x12			12x0.75	133.5	368x305	199	38.6	1228	169.4	9.8
14 x12			12x0.50	113.1	356x305	168	32.6	965	137.9	6.5
15 x14	12x6	x54	14x1.50	253.1	381x356	377	73.8	2363	315.0	18.3
14 x14			14x1	205.5	356x356	306	59.8	1712	244.6	12.1
13.50x14			14x0.75	181.7	343x356	270	52.8	1419	210.3	9.0
13 x14			14x0.50	157.9	330x356	235	45.8	1148	176.6	5.0
15 x14	12x6	x44	14x1.50	233.5	381x356	347	68.0	2260	301.3	18.3
14 x14			14x1	185.9	356x356	277	54.0	1609	229.8	12.1
13.50x14			14x0.75	162.1	343x356	241	47.0	1316	195.0	9.0
13 x14			14x0.50	138.3	330x356	206	40.0	1045	160.7	6.0
15 x12	12x5	x32	12x1.50	188.9	381x305	281	54.9	1808	241.1	18.3
14 12			12x1	148.1	356x305	220	42.9	1262	180.3	12.1
13.50x12			12x0.75	127.7	343x305	190	36.9	1017	150.7	9.0
13 x12			12x0.50	107.3	330x305	160	30.9	790	121.5	6.0

TABLE NO. 3.21 — CHANNELS TO BRITISH STANDARD 6 — 1904
IMPERIAL UNITS — See separate page for notes

Reference No	Size D x B	Mass/ft	Metric Equivalent D x B	Metric Equivalent Mass/m	Thickness Web	Thickness Flange	Area	Position of c.g. from back	Mom. of Int. X - X	Mom. of Int. Y - Y	Rad. of Gyr. X - X	Rad. of Gyr. Y - Y	Section Modulus X - X	Section Modulus Y - Y min
	ins	lbs	mm	kg	ins	ins	ins2	ins	ins4	ins4	ins	ins	ins3	ins3
BSC 1	6x3	14.49	152x 76	22	0.31	0.44	4.26	0.94	24.0	3.50	2.4	0.91	8.0	1.7
BSC 2	6x3.50	17.90	152x 89	27	0.38	0.48	5.27	1.12	29.7	5.91	2.4	1.1	9.9	2.5
BSC 3	7x3	17.56	178x 76	26	0.38	0.48	5.17	0.87	37.6	4.02	2.7	0.88	10.8	1.9
BSC 4	7x3.50	20.23	178x 89	30	0.40	0.50	5.95	1.06	44.6	6.50	2.7	1.0	12.7	2.7
BSC 5	8x3	19.30	203x 76	29	0.38	0.50	5.68	0.84	53.4	4.33	3.1	0.87	13.4	2.0
BSC 6	8x3.50	22.72	203x 89	34	0.43	0.53	6.68	1.01	63.8	7.07	3.1	1.0	15.9	2.8
BSC 7	9x3	19.37	229x 76	29	0.38	0.44	5.70	0.75	65.2	4.02	3.4	0.84	14.5	1.8
BSC 8	9x3.50	22.27	229x 89	33	0.38	0.50	6.55	0.98	79.9	6.96	3.5	1.0	17.8	2.8
BSC 9	9x3.50	25.39	229x 89	38	0.45	0.55	7.47	0.97	88.1	7.66	3.4	1.0	19.6	3.0
BSC 10	10x3.50	23.55	254x 89	35	0.38	0.50	6.93	0.93	102.6	7.19	3.9	1.0	20.5	2.8
BSC 11	10x3.50	28.21	254x 89	42	0.48	0.58	8.30	0.93	117.9	8.19	3.8	1.0	23.6	3.2
BSC 12	10x4	30.16	254x102	45	0.48	0.58	8.87	1.10	130.7	12.0	3.8	1.2	26.1	4.1
BSC 13	11x3.50	29.82	279x 89	44	0.48	0.58	8.77	0.90	148.6	8.4	4.1	1.0	27.0	3.2
BSC 14	12x3.50	26.10	305x 89	39	0.38	0.50	7.68	0.86	158.6	7.6	4.6	1.0	28.4	2.9
BSC 15	12x3.50	32.88	305x 89	49	0.50	0.60	9.67	0.87	190.7	8.9	4.4	1.0	31.8	3.4
BSC 16	12x4	36.47	305x102	54	0.53	0.63	10.73	1.03	218.2	13.7	4.5	1.1	36.4	4.6
BSC 17	15x4	41.94	381x102	62	0.53	0.63	12.33	0.94	377.0	14.6	5.5	1.1	50.3	4.7

TABLE NO. 3.22 — CHANNELS TO BRITISH STANDARD 4 — 1921
IMPERIAL UNITS — See separate page for notes

Reference No.	Size D x B	Mass/ft	Metric Equivalent D x B	Metric Equivalent Mass/m	Thickness Web	Thickness Flange	Area	Position of c.g. from back	Mom. of Int. X -X	Mom. of Int. Y - Y	Rad. of Gyr. X - X	Rad. of Gyr. Y - Y	Section Modulus X - X	Section Modulus Y - Y min
	ins	lbs	mm	kg	ins	ins	ins2	ins	ins4	ins4	ins	ins	ins3	ins3
NBSC 1	3x1.50	4.6	76x 38	7	0.20	0.28	1.35	0.48	1.82	0.26	1.2	0.44	1.22	0.26
NBSC 2	4x2	7.1	102x 51	11	0.24	0.31	2.09	0.60	5.06	0.70	1.6	0.58	2.53	0.50
NBSC 3	5x2.50	10.2	127x 64	15	0.25	0.38	3.01	0.77	11.9	1.64	2.0	0.74	4.75	0.95
NBSC 4	6x3	12.4	152x 76	19	0.25	0.38	3.65	0.89	21.3	2.83	2.4	0.88	7.09	1.3
NBSC 5	6x3.50	16.5	152x 89	25	0.28	0.48	4.85	1.14	28.9	5.29	2.4	1.0	9.6	2.2
NBSC 6	7x3	14.2	178x 76	21	0.26	0.42	4.18	0.88	32.8	3.26	2.8	0.88	9.4	1.5
NBSC 7	7x3.50	18.3	178x 89	27	0.30	0.50	5.38	1.09	42.8	5.83	2.8	1.0	12.2	2.4
NBSC 8	8x3	16.0	203x 76	24	0.28	0.44	4.69	0.83	46.7	3.58	3.2	0.87	11.7	1.7
NBSC 9	8x3.50	20.2	203x 89	30	0.32	0.52	5.94	1.05	60.6	6.37	3.2	1.0	15.1	2.6
NBSC 10	9x3	17.5	229x 76	26	0.30	0.44	5.14	0.78	62.5	3.75	3.5	0.86	13.9	1.7
NBSC 11	9x3.50	22.3	229x 89	33	0.34	0.54	6.55	1.00	82.6	6.90	3.6	1.0	18.4	2.8
NBSC 12	10x3	19.3	254x 76	29	0.32	0.45	5.67	0.74	82.7	3.98	3.8	0.84	16.5	1.8
NBSC 13	10x3.50	24.5	254x 89	36	0.36	0.56	7.19	0.97	109.5	7.42	3.9	1.0	21.9	2.9
NBSC 14	12x3.50	25.3	305x 89	38	0.35	0.50	7.43	0.85	156.4	7.07	4.6	0.98	26.1	2.7
NBSC 15	12x3.50	29.2	305x 89	44	0.40	0.60	8.60	0.90	180.3	8.44	4.6	0.99	30.0	3.2
NBSC 16	12x4	31.3	305x102	47	0.40	0.60	9.21	1.06	200.1	12.12	4.7	1.1	33.3	4.1
NBSC 17	15x4	36.4	381x102	54	0.41	0.62	10.70	0.97	349.1	13.34	5.7	1.1	46.5	4.4
NBSC 18	17x4	44.3	432x102	66	0.48	0.68	13.04	0.92	520.2	15.26	6.3	1.1	61.2	5.0

TABLE NO.3.23 CHANNELS TO BRITISH STANDARD 4 1932

IMPERIAL UNITS See separate page for notes

Reference No.	Size D x B*	Mass/ft	Metric Equivalent D x B	Metric Equivalent Mass/m	Thickness Web	Thickness Flange	Area	Position of c.g. from back	Mom. of Int. X - X	Mom. of Int. Y - Y	Rad. of Gyr. X - X	Rad. of Gyr. Y - Y	Section Modulus X - X	Section Modulus Y - Y min
	ins	lbs	mm	kg	ins	ins	ins2	ins	ins4	ins4	ins	ins	ins3	ins3
BSC 101	3x1.50	4.60	76x 38	7	0.20	0.28	1.35	0.48	1.82	0.26	1.16	0.44	1.22	0.26
BSC 101A	3x1.55	5.11	76x 39	8	0.25	0.28	1.50	0.48	1.94	0.30	1.14	0.44	1.29	0.28
BSC 102	4x2	7.09	101x 51	11	0.24	0.31	2.09	0.60	5.06	0.70	1.56	0.58	2.53	0.50
BSC 102A	4x2.06	7.91	101x 53	12	0.30	0.31	2.33	0.59	5.38	0.79	1.52	0.58	2.69	0.54
BSC 103	5x2.50	10.22	127x 64	15	0.25	0.38	3.01	0.77	11.9	1.6	1.99	0.74	4.75	0.95
BSC 103A	5x2.56	11.24	127x 66	17	0.31	0.38	3.31	0.76	12.5	1.8	1.94	0.74	5.00	1.01
BSC 104	6x3	12.41	152x 76	19	0.25	0.38	3.65	0.89	21.3	2.8	2.41	0.88	7.09	1.34
BSC 104A	6x3.06	13.64	152x 78	20	0.31	0.38	4.01	0.87	22.4	3.1	2.36	0.88	7.45	1.42
BSC 105	6x3	16.51	152x 76	25	0.38	0.48	4.86	0.91	26.3	3.7	2.33	0.87	8.76	1.77
BSC 105A	6x3.05	17.53	152x 77	26	0.43	0.48	5.16	0.90	27.2	4.0	2.30	0.88	9.06	1.84
BSC 106	6x3.50	16.48	152x 89	25	0.28	0.48	4.85	1.14	28.9	5.3	2.44	1.05	9.63	2.25
BSC 106A	6x3.60	18.52	152x 92	28	0.38	0.48	5.45	1.11	30.7	6.1	2.37	1.05	10.2	2.43
BSC 107	7x3	14.22	178x 76	21	0.26	0.42	4.18	0.88	32.8	3.3	2.80	0.88	9.36	1.53
BSC 107A	7x3.12	17.07	178x 79	25	0.38	0.42	5.02	0.84	36.2	3.9	2.68	0.88	10.3	1.70
BSC 108	7x3.50	18.28	178x 89	27	0.30	0.50	5.38	1.09	42.8	5.8	2.82	1.04	12.2	2.42
BSC 108A	7x3.58	20.18	178x 91	30	0.38	0.50	5.94	1.07	45.1	6.5	2.76	1.05	12.9	2.58
BSC 109	8x3	15.96	203x 76	24	0.28	0.44	4.69	0.83	46.7	3.6	3.16	0.87	11.7	1.65
BSC 109A	8x3.10	18.68	203x 79	28	0.38	0.44	5.49	0.81	51.0	4.1	3.05	0.87	12.8	1.79
BSC 110	8x3.50	20.21	203x 89	30	0.32	0.52	5.94	1.05	60.6	6.4	3.19	1.04	15.1	2.60
BSC 110A	8x3.61	23.20	203x 92	35	0.43	0.52	6.92	1.01	65.3	7.3	3.09	1.03	16.3	2.81
BSC 111	9x3	17.46	229x 76	26	0.30	0.44	5.14	0.78	62.5	3.8	3.49	0.86	13.9	1.69
BSC 111A	9x3.08	19.91	229x 78	30	0.38	0.44	5.86	0.76	67.4	4.2	3.39	0.85	15.0	1.80
BSC 112	9x3.50	22.27	229x 89	33	0.34	0.54	6.55	1.00	82.6	6.9	3.55	1.03	18.4	2.76
BSC 112A	9x3.54	23.49	229x 90	35	0.38	0.54	6.91	0.99	85.1	7.3	3.51	1.03	18.9	2.85
BSC 112B	9x3.61	25.63	229x 92	38	0.45	0.54	7.54	0.97	89.3	7.9	3.44	1.02	19.8	2.98
BSC 113	10x3	19.28	254x 76	29	0.32	0.45	5.67	0.74	82.7	4.0	3.82	0.84	16.5	1.76
BSC 113A	10x3.06	21.33	254x 78	32	0.38	0.45	6.27	0.73	87.7	4.3	3.74	0.83	17.5	1.85
BSC 114	10x3.50	24.46	254x 89	36	0.36	0.56	7.19	0.97	109.5	7.4	3.90	1.02	21.9	2.93
BSC 114A	10x3.62	28.54	254x 92	43	0.48	0.56	8.39	0.94	119.5	8.5	3.77	1.01	23.9	3.17
BSC 115	11x3.50	26.78	279x 89	40	0.38	0.58	7.88	0.93	141.9	7.9	4.24	1.00	25.8	3.09
BSC 115A	11x3.60	30.52	279x 92	45	0.48	0.58	8.98	0.91	153.0	8.9	4.13	0.99	27.8	3.30
BSC 116	12x3.50	26.37	305x 89	39	0.38	0.50	7.76	0.83	159.7	7.2	4.54	0.96	26.6	2.68
BSC 116A	12x3.60	30.45	305x 92	45	0.48	0.50	8.96	0.81	174.1	8.0	4.41	0.94	29.0	2.86
BSC 117	12x4	31.33	305x102	47	0.40	0.60	9.21	1.06	200.1	12.1	4.66	1.15	33.4	4.12
BSC 117A	12x4.13	36.63	305x105	55	0.53	0.60	10.77	1.02	218.8	13.8	4.51	1.13	36.5	4.44
BSC 118	13x4	33.18	330x102	49	0.40	0.62	9.76	1.04	246.9	12.8	5.03	1.14	38.0	4.31
BSC 118A	13x4.13	38.92	330x105	58	0.53	0.62	11.45	1.01	270.7	14.5	4.86	1.13	41.6	4.64
BSC 119	15x4	36.37	381x102	54	0.41	0.62	10.70	0.97	349.1	13.3	5.71	1.12	46.6	4.40
BSC 119A	15x4.12	42.49	381x105	63	0.53	0.62	12.50	0.94	382.9	15.0	5.54	1.09	51.1	4.71
BSC 120	17x4	44.34	432x102	66	0.48	0.68	13.04	0.92	520.2	15.3	6.32	1.08	61.2	4.96
BSC 120A	17x4.12	51.28	432x105	76	0.50	0.68	15.08	0.91	569.3	17.0	6.14	1.06	67.0	5.28

* In this table only the breadth dimension is accurate and not a decimal equivalent of a fraction of an inch

TABLE NO. 3.24 — CHANNELS TO BRITISH STANDARD 4 PART 1 — 1962
IMPERIAL UNITS — See separate page for notes

Designation Serial Size D x B	Mass/ft	Dimensions Depth D	Breadth B	Metric Equivalent D x B	Mass/m	Thickness Web	Flange	Area	Position of c.g. from back	Mom. of Int. X - X	Y - Y	Rad. of Gyr. X - X	Y - Y	Section Modulus X - X	Y - Y min
ins	lbs	ins		mm	kg	ins		ins2	ins	ins4		ins		ins3	
17x4	44	17	4	432x102	66	0.48	0.66	12.94	0.91	514.1	15.10	6.3	1.1	60.5	4.9
15x4	37	15	4	381x102	55	0.41	0.64	10.88	0.99	537.2	13.93	5.7	1.1	47.7	4.6
12x4	31	12	4	305x102	46	0.4	0.58	9.12	1.05	197.3	12.00	4.7	1.2	32.9	4.1
12x3.50	28	12	3.5	305x 89	42	0.4	0.54	8.23	0.86	169.6	7.82	4.5	1.0	28.3	3.0
10x3.50	24	10	3.5	254x 89	36	0.36	0.54	7.06	0.95	106.9	7.27	3.9	1.0	21.4	2.9
10x3	19	10	3	254x 76	28	0.32	0.43	5.59	0.73	80.88	3.91	3.8	0.84	16.2	1.7
9x3.50	22	9	3.5	229x 89	33	0.34	0.52	6.47	1.00	81.38	6.85	3.6	1.0	18.1	2.7
9x3	17.50	9	3	229x 76	26	0.30	0.44	5.15	0.79	62.70	3.81	3.5	0.86	13.9	1.7
8x3.50	20	8	3.5	203x 89	30	0.32	0.51	5.88	1.04	59.85	6.35	3.2	1.0	15.0	2.6
8x3	16	8	3	203x 76	24	0.28	0.44	4.70	0.84	46.86	3.64	3.2	0.88	11.7	1.7
7x3.50	18	7	3.5	178x 89	27	0.30	0.48	5.29	1.09	42.12	5.79	2.8	1.1	12.0	2.4
7x3	14	7	3	178x 76	21	0.26	0.41	4.11	0.87	32.13	3.22	2.8	0.88	9.18	1.5
6x3.50	16	6	3.5	152x 89	24	0.28	0.46	4.71	1.13	28.01	5.17	2.4	1.1	9.34	2.2
6x3	12	6	3	152x 76	18	0.25	0.36	3.53	0.87	20.46	2.73	2.4	0.88	6.82	1.3
5x2.50	10	5	2.5	127x 64	15	0.25	0.36	2.94	0.76	11.59	1.62	2.0	0.7	4.64	0.93
4x2	7	4	2	102x 51	10	0.24	0.30	2.06	0.60	4.99	0.70	1.6	0.6	2.50	0.50
3x1.50	4.50	3	1.5	76x 38	7	0.20	0.27	1.32	0.47	1.78	0.26	1.2	0.4	1.19	0.25

TABLE NO. 3.25 — PROPERTIES OF BROAD FLANGE BEAMS TO BS4B — 1959
IMPERIAL UNITS — See separate page for notes

Designation Serial Size	Mass/ft	Dimensions Depth D	Breadth B	Metric Equivalent D x B	Mass/m	Thickness Web	Flange	Area	Mom. of Int. X - X	Y - Y	Rad. of Gyr. X - X	Y - Y	Section Modulus X - X	Y - Y
ins	lbs	ins		mm	kg	ins		ins2	ins4		ins		ins3	
24x12	165	24.0	12.0	610x305	246	0.70	1.36	48.53	4857	393.2	10.00	2.85	404.8	65.54
22x12	150	22.0	12.0	559x305	223	0.65	1.28	44.12	3768	368.7	9.24	2.89	342.5	61.44
20x12	135	20.0	12.0	508x305	201	0.63	1.16	39.71	2818	334.2	8.42	2.90	281.8	55.70
18x12	122	18.0	12.0	457x305	182	0.59	1.08	35.88	2090	310.8	7.63	2.94	232.2	51.80
16x12	110	16.0	12.0	406x305	164	0.55	1.00	32.35	1508	289.2	6.83	2.99	188.5	48.20
14x12	100	14.0	12.0	356x305	149	0.55	0.92	29.41	1051	268.0	5.98	3.00	150.1	44.33
14x12	90	14.0	12.0	356x305	134	0.50	0.82	26.47	956.7	238.0	6.01	3.00	136.7	39.66
14x12	84	14.18	12.023	360x305	125	0.45	0.77	24.71	928.4	224.6	6.13	3.02	131.0	37.35
14x12	78	14.06	12.0	357x305	116	0.43	0.72	22.94	851.0	206.3	6.09	3.00	121.0	34.39
12x12	91	12.14	12.0	308x305	135	0.55	0.85	26.76	720.3	246.3	5.19	3.03	118.7	41.05
12x12	83	12.0	12.0	305x305	124	0.47	0.80	24.41	655.3	229.3	5.18	3.06	109.2	38.21
12x12	78	12.06	12.0	306x305	116	0.47	0.73	22.94	621.3	210.6	5.20	3.03	103.0	35.09
12x12	75	12.0	12.0	305x305	112	0.43	0.71	22.06	598.7	206.0	5.21	3.06	99.79	34.33
12x12	72	12.25	12.04	311x306	107	0.43	0.67	21.18	597.9	195.0	5.31	3.04	97.61	32.38
10x10	66	10.06	10.0	256x254	98	0.46	0.75	19.41	357.9	125.7	4.30	2.54	71.15	25.14
10x10	63	10.0	10.0	254x254	94	0.43	0.72	18.53	340.9	120.9	4.29	2.55	68.18	24.18
10x10	54	10.12	10.03	257x255	80	0.37	0.62	15.88	305.7	103.6	4.39	2.56	60.41	20.65
8x8	45	8.0	8.0	203x203	67	0.39	0.64	13.23	152.9	55.13	3.40	2.04	38.21	13.78
7x7	34	7.0	7.0	178x178	51	0.35	0.55	10.00	88.15	31.48	2.97	1.77	25.19	8.99
6x6	25	6.0	6.0	152x152	37	0.31	0.47	7.35	47.40	16.82	2.54	1.51	15.80	5.61

Notes relative to Tables 3.21 to 3.24 inc

These tables list most of the properties of channels from 1904 up to but not including the last revision of BS4 in 1980 and are as follows:—

BS6 1904 (Table 3.21)
Initially BS4 covered only beams. Channels and other structural sections appeared in BS6.

The channel sizes covered by this early specification are much heavier than later amendments.

BS4 1921 (Table 3.22)
These channels were known as *new* British Standard Channels and were produced with thinner web and flange to give lighter sections. They carry the reference NBSC 1 to 18 inclusive.

BS4 1932 (Table 3.23)
A completely new range of channels with the reference BSC101 to BSC120 inc. was listed and this list of twenty sizes was extended to a total of forty one sizes by giving a series of sections with thicker webs and having the reference BSC101A to BSC120A inclusive, and BSC112B.

These sizes with thicker webs were produced from the basic size by lifting the rolls. This had the effect of increasing the breadth B by an amount equal to the increase in web thickness — this increase is indicated in the tables in the size column.

BS4 1962 (Table 3.24)
A new range of channel sizes being minor adjustment to the properties in the 1932 range except that the derived sizes are now dropped from the standard.

In 1972 this range of channel sizes was repeated in metric units.

In each of the four tables the metric equivalent of depth, breadth and mass/unit length is given.

The properties of channel sections are based upon Fig 3.13.

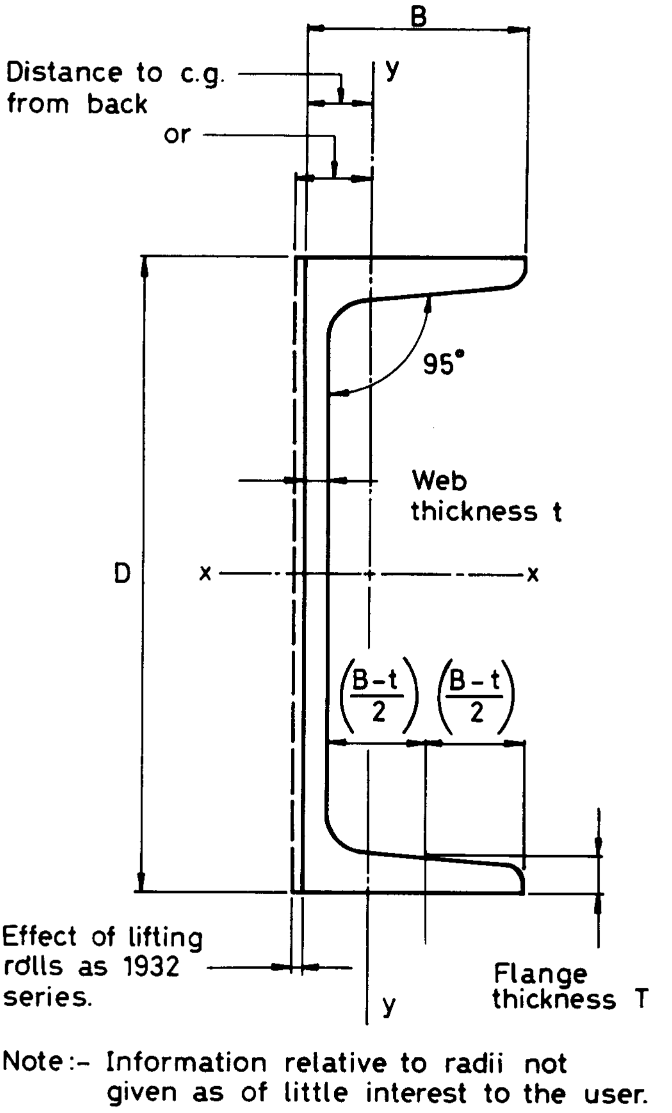


Figure 3.13 British Standard Channels.

Notes relative to Table 3.25

These Broad Flange Beams had parallel flanges and were introduced at the same time as Universal Beam and Column sections (1959) to suit those makers who could not porduce UBs or UCs.

After a relatively short period the sections were withdrawn from BS4 and in fact are not in the 1962 amendment.

TABLE NO. 3.26 — PROPERTIES OF EQUAL ANGLES TO BS4 PART 1 — 1962

IMPERIAL UNITS — See separate page for notes

Designation Size A x B	Nom. Th.	Mass/ft	Metric Equivalent Size A x B	Th.	Mass/m	Area	Centre of Gravity Cx	Cy	Moment of Inertia X - X	Y - Y	U - U	V - V	Radius of Gyration X - X	Y - Y	U - U	V - V	Section Modulus X - X	Y - Y minimum
ins	ins	lbs	mm	mm	kg	ins2	ins	ins	ins4				ins				ins3	
8 x8	1	51.0	203x203	25.3	76	15.01	2.36	2.36	88.56	88.56	140.42	36.69	2.43	2.43	3.05	1.56	15.69	15.69
	0.87	45.0	203x203	22.1	67	13.24	2.31	2.31	79.15	79.15	125.71	32.59	2.45	2.45	3.08	1.57	13.91	13.91
	0.75	38.9	203x203	19.0	58	11.44	2.26	2.26	69.30	69.30	110.19	28.41	2.46	2.46	3.10	1.58	12.08	12.08
	0.62	32.7	203x203	15.8	49	9.61	2.21	2.21	58.99	58.99	93.86	24.12	2.48	2.48	3.12	1.58	10.20	10.20
6 x6	0.87	33.1	152x152	22.2	49	9.74	1.81	1.81	31.73	31.73	50.18	13.28	1.81	1.81	2.27	1.17	7.58	7.58
	0.75	28.7	152x152	19.0	43	8.44	1.77	1.77	27.96	27.96	44.34	11.59	1.82	1.82	2.29	1.17	6.60	6.60
	0.62	24.2	152x152	15.8	36	7.12	1.72	1.72	24.00	24.00	38.12	9.87	1.84	1.84	2.31	1.18	5.61	5.61
	0.50	19.5	152x152	12.6	29	5.74	1.67	1.67	19.68	19.68	31.29	8.06	1.85	1.85	2.34	1.18	4.54	4.54
	0.37	14.8	152x152	9.4	22	4.35	1.62	1.62	15.15	15.15	24.10	6.20	1.87	1.87	2.35	1.19	3.46	3.46
5 x5	0.75	23.6	127x127	19.0	35	6.94	1.52	1.52	15.63	15.63	24.71	6.56	1.50	1.50	1.89	0.97	4.49	4.49
	0.62	19.9	127x127	15.8	30	5.86	1.47	1.47	13.45	13.45	21.32	5.57	1.52	1.52	1.91	0.98	3.81	3.81
	0.50	16.1	127x127	12.6	24	4.74	1.42	1.42	11.10	11.10	17.64	4.56	1.53	1.53	1.93	0.98	3.10	3.10
	0.37	12.3	127x127	9.5	18	3.61	1.37	1.37	8.63	8.63	13.73	3.53	1.55	1.55	1.95	0.99	2.38	2.38
4 x4	0.75	18.5	102x102	19.0	28	5.44	1.27	1.27	7.61	7.61	11.95	3.27	1.18	1.18	1.48	0.77	2.78	2.78
	0.62	15.7	102x102	15.9	23	4.62	1.22	1.22	6.60	6.60	10.42	2.78	1.20	1.20	1.50	0.78	2.37	2.37
	0.50	12.7	102x102	12.6	19	3.73	1.17	1.17	5.47	5.47	8.68	2.27	1.21	1.21	1.52	0.78	1.94	1.94
	0.37	9.7	102x102	9.5	14	2.85	1.13	1.13	4.28	4.28	6.80	1.76	1.22	1.22	1.54	0.78	1.49	1.49
3.50x3.50	0.62	13.5	89x 89	15.8	20	3.97	1.09	1.09	4.27	4.27	6.72	1.82	1.04	1.04	1.30	0.68	1.77	1.77
	0.50	11.0	89x 89	12.6	16	3.23	1.05	1.05	3.57	3.57	5.65	1.49	1.05	1.05	1.32	0.68	1.46	1.46
	0.37	8.4	89x 89	9.4	13	2.47	1.00	1.00	2.80	2.80	4.44	1.15	1.06	1.06	1.34	0.68	1.12	1.12
	0.25	5.7	89x 89	6.3	9	1.68	0.95	0.95	1.95	1.95	3.09	0.80	1.08	1.08	1.36	0.69	0.76	0.76
3 x3	0.50	9.3	76x 76	12.6	14	2.73	0.92	0.92	2.17	2.17	3.43	0.92	0.89	0.89	1.12	0.58	1.05	1.05
	0.37	7.1	76x 76	9.4	11	2.09	0.88	0.88	1.71	1.71	2.71	0.71	0.90	0.90	1.14	0.58	0.80	0.80
	0.25	4.8	76x 76	6.2	7	1.41	0.83	0.83	1.19	1.19	1.89	0.49	0.92	0.92	1.16	0.59	0.55	0.55
2.50x2.50	0.50	7.6	64x 64	12.5	11	2.23	0.80	0.80	1.21	1.21	1.90	0.52	0.74	0.74	0.92	0.48	0.71	0.71
	0.37	5.9	64x 64	9.5	9	1.73	0.76	0.76	0.97	0.97	1.54	0.41	0.75	0.75	0.94	0.49	0.56	0.56
	0.25	4.0	64x 64	6.2	6	1.18	0.71	0.71	0.69	0.69	1.09	0.28	0.76	0.76	0.96	0.49	0.38	0.38
2.25x2.25	0.37	5.2	57x 57	9.3	8	1.53	0.69	0.69	0.69	0.69	1.08	0.29	0.67	0.67	0.84	0.44	0.44	0.44
	0.25	3.6	57x 57	6.3	5	1.06	0.65	0.65	0.49	0.49	0.78	0.20	0.68	0.68	0.86	0.44	0.31	0.31
2 x2	0.37	4.6	51x 51	9.4	7	1.35	0.63	0.63	0.47	0.47	0.74	0.20	0.59	0.59	0.74	0.39	0.34	0.34
	0.25	3.2	51x 51	6.3	5	0.94	0.59	0.59	0.34	0.34	0.54	0.14	0.60	0.60	0.76	0.39	0.24	0.24
1.75x1.75	0.31	3.4	44x 44	7.9	5	1.00	0.55	0.55	0.27	0.27	0.42	0.11	0.52	0.52	0.65	0.34	0.22	0.22
	0.18	2.1	44x 44	4.7	3	0.62	0.50	0.50	0.17	0.17	0.28	0.07	0.53	0.53	0.67	0.34	0.14	0.14
1.50x1.50	0.31	2.85	38x 38	7.9	4	0.84	0.48	0.48	0.16	0.16	0.25	0.07	0.44	0.44	0.55	0.29	0.16	0.16
	0.18	1.8	38x 38	4.7	3	0.53	0.44	0.44	0.11	0.11	0.17	0.04	0.45	0.45	0.57	0.29	0.10	0.10
1.25x1.25	0.25	1.9	32x 32	6.3	3	0.56	0.40	0.40	0.07	0.07	0.12	0.03	0.37	0.37	0.46	0.24	0.09	0.09
	0.12	1.0	32x 32	3.1	2	0.29	0.35	0.35	0.04	0.04	0.07	0.02	0.38	0.38	0.47	0.24	0.05	0.05
1 x1	0.25	1.5	25x 25	6.4	2	0.44	0.34	0.34	0.04	0.04	0.06	0.02	0.29	0.29	0.36	0.19	0.05	0.05
	0.12	0.8	25x 25	3.2	1	0.24	0.29	0.29	0.02	0.02	0.03	0.01	0.30	0.30	0.37	0.19	0.03	0.03

TABLE NO.3.27 PROPERTIES OF UNEQUAL ANGLES TO BS4 PART 1 1962

IMPERIAL UNITS See separate page for notes

Designation Size A x B	Nom. Th.	Mass/ft	Metric Equivalent Size A x B	Th.	Mass/m	Area	Centre of Gravity Cx	Cy	Moment of Inertia X - X	Y - Y	U - U	V - V	Radius of Gyration X - X	Y - Y	U - U	V - V	Section Modulus X - X	Y - Y minimum
ins	ins	lbs	mm	mm	kg	ins2	ins	ins	ins4				ins				ins3	
9 x4	0.75	31.2	229x102	18.9	46	9.17	3.39	0.90	75.78	9.50	78.87	6.42	2.88	1.02	2.93	0.84	13.50	3.07
	0.62	26.3	229x102	15.8	39	7.74	3.34	0.85	64.75	8.22	67.47	5.49	2.89	1.03	2.95	0.84	11.43	2.61
	0.50	21.2	229x102	12.6	32	6.23	3.28	0.80	52.79	6.79	55.07	4.50	2.91	1.04	2.97	0.85	9.23	2.12
8 x6	0.75	33.8	203x152	19.0	50	9.93	2.55	1.56	63.07	30.46	77.09	16.44	2.52	1.75	2.79	1.29	11.57	6.85
	0.62	28.4	203x152	15.8	42	8.36	2.50	1.51	53.74	26.07	65.82	13.98	2.54	1.77	2.81	1.29	9.77	5.80
	0.50	22.9	203x152	12.6	34	6.73	2.45	1.46	43.86	21.38	53.81	11.43	2.55	1.78	2.83	1.30	7.90	4.71
8 x4	0.75	28.7	203x102	19.0	43	8.44	2.94	0.95	54.69	9.26	57.89	6.07	2.55	1.05	2.62	0.85	10.80	3.04
	0.62	24.2	203x102	15.8	36	7.12	2.89	0.90	46.78	8.01	49.60	5.19	2.56	1.06	2.64	0.85	9.15	2.58
	0.50	19.5	203x102	12.6	29	5.74	2.83	0.85	38.22	6.62	40.59	4.25	2.58	1.07	2.66	0.86	7.40	2.10
7 x3.50	0.62	21.0	178x 89	15.8	31	6.18	2.56	0.82	30.75	5.22	32.56	3.41	2.23	0.92	2.30	0.74	6.92	1.94
	0.50	17.0	178x 89	12.6	25	5.00	2.50	0.77	25.25	4.34	26.79	2.80	2.25	0.93	2.32	0.75	5.62	1.59
	0.37	12.9	178x 89	9.5	19	3.79	2.45	0.72	19.46	3.39	20.67	2.17	2.27	0.94	2.33	0.76	4.28	1.22
6 x4	0.62	19.9	152x102	15.8	30	5.86	2.02	1.03	20.92	7.43	24.02	4.33	1.89	1.13	2.03	0.86	5.26	2.50
	0.50	16.1	152x102	12.6	24	4.74	1.97	0.98	17.21	6.17	19.82	3.56	1.91	1.14	2.05	0.87	4.27	2.04
	0.37	12.3	152x102	9.5	18	3.61	1.92	0.93	13.34	4.82	15.40	2.76	1.92	1.15	2.06	0.87	3.27	1.57
6 x3.50	0.62	18.8	152x 89	15.8	28	5.53	2.12	0.87	19.89	5.00	21.78	3.11	1.90	0.95	1.99	0.75	5.12	1.90
	0.50	15.3	152x 89	12.6	23	4.50	2.07	0.83	16.45	4.18	18.07	2.56	1.91	0.96	2.00	0.76	4.18	1.56
	0.37	11.6	152x 89	9.4	17	3.41	2.01	0.78	12.68	3.26	13.96	1.98	1.93	0.98	2.02	0.76	3.18	1.20
6 x3	0.62	17.8	152x 76	15.8	27	5.24	2.22	0.73	18.88	3.17	19.95	2.09	1.90	0.78	1.95	0.63	5.00	1.40
	0.50	14.4	152x 76	12.6	21	4.24	2.17	0.69	15.54	2.64	16.47	1.72	1.92	0.79	1.97	0.64	4.06	1.14
	0.37	11.0	152x 76	9.5	16	3.24	2.12	0.64	12.08	2.08	12.82	1.34	1.93	0.80	1.99	0.64	3.11	0.88
5 x3.50	0.62	16.7	127x 89	15.8	25	4.91	1.69	0.95	11.91	4.76	13.93	2.74	1.56	0.99	1.69	0.75	3.60	1.86
	0.50	13.6	127x 89	12.7	20	4.00	1.64	0.90	9.89	3.99	11.62	2.26	1.57	1.00	1.70	0.75	2.95	1.53
	0.37	10.3	127x 89	9.4	15	3.03	1.59	0.85	7.65	3.11	9.01	1.74	1.59	1.01	1.72	0.76	2.24	1.17
5 x3	0.50	12.7	127x 76	12.6	19	3.73	1.74	0.74	9.34	2.53	10.32	1.55	1.58	0.82	1.66	0.64	2.86	1.12
	0.37	9.7	127x 76	9.5	14	2.85	1.69	0.70	7.27	1.99	8.05	1.20	1.60	0.84	1.68	0.65	2.19	0.86
4 x3.50	0.62	14.6	102x 89	15.8	22	4.30	1.29	1.04	6.30	4.47	8.57	2.20	1.21	1.02	1.41	0.72	2.32	1.81
	0.50	11.9	102x 89	12.7	18	3.50	1.24	0.99	5.26	3.74	7.19	1.80	1.23	1.03	1.43	0.72	1.90	1.49
	0.37	9.1	102x 89	9.5	14	2.68	1.19	0.94	4.12	2.94	5.65	1.40	1.24	1.05	1.45	0.72	1.47	1.15
4 x3	0.50	11.0	102x 76	12.6	16	3.23	1.32	0.82	4.97	2.37	6.04	1.30	1.24	0.86	1.37	0.63	1.85	1.09
	0.37	8.4	102x 76	9.4	13	2.47	1.27	0.77	3.88	1.87	4.74	1.01	1.25	0.87	1.39	0.64	1.42	0.84
4 x2.50	0.37	7.8	102x 64	9.5	12	2.29	1.36	0.61	3.66	1.10	4.10	0.66	1.26	0.69	1.34	0.54	1.39	0.58
	0.25	5.3	102x 64	6.3	8	1.56	1.30	0.56	2.54	0.77	2.86	0.46	1.28	0.70	1.35	0.54	0.94	0.40
3.50x3	0.50	10.2	89x 76	12.7	15	3.00	1.12	0.87	3.41	2.29	4.56	1.14	1.07	0.87	1.23	0.62	1.43	1.08
	0.37	7.8	89x 76	9.5	12	2.29	1.07	0.82	2.67	1.81	3.60	0.88	1.08	0.89	1.25	0.62	1.10	0.83
	0.25	5.3	89x 76	6.3	8	1.56	1.02	0.77	1.86	1.26	2.51	0.61	1.09	0.90	1.27	0.63	0.75	0.57
3.50x2.50	0.37	7.1	89x 64	9.4	11	2.09	1.15	0.65	2.50	1.05	2.96	0.59	1.09	0.71	1.19	0.53	1.06	0.57
	0.25	4.8	89x 64	6.2	7	1.41	1.09	0.60	1.73	0.74	2.06	0.41	1.11	0.72	1.21	0.54	0.72	0.39
3 x2.50	0.37	6.5	76x 64	9.5	10	1.91	0.94	0.70	1.62	1.01	2.12	0.51	0.92	0.73	1.05	0.52	0.79	0.56
	0.25	4.4	76x 64	6.3	7	1.30	0.89	0.65	1.13	0.71	1.48	0.35	0.93	0.74	1.07	0.52	0.54	0.38
3 x2	0.37	5.9	76x 51	9.5	9	1.73	1.03	0.54	1.52	0.54	1.74	0.32	0.94	0.56	1.00	0.43	0.77	0.37
	0.25	4.0	76x 51	6.2	6	1.18	0.98	0.49	1.07	0.38	1.23	0.22	0.95	0.57	1.02	0.43	0.53	0.25
2.50x2	0.37	5.2	64x 51	9.3	8	1.53	0.82	0.58	0.89	0.50	1.13	0.27	0.76	0.57	0.86	0.42	0.53	0.35
	0.25	3.6	64x 51	6.3	5	1.06	0.78	0.58	0.64	0.36	0.82	0.19	0.78	0.59	0.88	0.42	0.37	0.25
2.50x1.50	0.31	3.9	64x 38	7.8	6	1.15	0.89	0.39	0.70	0.19	0.77	0.12	0.78	0.40	0.82	0.32	0.43	0.17

Notes relative to Tables 3.26 and 3.27

These tables give sizes and section properties of a selection of equal and unequal angles extracted from BS4 Part 1 1962.

At least two thicknesses have been selected from each size of angle, other thicknesses for the same sizes can be assumed to have properties pro rata and therefore these can be found by interpolation. The metric equivalents of the leg lengths A & B as well as the thickness and mass/ unit length are given.

The sketches, Figure 3.14 and 3.15 show the position of the axes.

It will be noted from the tables that the maximum moment of inertia and radius of gyration occur about the inclined axis U.U, and that the minimum moment of inertia and radius of gyration occur about axis V.V, pendicular to axis U.U.

Because of the asymetrical shape of the sections there will be two values for the section modulus about each axis. The values given in the tables for section modulus x—x and y—y are minimum and are found by dividing the moment of inertia by the distance from the centre of gravity to the toes.

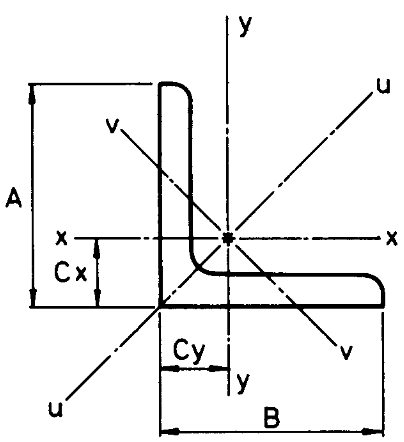


Figure 3.14
Equal Angle.

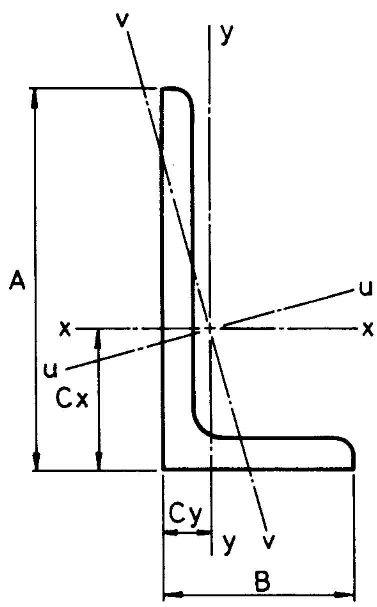


Figure 3.15
Unequal Angle.

3.6 Conclusion

It is considered thast the contents of this section gives sufficient information in both the tables and the notes to enable the engineer to assess existing construction with accuracy and the minimum of trouble.

A certain number of additional shapes were produced in both iron and steel. These included Zed bars, bulb angles, tee bars etc.

Such sections were frequently used as stiffeners in plate work, both for bridges and in shipbuilding.

Though plastic methods of design are now in common use it has been assumed that any investigation of existing construction will be based on elastic concepts and therefore plastic properties of sections have not been provided.

SECTION NO. 4 Codes of Practice & Building Regulations

4.1 Introduction

Whilst it is intended in later sections to deal in some detail with loads and stresses, a review of some of the many codes of practice for the design of structures, and building regulations concerned therewith, will serve as a reminder that various authorities have from time to time introduced requirements, some of which were mandatory and others purely recommendations.

The authorities which will be considered are:—
London County Council
Institution of Structural Engineers
British Standards Institution

In addition, many public and private concerns have refused to accept the supply of structures by contractors which did not conform to their own codes of practice. These firms etc include:—
Railway Companies (now British Rail)
Imperial Chemical Industries
Lloyds of London
etc

It is impossible to discuss all these in this publication.

It is probable that the first Building Regulation was that promulgated by London in the year 1189 (almost 800 years ago). This gave requirements for the thickness of party walls!

Over the years between1189 and 1909 many Building Acts were passed, mainly confined to the City of London and the surrounding home counties like Middlesex, Surrey, Westminster etc.

During the period 1850 to 1900 many important and historic structures stimulated improvements in design in Cast and Wrought Iron. For example, Crystal Palace, constructed in Cast Iron in 1851, and the railway terminals at Euston and Paddington, also constructed in 1851 but mainly in Wrought Iron, are just a few of many such structures.

The first major step towards controlling the design of Steel Structures in the area of the County of London came in 1909 though some control of Reinforced Concrete was introduced a few years earlier.

It is fitting to conclude this introduction with a reference to the District Surveyors who play a major part in the control of building in London.

In 1667 an act was passed for the rebuilding of the City of London. This act was replaced in 1774 and the new act caused the appointment of a number of surveyors to overlook construction. In 1832 a government report showed that there were currently 32 surveyors, 4 in the City, 5 in Westminster; 18 in Middlesex, 4 in Surrey and 1 in Tower Royalty.

The 1844 Building Act gave the surveyors the title District Surveyors and in 1845 the District Surveyors Association was established. This is of course still in existence.

4.2 London County Council

4.2.1 The London County Council (General Powers) Act 1909

The act made it lawful to erect — "buildings wherein the loads and stresses are transmitted through each storey to the foundations by a skeleton framework of metal or partly by a skeleton framework of metal and partly by a party wall or party walls."

Party walls *could not be framed* by this act, however the permissible loads on the floors etc and the limiting stresses on the structural members were specified, and full details including calculations had to be deposited with the District Surveyor.

In connection with the submission of calculations etc, the District Surveyors Association published a document in 1911 entitled Skeleton Frame Buildings showing the format in which calculations should be prepared for submission.

4.2.2 L.C.C. (General Powers) Act 1915

This act gave the London County Council more powers for dealing with buildings erected in proximity to dangerous businesses, and some other provisions, but did not have any structural effect. In 1915 however the Reinforced Concrete Regulations were passed which controlled both design and site work in construction.

4.2.3 London County Council (General Powers) Acts 1920 to 1929

A number of acts were passed during this period of which the most significant was the 1926 act which gave the Council the right to make and enforce regulations with respect to the conversion of any building or part of a building constructed in Reinforced Concrete.

4.2.4 London Building Acts 1930 to 1939

Again, this period showed many changes in the requirements. In 1932 a Code of Practice for the use of structural steel and other materials was issued giving reduced floor loads and higher stresses. In 1938 Building By Laws were issued giving more details of loading, wind pressure and stresses etc.

In between these two, the London Building (Amendment) Act 1935 was issued.

4.2.5. London Building (Constructional) Bylaws 1952

These Bylaws give additional requirements for the design of structural steelwork.

4.2.6 London Building Acts 1930–39 Bylaws made 2 March 1965 amending the London Building (Constructional) Bylaws 1952

This comprehensive document gives details of requirements for loading and design in steel, reinforced concrete, timber etc.

4.2.7 General

As will be seen from the foregoing, changes were constantly taking place during the best part of the present century. The L.C.C. as a body producing bylaws however was superseded by the Building Regulations Advisory Committee, who were responsible for The Building Regulations 1965.

4.3 The Building Regulations 1965

These were prepared for the Minister of Public Buildings and Works and came into effect on 1 February 1966. They gave comprehensive requirements from materials, preparation of site, structural stability etc to such things as sanitary conveniences.

It was following upon the disastrous collapse at Ronan Point that the "Fifth Amendment" designed to prevent progressive failure in future, was issued. This, in the simplest of terms, requires the tying together structurally of walls, beams, columns etc.

4.4 Institution of Structural Engineers

In June 1927 the Institution published Part 1 of what was intended to be a comprehensive report on Steelwork for Buildings. This Part 1 was entitled Loads and Stresses and gave recommendations for superimposed and wind loads for which the structure should be designed, together with working stresses for the design of beams and columns.

This report preceeded the issue of the first edition of BS449 by some five years.

Various revisions were made to Part 1 including the second revision in 1938 which made many changes from the original. It was replaced by the issue in 1948 of British Standard Code of Practice CP113 which was sponsored by the Institution.

Subsequent parts of the report on Steelwork for Building were:—

Part 2 Steelwork Connections published in July 1927

Part 3 Materials and Workmanship in June 1931
Part 4 Foundations } not issued
Part 5 Details of Design & Construction } as such

An additional report published in June 1927 was on Loads and Stresses for Gantry Girders.

Part 1 of the Insitutions's report on steelwork for buildings was used in the preparation of BS449 in 1932 and acknowledge is given in that standard.

4.5. British Standards Institution

At various places in this manual reference is made to the British Standards Institution and to Specifications and Codes of Practice developed under the influence of this Institution. It is interesting to note that BSI came into being as a direct result of the wide variety of iron and steel products produced by individual manufacturers. BS1 was titled "Rolled steel sections for structural purposes".

In the last decade of the nineteenth century technical advances in the production and use of iron and steel were running full spate. Since every architect or builder ordered the size and quality of iron or steel sections which he required for his own projects, the range and variety became excessive and the economics of marketing and storing had to be seriously considered.

Various attempts were made to alleviate this problem by standardisation but it was not until April 26 1901 that the Engineering Standards Committee – the forerunner of the British Standards Institution – came into being. The Engineering Standards Committee was representative of the Institutions of Civil and Mechanical Engineers and of Naval Architects, the Iron and Steel Institute, and later other Professional Institutions.

The original terms of reference of this Committee were the standardisation of iron and steel sections, and as a result the number of structural sections in common use reduced from 175 to 113, whilst tramway rails were slashed from 75 to 5. It is estimated that immediate economies in production costs were of the order of £1,000,000 per year.

A great deal more could be written on this subject but this short precis shows the influence exerted by the iron and steel products discussed in this manual on the development of standardisation.

4.5.1 BS449 Use of Structural Steel in Buildings

This was first issued in 1932, the same year as the L.C.C. Code of Practice, and whilst the L.C.C. Code was the established standard for building in London, BS449 was generally accepted elsewhere in the United Kingdom and indeed in many places overseas.

BS449 1932 specified superimposed and wind loads and also design stresses for beams, columns etc.

In 1935 a revision to BS449 was issued to allow recognition of the work of the Steel Structures Research Committee and to give design stresses for the new High Tensile Steel to BS548 1934.

In 1937 a further revision to BS449 was issued making minor alterations only. This remained effective until 1948 apart from two war emergency revisions, the first being issued in November 1939 and the second in May 1940. These were substantially the same except whereas the first was to remain effective for a period not exceeding 6 months after the end of the war the second specified 12 months.

The 1948 edition of this specification made major changes to loading including wind pressure etc which was now zoned and classified by degree of protection from *natural ground features and other buildings.*

BS449 was next altered in 1959. This revision incorporated CP113 which was then withdrawn. Minor amendments were issued and subsequently incorporated in BS449.

In 1969 BS449 Part 2 in metric units was issued. This included provision for steel to BS4360 which had then replaced BS15 BS968 and BS2762. Though this Part 2 was the metric version of BS449, Part 1, the imperial version was not issued until 1970. This did not introduce any technical change from Part 2 and provision was made for the designer to use either part provided one set of values only was used throughout.

Over many years committees have been active in an attempt to update BS449. It has been agreed that when the replacement is issued – to be given the number BS5950 – BS449 will not immediately be withdrawn but will coexist with the new version for some period of time.

4.5.2 Code of Practice CP113 1948. The structural use of steel in building.

This document was the result of a programme of Codes of Practice for Buildings developed under the aegis of the Ministry of Works.

Whilst much of the information given in both BS449 and CP113 was the same, there were a number of fundamental differences and these caused some confusion amongst engineers.

With the formation of the Codes of Practice Council within BSI it was decided to combine BS449 and CP113 into one document and this was subsequently the 1959 issue of BS449.

4.5.3 CP3 Chapter V Loading, Code of Basic Data for the design of Buildings.

This was first published as CP4 in November 1944 but was not generally accepted until it was issued as Chapter V of CP3 in August 1952.

The purpose was to extract from the design codes fundamental information regarding dead, imposed and wind loadings and publish this separately to be applicable to the type of building rather than the construction thereof.

CP3 Chapter V was amended in 1958 and 1965 and a reset version was printed and issued in 1965.

Subsequently, in 1967 Part 1 of CP3 Chapter V – Dead and Imposed Loads – Metric Units – was published and in 1970 Part 2 of CP3 Chapter V – Wind Loads – Metric Units – was issued. This Part 2 was again revised in 1972 to include additional information.

4.5.4 BS648 Schedule of Weights of Building Materials.

This was first published in 1935 as an attempt to provide a solution to the problems which had arisen in preparing structural calculations based on different data for the weights of the materials concerned.

In 1949 a revision was issued which made the data provided much more complete, and which also changed items where such changes were considered necessary.

The 1964 revision continued the process of updating and improving, and in 1968 metric equivalents were added based upon the imperial units and to the same degree of accuracy.

4.6 Other specifications and codes

Whilst many private specifications have been prepared to meet the requirements of particular industries and companies these cannot be discussed at length. It is however interesting to note that in the absence of official guidance on certain aspects, the structural fabricators themselves prepared and published codes of good design which they incorporated in Handbooks of Structural Steelwork. From very small beginnings at the end of the last century these handbooks became very comprehensive volumes containing 800/900 pages of useful data. The British Constructional Steelwork Association also contributed extensively to these provisions.

SECTION NO. 5 Loads

5.1 Introduction

The question of the loading for which a structure was designed, or for which it should be designed requires a great deal of consideration. Since the regulations and codes discussed in the previous section became established loading can be assumed with a fair degree of accuracy, but prior to the introduction of such regulations loading often depended upon the whim of the engineer.

Experience has shown that some engineers calculated with some accuracy the amount of loading that a structure or structural element would have to carry in order to serve its purpose and designed exactly to this amount giving no margin whatsoever to possible change of process or occupancy at a later stage!

Loadings will be discussed under three main headings viz:–

Dead Loads
Live or Imposed Loads
Wind Loads.

5.2 Dead Loads

The dead load to be carried by a structural member is the mass per unit area multiplied by the area supported. The area supported is usually easy to determine whilst the mass per unit area must be calculated from an assessment of the construction.

It was mentioned in an earlier section that BS648 which was first published in 1935 was an attempt to rationalise the calculation of dead loads.

Earlier efforts at achieving this object can be found on investigation.

In the introduction to their 1895 Handbook Dorman Long and Company state:– "In planning a floor the first thing to be determined is the load that will be placed upon it. This consists of the weight of the materials composing the floor – or the dead load – and the weight of the persons or goods – being the live load, which together make up the total load. The dead load of a fire-proof floor made of steel joists and 6in coke-breeze concrete may be taken as 70lbs/sq foot . . . ".

In their various handbooks Redpath, Brown and Co Limited gave extensive tables of approximate weights of materials for estimating dead and superimposed loads, from which extracts are given in Table 5.1, these were sufficiently comprehensive to enable dead loads to be calculated with a fair degree of accuracy.

Table 5.1 Weights for calculating dead loads

Material	Mass per cubic foot	Mass per sq foot per inch thickness
Asphalt	112 lbs	9 to 10 lbs
Brickwork:–		
Pressed	140 lbs	11 to 12 lbs
Common	120 lbs	10 lbs
Inferior	100 lbs	8 to 9 lbs
Concrete:–		
Breeze	96 lbs	8 lbs
Brick	120 lbs	10 lbs
Stone	144 lbs	12 lbs
Masonry:–		
Dressed freestone	150 lbs	12 to 13 lbs
Dressed granite	165 lbs	13 to 14 lbs
Timber:–		
Jarrah paving	60 lbs	5 lbs
Pine boarding	30 to 45 lbs	2½ to 3¾ lbs
Plaster	96 lbs	8 lbs
Slate	180 lbs	15 lbs
Lead sheet	710 lbs	60 lbs
Copper sheet	558 lbs	48 lbs

Note:– The usual allowance for a plaster suspended ceiling was 10 lbs/sq foot to include laths etc, and 5lbs/sq foot per plastered face was added to the weight of brickwork in walls etc.

5.3 Live Loads

The term "live" in this context is intended to cover the use to which a floor is subjected, and is also called "imposed" or "superimposed". It is not intended to cover moving or dynamic loads.

The allowance made for live load has varied appreciably and prior to the turn of the century was very much a factor to be decided by the architect, having regard to the circumstances.

In about 1945 an investigation carried out on the capacity of the floors of a cotton spinning mill in Lancashire showed an allowance for live load of well under 20lbs/sq foot! The floors had been provided to support spinning mules, and a calculation of the weight of such a machine in operation revealed an imposed load of 7lbs/sq foot.

It follows from this that when dealing with the strength of old construction care must be taken to carefully assess the dead load if the margin for live load is to be factual.

Not all buildings were designed to so narrow a margin, and advice on live loads was available from various sources. Some of these are as follows:

5.3.1 Encyclopaedia of Architecture 1881 (first published 1842)

1. Light workshops and factories, public halls and churches and other buildings in which people only accumulate, with warehouses for light goods. An allowance of 168lbs/sq foot (including 40lbs/sq foot for timber floor) ie a live load of 128lbs/sq foot.
2. Storehouses for heavy goods 280lbs/sq foot (including 40lbs/sq foot dead load) ie a live load of 240lbs/sq foot.
3. Ordinary dwelling houses 140lbs/sq foot (including 40lbs/sq foot dead load as before) ie a live load of 100lbs/sq foot.

5.3.2 Dorman Long and Co Handbook 1895

Deducting the dead load allowance already referred to, this handbook makes the following recommendations:-

1.	Dwellings or Office Buildings	80lbs/sq foot
2.	Public Halls or Schools	110lbs/sq foot
3.	Warehouses	120 to 320lbs/sq foot
4.	Heavy Machinery	220 to 420lbs/sq foot

In the case of 1 and 2 70lbs/sq foot has been deducted for dead load but in the case of 3 and 4 this has been increased to 80lbs/sq foot as a more realistic amount.

5.3.3 Appleby's Handbook of Machinery 1903

The approximate live loads for various classes of building are as given in Table 5.2

Table 5.2 Live Loads on Floors

Classification	Live Load
Attic floors	34 to 56 lbs/sq ft
Dwelling room floors	56 to 70 lbs/sq ft
Offices, libraries etc	70 to 80 lbs/sq ft
Stairs and passages	80 to 90 lbs/sq ft
Work rooms, light business premises etc	90 to 100 lbs sq ft
Churches, theatres, ballrooms, public halls, stores etc	100 to 125 lbs/sq ft
Workshops and light warehouses	125 to 150 lbs/sq ft
Warehouses for heavy materials	150 to 400 lbs/sq ft
Heavy machinery	250 to 500 lbs/sq ft

5.3.4 London County Council (General Powers) Act 1909

Clause 18(A) of the above Act gave the following requirements for live loads:—

1. For a floor intended to be used wholly for the purpose of human habitation — 70lbs/sq foot
2. For a floor intended to be used wholly for office or counting-house etc — 100lbs/sq foot
3. For a floor intended to be used wholly for workshop or a retail store — 112lbs/sq foot
4. For every floor of a building of the warehouse class not intended to be used wholly for any of the purposes aforesaid not less than — 224lbs/sq foot
5. For a roof the plane of which inclines upwards at a greater angle than 20 degrees to the horizontal a live load (deemed to include wind pressure) of — 28lbs/sq foot of surface
6. For all other roofs — 56lbs/sq foot on plan.

5.3.5 Institution of Structural Engineers Report on Steelwork for buildings 1927

This report gave a very comprehensive classification of live loads which is shown in Table 5.3. It also gave loads for flat and sloping roofs. In 1933, after BS449 1932 was issued a revised schedule was published which is shown in Table 5.4. The roof loads in the 1927 report are compared with the 1933 revision in Table 5.5.

An interesting development shown in the 1933 revision was the requirement of minimum loads for the design of slabs in some instances greater than those for the structure. These are given in brackets in Table 5.4.

Table 5.3 Live loads on floors per I.S.E. 1927

Class and loading		Applications
(a)	40 lb/sq ft	Tenements and upper floors of houses not exceeding 4 storeys in height
(b)	60 lb/sq ft	Upper floors of houses of more than 4 storeys Ground floor of houses not exceeding 4 storeys Bedrooms on upper floors of hotels Private bedrooms in hospitals etc Residential flats
(c)	80 lb/sq ft	Classrooms in schools etc. Dormitories and upper floors in offices
(d)	100 lb/sq ft	Assembly Halls etc including access thereto, churches, chapels, assembly rooms in hospitals, colleges etc. Theatres etc. Dance halls, ballrooms and reception rooms in hotels and private houses. Ground floors of houses exceeding 4 storeys, Ground floors and below of offices, hospitals etc. Retail shops for display and sale of lightweight goods. Garages for private cars. Light workshops and storage.
(e)	150 lb/sq ft	Garages for vehicles up to 3 ton gross weight, Rooms for storage of medium weight goods and medium workshops, Theatre stages, Drill Halls and Spectators stands.
(f)	200 lb/sq ft	Book stores at libraries, Museums for heavy goods, Heavy storage and workshops etc, Pavements surrounding buildings.
(g)	Over 200 lb/sq ft	Storage of extra heavy goods and floors supporting printing machinery and the like
(h)	Staircases etc.	Same as floor served but not to exceed 100 lb/sq foot.

Table 5.4 Live loads on floors per I.S.E. 1933

Class and loading		Applications
(a)	40 lb/sq ft (50 lb/sq ft for slabs)	Bedrooms, living rooms, toilets, bathrooms and private corridors in private houses, hotels, flats, hospitals, tenements etc; dormitories and wards in hospitals etc.
(b)	50 lb/sq ft (60 lb/sq ft for slabs)	Offices, corridors and passages above entrance floor; public corridors to class (a)
(c)	70 lb/sq ft (80 lb/sq ft for slabs)	Rooms and halls for public assembly with **fixed** seating including theatres etc. classrooms etc in schools and colleges, reading and writing rooms in libraries, clubs and hotels; churches, chapels and art galleries.
(d)	80 lb/sq ft (ditto for slabs)	Retail shops, offices on entrance floor and below. Garages for cars not exceeding 2 ton gross wt.
(e)	100 lb/sq ft (ditto for slabs)	Rooms and halls for public assembly without fixed seating; drill halls, dance halls and public rooms in hotels, hospitals and restaurants spectators stands, lobbies, corridors and stairs to this class. Light workshops.
(f)	120 lb/sq ft (150 lb/sq ft for slabs)	Garages for vehicles up to 3 tons gross weight when loaded. Storage rooms, workships, retail shops, bookshops and libraries where it can be shown that the average load/sq foot does not exceed 120 lbs. Staircases etc to this class.
(g)	200 lb/sq ft (ditto for slabs)	Storage rooms workshops and the like where it can be shown that the average load/sq foot does not exceed 200 lbs. Staircases etc to this class. Pavements surrounding buildings but not adjoining roadway.

Table 5.6 Imposed loads from BS449 1948

Class of loading	Floor space occupancy	Superimposed floor load per sq.ft.	Minimum* loads on slabs or floor boards per ft. width, uniformly distributed	Minimum* load on beams uniformly distributed
		lbs	lbs	lbs
I	Private dwellings of not more than two storeys	30	240	1920
II	Rooms in private dwellings of more than two storeys, including flats; hospital rooms and wards; bedrooms and private sitting rooms in hotels and tenement houses; and similar occupancies	40	320	2560
III	Rooms used as offices	50	400	3200
IV	Classrooms in schools and colleges; minimum for light workshops	60	480	3840
V	Banking halls and offices where the public may congregate	70	560	4480
VI	Retail shops; places of assembly with fixed seating†; churches and chapels; restraurants; garages for vehicles not exceeding 2½ tons gross weight (private cars, light vans, etc.); circulation space in machinery halls, power stations, pumping stations etc., where not occupied by plant or equipment	80	640	5120
VII	Places of assembly without fixed seating (public rooms in hotels, dance halls, etc.); minimum for filing or record rooms in offices; light, workshops generally, including light machinery	100	800	6400
VIII	Garages to take all types of vehicles	100	Worst combination of actual wheel loads or, if the slab is capable of effective lateral distribution of load, 1.5 x maximum wheel load, but not less than 2000 lb, considered to be distributed over a floor area 2 ft.6 in. square.	
IX	Light storage space in commercial and industrial buildings; medium workshops	150	–	–
X	Minimum for warehouses and general storage space in commercial and industrial buildings; heavy workshops. (The loads imposed by heavy plant and machinery should be determined and allowed for.)	200	–	–

* Minimum load for slabs becomes operative at spans of less than 8 ft. Minimum load for beams becomes operative on areas less than 64 sq. ft. Beams, ribs and joists spaced at not more than 3 ft. centres may be calculated for slab loadings.

The loadings stated in these columns refer to the design of the slabs and individual beams respectively, including their connections.

† Fixed seating implies that the removal of the seating and the use of the space for other purposes are improbable.

Table 5.5 Comparison of roof loads to I.S.E.

Report published 1927	Report revised 1933
The following imposed loads apply to the horizontal and vertical projection of the roof (i) Flat roofs with inclination not exceeding 15° to horizontal Vertical load 50 lb/sq ft Horizontal load 0 lb/sq ft (ii) Sloping roofs with inclination not exceeding 40° to horizontal Vertical load 25 lb/sq ft Horizontal load 10 lb/sq ft (iii) Sloping roofs with inclination not exceeding 75° to horizontal Vertical load 15 lb/sq ft Horizontal load 15 lb/sq ft (iv) Sloping roofs with inclination exceeding 75° to horizontal to be treated as vertical surfaces. The above loads are to be considered as inclusive of temporary loads, snow and wind, and only apply to roofs in multi-storey steel frame buildings not exceeding 50 ft in span. However, the imposed load on a flat roof need not exceed the imposed load on the floor below.	The following imposed loads deemed to include snow and wind (i) On roofs with inclination not exceeding 10° to horizontal:– (a) Where no direct access 15lb/sq foot (b) Where direct access 30 lb/sq foot (ii) On all roofs inclined at more than 10° to to horizontal, curved and barrel roofs etc. without access. 10 lb/sq foot on plan taken as uniformly distributeol over the slope of the roof plus the normal wind load.

5.3.6 British Standard 449 1932

This specification gave a much simpler schedule of loading viz:–

Imposed loads

Floors of rooms used for domestic purposes	40lb/sq ft.
Offices – floors above entrance floor	50lb/sq ft
Offices – entrance floor and below	80lb/sq ft
Churches, reading rooms etc	70lb/sq ft
Retail stores	80lb/sq ft
Assembly Halls etc	100lb/sq ft
Flat Roofs	30lb/sq ft

Inclined Roofs – wind load only
at 15lb/sq ft inwards on windward slope
and 10lb/sq ft outwards on leeward slope

This substantially remained unaltered until 1948.

5.3.7 British Standard 449 1948

Ten categories of imposed load were tabulated. In addition to the distributed loads per square foot of area minimum loads on slabs and on beams were also given.

This is given as Table 5.6.

5.3.8 General

Sufficient information has been given to show the development of live or imposed loads over a long period of time. The publication of CP3 Chapter V 1952 and subsequent amendments transferred loadings from design specifications to separate documents.

CP3 Chapter V should be consulted for any required information subsequent to BS449 1948.

It is interesting to note that E.S. Andrews in his book Theory and Design of Structures (Fifth Edition 1932) gives a table comparing live loads in Britain and those concurrently in use in Canada, New York and Germany.

The figures quoted for Canada show substantial reductions on the ISE and LCC values which have already been quoted herein.

5.4 Wind Loads

From the very nature of the subject this has been one of the most difficult matters to resolve.

Prior to the Tay Bridge disaster in 1879 comparatively little attention was given to the subject by engineers, though Smeatons formula, published in 1759, ie 120 years earlier, proves that it had long been appreciated that forces due to wind pressure were both real and important.

Smeatons formula is given as:–

$$p = 0.005V^2$$

where p is the pressure or load in lbs/sq foot and V the velocity of the wind in miles/hour.

Following upon experiments at the National Physical Laboratory it was considered that Smeaton's formula gave results which were too high and the formula was altered to:–

$$p = 0.003V^2$$

Using this latter formula a wind velocity of 100 miles per hour gives a pressure of 30lbs/sq foot, but as such a velocity of wind would not normally be sustained, the average velocity would give a more realistic loading.

Prior to the erection of the Forth Railway Bridge Sir Benjamin Baker conducted experiments on wind loads by measuring the pressure on plates exposed to the wind.

Records of such experiments over a period from 1884 to 1890 gave the following average results:–

(a)	On 1.5sq ft revolving gauge	27.6lb/sq ft
(b)	On 1.5sq ft fixed gauge	29.8lb/sq ft
(c)	On 300sq ft fixed gauge	16.9lb/sq ft

Subsequent to the erection of the Forth Railway Bridge records were kept on small fixed gauges 1.5sq ft in area placed at different heights above high water level. The average pressures recorded between 1901 and 1906 were:–

(a)	At 50ft above high water level	13lb/sq ft
(b)	At 163ft above high water level	23lb/sq ft
(c)	At 214ft above high water level	29lb/sq ft
(d)	At 378ft above high water level	50lb/sq ft.

It is on record that wind loads of 30, 40, 50 and even 56lb/sq ft have been specified by various authorities prior to the introduction of the L.C.C. loading in 1909.

In 1930 a volume, Wind Stresses in Buildings by Robins Fleming was published in USA. This details the investigation into wind loads at length and was accepted at that period as the most authoritative work on the subject.

Various specifications for wind loads are as follows:–

5.4.1 London County Council (General Powers) Act 1909

The requirements for loads on roofs which were deemed to include wind forces were given in item 5.3.4. and will not be repeated. The most important requirement is:–

"All buildings shall be so designed as to resist safely a wind pressure in any horizontal direction of not less than 30lb/sq ft of the upper two-thirds of the surface of such buildings exposed to wind pressure".

This requirement was strictly imposed in the design of buildings in London. It was also used outside London prior to the publication of the ISE Report.

5.4.2 Institution of Structural Engineers – Report on Steelwork for Buildings

Part 1 Loads and Stresses 1927

Apart from the loads on roofs which have already been specified (see 5.3.5.) the following simple requirement was given:–

"The whole building must be designed to resist a horizontal wind load equivalent to wind pressure on a projected vertical surface of:—

(a)	Up to a level of 30ft above ground	15lb/sq ft
(b)	At levels more than 30ft above ground	20lb/sq ft
(c)	Towers, turrets and like structures projecting above roof	30lb/sq ft

The negative wind pressure on the leeward side may be ignored for ordinary buildings".

5.4.3 Institution of Structural Engineers — Report on Steelwork for Buildings Part 1 Loads and Stresses 1938

This report made drastic amendments to wind loads on the complete structure, as well as on roofs which have already been reported upon (see 5.3.5.)

All wind forces must be calcualted on the whole area of the exposed surface irrespective of length and height as follows:—

(a) On vertical exposed surfaces normal to the direction of the wind.
A horizontal wind force of 5lb/sq ft at mean ground level increasing by 1lb/sq ft for each 10ft increase in height up to a maximum of 15lb/sq ft at a height of 100ft and then a constant value of 15lb/sq ft for all heights exceeding 100ft.

(b) Wind forces equal to 50% in excess of the above values for exposed chimneys, isolated ventilators and similar projections above general roof level.

(c) Wind forces normal to inclined windward surfaces transverse to the direction of the wind equal to the mean intensity of the wind between eaves and ridge, calculated as (a) above and multiplied by coefficient C from Table 5.7 below.

Table 5.7 List of Coefficients C for calculating wind forces normal to surface

θ	C	θ	C	θ	C
5°	0.173	30°	0.800	65°	0.995
10°	0.337	35°	0.863	70°	0.998
15°	0.486	40°	0.910	75°	0.999
20°	0.612	45°	0.943	80°	1.00
25°	0.718	50°	0.965	85°	1.00
26.34°	0.745	55°	0.980	90°	1.00
		60°	0.990		

NB. θ is the angle of inclination to the horizontal

(d) Wind Forces normal to inclined leeward surfaces transverse to the direction of the wind equal to 50% of the values given in (c) acting outward, to be considered as acting simultaneously with the downward acting force on the windward face specified in (c).

(e) For open sided buildings the wind load on the leeward slope to be 100% that on the windward slope.

(f) Wind loads on gable ends to be calculated from (a) except that between eaves and ridge the mean value to be used.

(g) A dragging force on the full area of surfaces parallel to the direction of the wind of 2½% of the value of the wind at the appropriate height from (a) above.

(h) Reduction of wind loads on multi-span roofs, viz

Span next windward span	50% reduction
Next span	75% reduction
Remaining spans	87½% reduction

these to be used to calculate the overall effect of the wind on the structure.

(i) Refers to wind on cylindrical surfaces to be taken at 60% of values in (a) and (b).

(j) All the forces specified to apply where velocity V of wind at a height of 50ft above mean ground level was not expected to exceed 80 miles/hour. On sea coast and other exposed positions the values given to be increased in ratio of:—

$$\frac{(\text{Anticipated Velocity V})^2}{80^2}$$

As will be seen the determination of wind loads to this report was very comprehensive, and much more related to fact than previous requirements as will be appreciated by reference to CP3 Chapter V 1972.

5.4.4. British Standard 449 1932

This substantially repeated the LCC requirements with some additions and alterations viz:—

Wind on vertical surfaces	15lb/sq ft horizontal on upper 2/3rds
Wind on inclined surfaces	
Windward	15lb/sq ft inward
Leeward	10lb/sq ft outward
Wind on projections above main roof	10lb/sq ft horizontal

5.4.5 British Standard 449 1948

Ten years after the Institution of Structural Engineers issued their amended Part 1 — Loads and Stresses 1938 of their Report on Steelwork for Buildings, which so drastically altered the whole approach to wind loading, British Standard 449 was also altered to give a more rational view of wind loading.

This specification now related the wind pressure to the assumed wind velocity in miles per hour and the exposed height of the building.

For assuming the wind velocity the United Kingdom was divided into three zones and three conditions of exposure as shown in Table 5.8.:

Table 5.8 Wind Velocities in miles/hour

District	With natural protection	Open country inland	Condition of max. exposure
West Scotland N W Ireland N W England S W England Wales	60	70	80
East Scotland N E Ireland N E England E England S E England S England	55	65	75
Central England including Severn Estuary	50	60	70

The unit wind pressure (p) in lbs/sq ft on the verical face of a building applied uniformly over the whole surface was given by the formula:—

$$p = \frac{V^2}{600}\sqrt{1 + 0.06\,(h-s)}$$

where:–

h – the height of the windward face above general ground level

s – the assumed sheltered height from permanent obstacles (not to be taken at more than 0.5h.

This unit wind pressure (p) was used to determine the applied forces as follows:–

(i) The external wind load on vertical surfaces of buildings was divided into a pressure of 0.5p on the windward face and a suction of 0.5p on the leeward face.
N.B. A surface inclined to the horizontal of 70° or more was considered to be vertical.

(ii) The external wind load on roofs was as shown in Table 5.9:–

Table 5.9 Wind Pressure on roofs

Slope of roof in degrees	Windward slope or half of flat roof	Leeward slope or half of flat roof
0	– 1.0p	– 0.5p
22½	– 0.25p	
30	0	
45	+ 0,25p	
70 and over	+ 0.5p	

The specification required that the supporting framework and foundation of a building must be designed to resist the accumulative effect of the wind on the sides and roof plus any projections above the main roof, with certain allowance being made for the stiffening effect of walls and floors, when stability calculations could be neglected. It also called for an examination of the permeability of the cladding and allowances depending thereon for internal pressure and suction.

These notes, which do not give a fully comprehensive repeat of the wind load requirements contained in the 1948 edition of BS449, are intended to indicate the extensive change in requirements for wind loading which occured shortly after the end of the wartime relaxations. Though the ISE report was issued before the war commenced in 1939 this was **not mandatory** whilst the use of BS449 was called for in the by-laws of a large number of local authorities.

5.4.6. C.P.3. Chapter V 1952 etc

This "code of functional requirements of buildings", Chapter V Loading gave very detailed information for the determination of wind loads on structures.

Due to extensive investigation at the Building Research Station, thinking on wind loads constantly altered, and therefore it is not intended giving any detailed explanation.

In 1965 a reset edition of CP3 was published, the title being amended to "code of basic data for the design of buildings". In the introduction to this edition it reported that the recommendations in the Code, and, in particular, those on wind loading were the subject of further investigation.

In the event, CP3 Chapter V was shortly re-issued in two parts viz:–

Part 1 Dead and Imposed Loads (1967)
Part 2 Wind Loads (1970)
Both parts gave information in metric and imperial units.

5.4.7 Code of basic data for the design of buildings CP3 Chapter V Part 2 Wind Loads 1972:

This is a reprint of the 1970 version, with additional information contained therein. The loads and other data apply to any type of building including steel framed hence the current design codes do not give details of loadings but specify the use of CP3 Chapter V to determine these.

Using this code the assessment of the wind loads on a structure can be shown by a series of steps thus:–

1. The basic wind speed V applicable to the district where the structure is to be erected is found from a map or table
2. The design wind speed V_s is found by multiplying V by factors S1, S2 and S3.
   Hence $V_s = V \times S1 \times S2 \times S3$
   where **S1** is topography factor varying between 0.9 and 1.1
   S2 is ground roughness, building size and height above ground factor and can vary between 0.47 and 1.27 for a building up to 200m in height
   S3 is building life factor based upon a statistical probability of winds of exceptional violence occuring during the life of the building
   This is usually taken as 1.0.
3. The design wind speed V_s is converted to dynamic pressure q using the formula
   $q = kV_s^2$
   where k is a constant based on the units being used viz:–
   k = 0.613 in S.I. Units (N/m² and m/sec)
   or k = 0.0625 in technical metric units (kg/m² and m/sec)
   or k = 0.00256 in imperial units. (lb/sq ft and miles/hour)
4. The dynamic pressure q is multiplied by pressure coefficients Cpe and Cpi or by force co-efficients Cf to find the pressure p exerted at any point on the surface of a building.

Numerous examples exist of the application of the provisions of CP3 Chapter V Part 2 Wind loading including Constrado Publication "Workshop with EOT Crane" published in 1977

5.5 General

The three basic loadings, ie dead, live and wind have been covered in some depth in this section. There are, of course, many others which need to be considered from time to time such as plant loads, dynamic loads from crane gantries etc which are of too variable a nature to be easily summarised in this publication.

SECTION NO. 6 Design stresses

6.1 Introduction

As no official requirements were available prior to the early part of this century, working stresses were very much left to the engineer to settle for himself.

It was of course fully understood that the ultimate or, breaking strengths of materials must be appreciably reduced before being used in design, by dividing by:—

(a) A factor of safety

(b) Factors depending upon the manner in which the member in question was to be used.

The factor of safety was usually fixed having regard to the reliability of the material and the relationship between the dead and the live load increments.

The Dorman Long and Company 1887 Handbook, gave safe distributed loads on beams at $^1/_3$rd, $^1/_4$th and $^1/_5$th the breaking strain, suggesting factors of safety of 3, 4 or 5 were in common use about that time.

As Wrought Iron and Steel were generally accepted as being more consistant than Cast Iron, lower factors of safety were adopted for the former than the latter.

It must be remembered that factors of safety are related to the ultimate strength of a material, but some time before this ultimate is reached the material will have become unservicable due to yield or other changes in state occuring. The true margin of safety is therefore much lower than the factor itself implies.

The second factor which must be observed in arriving at design stresses is the tendancy to buckle rather than fracture under direct compression. This is particularly true of columns where long slender columns can fail by buckling with insignificant direct load, and equally true, of compression flanges of beams when these are not adequately restrained laterally.

Since the turn of the century represented major changes in design rules etc the subject of design stresses will be covered in two separate periods, before 1900 in 6.3 and 6.4 and after 1900 in 6.5 and 6.6.

The stresses in this book relate to elastic allowable, sometimes also referred to as permissable or working stress methods of design. Care should be taken when attempting to use the information herein with other design methods viz. plastic design and limit state design.

6.2 Symbols

During the period under review in this publication a variety of symbols have been used to represent the same quantity. In the interests of uniformity the following will be assigned to the different items shown:—

P = Breaking load
A = Area of section
I = Moment of Inertia
Z = Modulus of Section
r = Radius of Gyration
L = Actual length
ℓ = Effective length — sometimes called equivalent length
d = smallest dimension of section
c = Slenderness Ratio = ℓ/r or L/r
pc = allowable axial stress in compression
pt = allowable axial stress in tension
pbc = allowable bending stress in compression
pbt = allowable bending stress in tension
pq = allowable shear stress
M = material constant in Goodmans formula
N = shape constant in Goodmans formula
E = Young's Modulus of Elasticity
K = Factor of Safety
p = safe compressive stress for short length of material sometimes called the squash load.
a = Rankine's material constant
e = American material constant
BM = Bending Moment
D = overall depth of section
W = applied load
x = lever arm
yt, yc = edge distances from centroid

6.3 Allowable stresses in beams before year 1900

6.3.1 Cast Iron Beams

In section 2.2 the average values of the ultimate strength of good quality cast iron are given as:—

6 tons/sq inch (92.7 N/mm^2) in tension
32 tons/sq inch (494.2 N/mm^2) in compression
8 tons/sq inch (123.6 N/mm^2) in shear

Whilst conservative averages were quoted it was still considered desirable to use a safety factor of 5, which gives the following allowable stresses:—

pbt or pt = 1.2 tons/sq inch (18.5 N/mm^2)
pbc = 6.4 tons/sq inch (98.8 N/mm^2)
pq = 1.6 tons/sq inch (24.7 N/mm^2)

Though it is not specifically mentioned pbc must be reduced if necessary to allow for lateral instability of the compression flange but this did not often occur from the nature of floor construction in that era.

6.3.2 Wrought Iron Beams

The figures quoted in 1879 for the ultimate strength values of wrought iron, which were generally accepted were:—

21 tons/sq inch (324.3 N/mm^2) in tension
16 tons/sq inch (247.1 N/mm^2) in compression
20 tons/sq inch (308.9 N/mm^2) in shear

A factor of safety of 4 was considered as satisfactory which gives allowable stresses of:—

pbt or pt = 5.25 tons/sq inch (81.1 N/mm^2)
pbc = 4.0 tons/sq inch (61.8 N/mm^2)
pq = 5.0 tons/sq inch (77.2 N/mm^2)

It has been reported that when the Forth Railway Bridge was being designed the use of steel instead of wrought iron was advocated "as the design stress could be increased from 5 tons/sq inch (77.2 N/mm^2) to 6.5 tons/sq inch (100.4 N/mm^2)". This suggests the use of 5 tons/sq inch in both tension and compression especially as it is stated that the ductile nature of the metal made observations on compressive strength difficult.

It is recommended therefore that when checking Wrought Iron beams a figure of 5 tons/sq inch (77.2 N/mm^2) should be used for pbt and pbc provided of course that the compression flange is adequately restrained laterally.

6.3.3 Mild Steel Beams

Mild steel beams began to replace wrought iron beams soon after 1850 and by the year 1900 had almost entirely taken over from the latter.

Figures quoted in 1879 for the average ultimate strength of mild steel are:—

28 to 32 tons/sq inch (432.4 to 494.2 N/mm^2) in tension
30 tons/sq inch (463.3 N/mm^2) in compression
24 tons/sq inch (370.7 N/mm^2) in shear

Using a factor of safety of 4 this gives allowable stresses as follows:—

pbt and pt = 7 tons/sq inch (108.1 N/mm^2)
pbc = 7½ tons/sq inch (115.8 N/mm^2)
pq = 6 tons/sq inch (92.7 N/mm^2)

These figures are a little higher than the available evidence suggests and therefore when checking mild steel beams installed about 1880 stresses of about 6.5 tons/sq inch (100.4 N/mm^2) should be used for both pbt and pbc, always having regard to the lateral restraint of the compression flange.

6.4 Allowable stresses in columns before year 1900

6.4.1 General

It had apparently been appreciated for a considerable time that the allowable stress in a column must be reduced as the slenderness increased, and many people attempted to develop formulae to give satsifactory results under all conditions.

One of these conditions was the situation at the ends of the column, ie the degree of restraint provided. Professor Hodgkinson, about 1850 took as the basis for design a column with flat, or firmly fixed ends and stated that a column, with both ends rounded or hinged should only be allowed to carry 33⅓% of the basic case, and a column with one end fixed and one end hinged should take 66⅔% of the basic case.

Though in some formulae, (even until as late as 1932), separate allowable stresses were specified for different end conditions (though not as widely apart as Hodgkinson's), other formulae were based on the effective or equivalent length of the column, ℓ, this being deduced from the actual length L having regard fo the end conditions. Table 6.1 gives one set of such equivalent lengths which is in some measure still valid today.

Table 6.1 Equivalent length ℓ for columns of actual length L

	Condition of Ends	Equivalent length ℓ
(a)	Both ends rounded ie fixed in position but not in direction	$\ell = L$
(b)	One end rounded other end fixed or built-in ie One end fixed in position but not direction and other end fixed in both position and direction	$\ell = \frac{L}{\sqrt{2}}$
(c)	Both ends fixed or built in ie both ends fixed in both position and direction	$\ell = \frac{L}{2}$
(d)	One end built in; other free ie one end fixed in position and direction and other end free to move	$\ell = 2L$

Two of the most important formulae for columns are those attributed to Euler and to Rankine, and these will be examined.

6.4.2 Euler's formula

This was intended for long slender columns where the direct stress was negligible compared with the buckling stress.

The Formula was usually given in the following form:—

$$\text{Breaking load } P = \frac{\pi^2 EI}{L^2}$$

Now, it is known that the radius of gyration r is found from

$$\sqrt{\frac{I}{A}} \qquad \text{then } r^2 = \frac{I}{A} \text{ and } I = Ar^2.$$

If both sides the formula are divided by A

$$\text{Breaking stress } \frac{P}{A} = \frac{\pi^2 EI}{AL^2}$$

and substituting Ar^2 for I

$$\frac{P}{A} = \frac{\pi^2 AEr^2}{AL^2} = \frac{\pi^2 Er^2}{L^2} = \frac{\pi^2 E}{(L/r)^2} = \frac{\pi^2 E}{c^2}$$

If the factor of safety K = 4

$$\text{allowable stress pc} = \frac{\pi^2 E}{4c^2}$$

If E for steel is 13,400 tons/sq inch

$$pc = \frac{33000}{c^2} \text{ for mild steel.}$$

and E for wrought iron is approximately 12,000 tons/sq inch.

$$pc = \frac{30{,}000}{c^2} \text{ for wrought iron}$$

and E for cast iron is approximately 6,000 tons/sq inch.

$$pc = \frac{15{,}000}{c^2} \text{ for cast iron}$$

The values of E for wrought and cast iron are attributable to Goodman.

6.4.3 Rankine's Formula sometime the Gordon-Rankine

This is usually given in the form

$$pc = \frac{p}{1 + a\,(L/r)^2} = \frac{p}{1 + ac^2} \text{ tons/sq inch}$$

For mild steel

$$a = \frac{1}{9000} \text{ to } \frac{1}{6000},\ p = 6.7 \text{ tons/sq.in.}$$

For wrought iron

$$a = \frac{1}{9000} \text{ to } \frac{1}{8000},\ p = 4.0 \text{ tons/sq.in.}$$

For cast iron

$$a = \frac{1}{2500} \text{ to } \frac{1}{1800},\ p = 7.0 \text{ tons/sq.in.}$$

The variations in the values of the constant a are due to different authorities, whilst the value of p can also be the subject of some questions. Thus the Rankine or Gordon-Rankine formula must be regarded with some suspicion.

6.4.4 Other early column formulae

Two straight-line formulae are quoted, the first from American sources being:—

$pc = p(1 - ec)$ tons/sq.in.

where e and p had the following values:—

Mild steel	e = 0.0053,	p = 6.7 tons/sq.in
Wrought iron	e = 0.0053,	p = 4.0 tons/sq.in
Cast iron	e = 0.0080,	p = 7.0 tons/sq.in

again, however, these constants can vary depending upon the different authorities.

The second straight line formula is from Prof Goodman and is:—

$$P = M-N\,\ell/d \text{ ie } pc = \frac{M-N\,\ell/d}{K} \text{ lbs/sq.in}$$

Limiting values of ℓ/d are given, in the case of cast iron this being fixed low at 15 to avoid the buckling stress causing a residual tension at the surface.

Constants provided by Goodman are listed in Table 6.2. These figures can only be considered as average and offered endless scope for variety by the individual engineer. A comparison for a typical example in cast iron, wrought iron and mild steel is given below.

6.4.5 Comparison of early column formulae

6.4.5.1 Cast Iron Columns

Consider a hollow circular cast iron column 8 inches external diameter, 6 inches internal diameter and on a length of 10 feet with both ends hinged.

The properties of the column are:—

$$A = \frac{\pi}{4}(d^2-d_1^2) = \frac{\pi}{4}(64-36) = \frac{\pi}{4}(28)$$

$$= \underline{21.99\text{ins}^2}$$

$$I = \frac{\pi}{64}(d^4-d_1^4) = \frac{\pi}{64}(4096-1296) = \frac{\pi}{64}(2800)$$

$$= \underline{137.44\text{ins}^4}$$

$$r = \frac{\sqrt{d^2+d_1^2}}{4} = \frac{\sqrt{64+36}}{4} = \frac{\sqrt{100}}{4} = \underline{2.5\text{ins}}$$

$$\text{Then } c = \frac{\ell}{r} = \frac{10\text{x}12}{2.5} = 48;\ c^2 = \underline{2304;}$$

$$\frac{\ell}{d} = \frac{10\text{x}12}{8} = \underline{15.}$$

1. Euler's Formula

For factor of safety K of 4

$$pc = \frac{15000}{c^2} \text{ tons/sq.in.}$$

But cast iron less reliable so increase K to 6, then

$$pc = \frac{15000}{c^2} \times \frac{4}{6} = \frac{10000}{c^2} = \frac{10000}{2304}$$

$$= \underline{4.34 \text{ tons/sq.in.}}$$

2. Gordon-Rankine Formula

Using an average value for a of $\frac{1}{2150}$

$$pc = \frac{7.0}{1+\frac{2304}{2150}} = \frac{7.0}{1+1.07} = \underline{3.38 \text{ tons/sq.in.}}$$

3. American Formula

$$pc = 7.0\,(1-0.008 \times 48) = 7.0\,(1-0.384)$$
$$= 7.0\,(0.616) = \underline{4.31 \text{ tons/sq.in.}}$$

4. Goodman's Formula

$$pc = \frac{M-N(\ell/d)}{K} \text{ lbs/sq.in} \quad \frac{M-N(\ell/d)}{2240\text{ K}} \text{ tons/sq.in.}$$

$$= \frac{140{,}000-6100\text{x}15}{2240\text{ K}} = \frac{140{,}000-92500}{2240\text{ K}}$$

$$= \frac{47500}{2240\text{ K}} = \frac{21.2}{K} = \underline{3.53 \text{ tons/sq.in.}}$$

(Using 6 for K as before)

6.4.5.2 Wrought Iron Columns

Consider a joist section column 12" x 6" x 57 lbs as produced by Dorman Long and Company in 1887, assuming that these sections were rolled in wrought iron as well as in mild steel. The effective length will be taken as 15 feet.

The properties of the column can be obtained from Table No 3.3 and are:—

$$A = 16.96 \text{ ins}^2 \quad r_{min} = 1.31 \text{ ins.} \quad d = 6.11 \text{ ins.}$$

$$\text{Then } c = \frac{\ell}{r} = \frac{15\text{x}12}{1.31} = \underline{137.4};\ c^2 = \underline{18880;}$$

$$\frac{\ell}{d} = \frac{15\text{x}12}{6.11} = \underline{29.46}$$

1. Euler's Formula

With factor of safety of 4

$$pc = \frac{30000}{c^2} = \frac{30000}{18880} = \underline{1.59 \text{ tons/sq.in.}}$$

2. Gordon-Rankine Formula

Using an average value of a of $\frac{1}{8500}$

$$pc = \frac{p}{1+ac^2} = \frac{4.0}{1+\frac{18880}{8550}} = \frac{4}{1+2.22}$$

$$= \underline{1.24 \text{ tons/sq.in.}}$$

3. American Formula

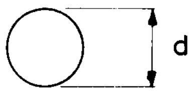
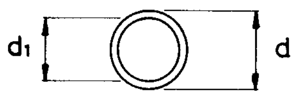
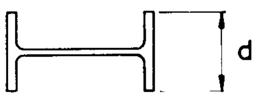
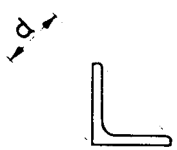
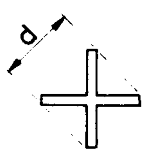
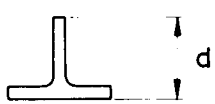
$$pc = p(1-ec) = 4.0\,(1-0.0053\text{x}137.4)$$
$$= 4.0\,(1-0.728) = 4.0\,(0.272)$$

$$= \underline{1.09 \text{ tons/sq.in.}}$$

4. Goodman's Formula

$$pc = \frac{M-N(\ell/d)}{K} = \frac{47000-1070\text{x}29.46}{K}$$

$$= \frac{47000-31522}{K} = \frac{15478}{K} \text{ lbs/sq.in.}$$

TABLE NO 6.2	GOODMANS COEFFICIENTS FOR COLUMN DESIGN								1914
	Hard Cast Iron			Wrought Iron			Mild Steel		
Shape and dimension d	Constant M	Constant N	Limit ℓ/d	Constant M	Constant N	Limit ℓ/d	Constant M	Constant N	Limit ℓ/d
Rectangle 	140,000	6,600	15	47,000	825	40	71,000	1570	30
Solid round 	140,000	7,000	15	47,000	900	40	71,000	1700	30
Hollow round 	140,000	6,100	15	47,000	775	40	73,000	1430	30
Joist 	140,000	8,000	15	47,000	1070	30	71,000	1870	30
Channel 	140,000	8,000	15	47,000	1070	30	71,000	1870	30
Angle 	140,000	8,000	15	47,000	1070	30	71,000	1870	30
Cruciform 	140,000	8,000	15	47,000	1070	30	71,000	1870	30
Tee 	140,000	8,000	15	47,000	1070	30	71,000	1870	30

$$= \frac{6.91}{K} \text{ tons/sq.in.} \qquad = \underline{1.73 \text{ tons/sq.in.}}$$

(Using 4 for K)

If K increased to 5 $= \underline{1.38 \text{ tons/sq.in.}}$

6.4.5.3 Mild Steel Columns

Using the same example as for wrought iron.

1. Euler's Formula

$$pc = \frac{33000}{c^2} = \frac{33000}{18880} \qquad = \underline{1.75 \text{ tons/sq.in.}}$$

2. Gordon-Rankine Formula

Using an average value for a of $\frac{1}{7500}$

$$pc = \frac{6.7}{1 + \frac{18880}{7500}} = \frac{6.7}{1 + 2.52} \qquad = \underline{1.90 \text{ tons/sq.in.}}$$

3. American Formula

$$pc = 6.7\,(1-0.0053 \times 107.4)$$
$$= 6.7\,(0.272) \qquad = \underline{1.82 \text{ tons/sq.in.}}$$

4. Goodman's Formula

$$pc = \frac{M-N\,(\ell/d)}{2240\text{ K}} \text{ tons/sq.in}$$
$$= \frac{71000-1870 \times 29.46}{2240\text{ K}}$$
$$= \frac{71000-55090}{2240\text{ K}} = \frac{7.10}{K} \qquad = \underline{1.78 \text{ tons/sq.in.}}$$

(Using 4 for K)

6.4.5.4. Comments on comparison and recommendations

Comparing the results for cast iron it will be observed that the Euler value is higher than the Gordon-Rankine and Goodman figures. This is probably because whilst the example was selected to be on the limit of ℓ/d given by Goodman a slenderness ratio of 48 cannot be considered to show a long slender column, the basis of Euler's formula.

The result from the American Formula is also high.

As far as wrought iron is concerned, the Goodman result is roughly equal to the average obtained from the other three once the factor K is increased to 5.

The most satisfactory comparison, is that for mild steel where all four formulae give very close results.

In the light of these answers it is recommended that columns erected, prior to 1900 should be checked using Goodman's formula, with values for K as follows:–

Cast Iron K = 6
Wrought Iron K = 5
Mild Steel K = 4.

It must be remembered that all the figures so far quoted are for centrally applied axial loads and whilst the formulae include some provision for incidental eccentricity, observed eccentricity of loading must be provided for. This will be discussed later.

Please note:– As these column formulae were developed in imperial terms the results only should be converted to metric if required.

6.5 Allowable stresses in beams since 1900

6.5.1 Cast Iron Beams

Though there is not much evidence of the use of cast iron beams since the turn of the century, the London County Council (General Powers) Act 1909 recognised that these could be made and used if desired, and the allowable stresses on cast iron beams were published as follows:–

pbt = 1.5 tons/sq.in ($23.2\ N/mm^2$)
pbc = 8.0 tons/sq.in ($123.6\ N/mm^2$)
pq = 1.5 tons/sq.in ($23.2\ N/mm^2$)

These stresses can be used for good quality cast iron beams in the L.C.C. area but the figures quoted in 6.3.1. are probably more reliable to use elsewhere.

6.5.2 Wrought Iron Beams

Wrought iron ceased to be used for structural purposes about 1900 when it was almost entirely replaced by the cheaper and more reliable mild steel.

The L.C.C. 1909 Act specified the following allowable stresses:–

pbt = 5.0 tons/sq.in ($77.2\ N/mm^2$)
pbc = 5.0 tons/sq.in ($77.2\ N/mm^2$)
pq = 4.0 tons/sq.in ($61.8\ N/mm^2$)

These stresses approximate to those recommended for earlier wrought iron and should be used if required.

6.5.3 Mild Steel Beams

Subsequent to 1900 the allowable stresses in mild steel beams have seen many changes not the least being substantial increases in pbt and pbc where the beam was adequately restrained against lateral instability, as well as the introduction of more precise formulae for determining the reduced allowable stress when lateral instability occurs.

Andrews, in Theory and Design of Structures quotes allowable stresses as follows:–

Mild steel in tension 8.0 tons/sq.in ($123.6\ N/mm^2$)
Mild steel in compression 6.8 tons/sq.in ($105.0\ N/mm^2$)
Mild steel in shear 5.0 tons/sq.in ($77.2\ N/mm^2$)

In the L.C.C. 1909 Act the allowable stresses are somewhat different as follows:–

pbt = 7.5 tons/sq.in ($115.8\ N/mm^2$)
pbc = 7.5 tons/sq.in ($115.8\ N/mm^2$)
pq = 5.5 tons/sq.in ($84.9\ M/mm^2$)

Neither of these two authorities mentioned lateral instability, possibly because the methods of construction then in use inhibited to a large degree buckling of the compression flange.

In 1927 the Institution of Structural Engineers Report on Steelwork for Buildings Part 1 Loads and Stresses was first published. The allowable bending stresses were as follows:–

pbt = 8.0 tons/sq.in on net section ($123.6\ N/mm^2$)
pbc = 8.0 tons/sq.in on net section ($123.6\ N/mm^2$)
or 6.8 tons/sq.in on gross section of rivetted compression flange ($105.0\ N/mm^2$)

The report then said:–

"If the unsupported length (ℓ) of the flange of a beam is greater than twenty times the breadth B of the flange the maximum fibre compressive stress on the net area shall not exceed [11–0.15 ℓ/B]" ℓ/B was not to exceed 50.

In 1938 this report was reprinted and gave the following allowable stresses for beams:–

pbt = 8.0 tons/sq.in ($123.6\ N/mm^2$)
pbc = 8.0 tons/sq.in ($123.6\ N/mm^2$)
where the beam compression flange was efficiently restrained laterally or where the effective laterally unsupported length ℓ did not exceed 107 times the least radius of gyration r. When this latter did occur
pbc = 1.0 + 750 r/ℓ (or 1.0 + 750/c) tons/sq.in.

This stress was to be applied to the gross section, and ℓ/r, or c was not permitted to exceed 300.

In 1932 British Standard 449 was first published. The allowable stresses in beams in this specification repeated the 1927 report of the Institution of Structural Engineers.

During the period 1940/1945 war time emergency relaxations permitted pbt and pbc with lateral restraint to be increaed to 10 tons/sq.in and the formula to:—

pbc = [14.4—0.22 ℓ/B] tons/sq.in.

In 1948, BS449 was again revised and CP113 was issued. These, together with the London Building (Constructional) By Laws 1951, ratified the use of a bending stress of 10 tons/sq. in (154.4 N/mm^2) in tension and also in compression where lateral restraint was provided, and where the compression flange was not continuously restrained the stress was calculated by a formula viz:—

In BS449:—

Bending stress in compression

$$pbc = 1000 \frac{K_1}{(\ell/r)} \text{ tons/sq.in.}$$

where ℓ is the length between effective restraints.
r is the radius of gyration of the beam section perpendicular to the plane of bending, and
K_1 is the shape factor based on the ratio of r_{xx}/r_{yy} as given in Table 6.5

In CP113 and LCC regulations the formula was:—

$$\text{Bending stress in compression } pbc = 920 \frac{K_1}{(\ell/r)} \text{ tons/sq.in.}$$

where ℓ and r are as before and K_1 has a slightly different value as also shown in Table 6.3.

Table 6.3 Values of shape factor K_1

r_{xx}/r_{yy}	BS449 1948	CP113 1948 LCC 1951
5.0	1.00	1.05
4.5	1.125	1.15
4.0	1.25	1.30
3.5	1.375	1.50
3.0 or less	1.50	1.50

It is not considered necessary to take this further as current regulations are readily available and a summary of allowable stresses in BS449 from 1932 to 1959 is given in Table 6.4.

It can however be noted in passing that a bending stress of 10.7 tons/sq.in or the equivalent in metric terms of 165 N/mm^2 is now permitted for steel to Grade 43 in BS4360 which is roughly the equivalent of mild steel to BS15.

6.6 Allowable stresses in columns since 1900

6.6.1 Cast Iron Columns

The London County Council (General Powers) Act 1909 gave working stresses for cast iron columns as given in Table 6.5a. These working stresses can reasonably be used for columns made after the turn of the century.

It should be assumed that L/r = 80, is the limit which should not be exceeded for cast iron.

Intermediate values can be found by interpolation. It is interesting to note that the LCC 1909 Act gave three stress ranges based on end conditions and actual lengths rather than deducing an effective length.

6.6.2 Wrought Iron Columns

Few, if any wrought iron columns were used after the turn of the century. However, the LCC 1909 Act specified working stresses for wrought iron columns as two-thirds those of the equivalent mild steel columns. Table 6.5b gives these allowable stresses which can readily be converted to metric if desired.

6.6.3 Mild Steel Columns

6.6.3.1 Mild Steel Columns to LCC 1909

In 1909 the London County Council (General Powers) Act quoted the figures given in Table 6.5c.

6.6.3.2 Mild Steel Columns to Moncrieff Formula 1909

Whilst the LCC stresses had to be used when designing for construction in London elsewhere a more relaxed attitude was taken. Redpath Brown and Co Ltd put forward a set of values determined from formulae developed by J Mitchell Moncrieff and these were widely accepted. They are tabulated in Table 6.6, and it can be assumed that they date from the early part of the century.

6.6.3.3 Mild Steel Columns to ISE 1927

These two approaches to the design of steel columns remained effective for many years. In 1927 the ISE introduced an empirical formula based on a series of straight lines giving a stress of 6 tons/sq.in maximum for c ratio's up to 60, dropping to 3 tons/sq.in at c = 120, etc. This was not widely adopted and the first major step forward was in 1937 when BS449 gave a more comprehensive formula which was also adopted by ISE.

This is sufficiently important as to warrant its own part.

6.6.4 Column stresses to BS449 1937

Table 6.7 gives the allowable axial compressive stresses in columns of mild steel to BS15.

Limiting values of c were specified ie:—

(a) For all columns forming part of the main structure 150
(b) For subsidiary members in compression 240

Rules for finding the effective lengths of columns were given in detail in this specification. They are summarised as follows:—

(a) Both ends held in position and direction ℓ = 0.7L
(b) Both ends held in position and one end restrained in direction ℓ = 0.85L
(c) Both ends held in position but unrestrained in direction ℓ = L
(d) One end held in position and restrained in direction and other end restrained in direction but free to move in position ℓ = 1.0 to 1.5L depending on degree of restraint

BS449 1937 gave very comprehensive rules for dealing with eccentric loads on columns which will be examined later.

6.6.5 Column stresses to BS449 1948

In 1948 another major change in column stresses was made with the issue of a revised BS449. These new stresses were included in Code of Practice CP113 1948 and shortly afterwards they were adopted by the L.C.C., with the issue of the London Building (Constructional) By laws 1951.

Table 6.8 tabulates the allowable axial stresses for mild steel columns for steel to BS15, and whilst a lower limit of 20 for c is used, BS449 only extended the table to show a stress of 9 tons/sq.in (139 N/mm^2) at a slenderness ratio c of zero.

In addition to increases in the allowable axial stress pc the limits for the slenderness ratio c were raised as follows:—

(a) For all columns forming part of the main structure 180
(b) For members carrying loads from wind only 250
(c) For members normally acting as ties in roof trusses but subject to reversal from wind load 350

TABLE NO. 6.4 WORKING STRESSES IN TONS/SQ.IN TO BS449

Year	Steel Grade	Tension Thickness (ins)	Tension Stress	Compression (Maximum)	Bending Thickness (ins)	Bending Stress (Maximum)	Shear Max Stress	Shear Thickness (ins)	Shear Average Stress	Bearing
1932	MS		8	8		8	5			
1935&37	MS		8	8		8	5			
	HY		12	12		12	7.5			
1939&40 (Admts)	MS		8	10		10	5			
	HY		12	12		12	7.5			
1948	MS		9	9*		10(9.5)	6.5			12
	HY	≤1.75	13.5	13.5	≤1.75	15(14.5)	9			18
		>1.75	11.5	13.5	>1.75	13(12.25)	8			18
1959	MS	≤1.50	9.5	9.5	≤1.50	10.5(10.0)	7.0	≤0.75	6.0(6.0)	12.0
		>1.50	9.0	9.5	>1.50	10.0(9.5)	7.0	>0.75	6.0(5.5)	12.0
	HY	≤2	13.5	13.5	≤2	14.5(13.5)	10.0	≤2	8.5(8.0)	17.0
		>2	$\frac{Ys}{1.63}$	13.5	>2	$\frac{Ys}{1.52}$ $\left(\frac{Ys}{1.63}\right)$	$\frac{Ys}{2.2}$	>2	- (7.0)	17.0

* for discontinuous angle struts; MS-6. HY-9
() values refer to plated members

Note: This table cannot cover all the nuances of the standard, thus for detailed requirements reference must be made to the original text of BS449.

MS refers to mild steel to BS 15
HY refers to high yield steel to BS 548 before 1959
and to BS 968 after 1959

TABLE NO.6.5a L.C.C. requirements for C.I. Columns 1909

Ratio actual length L to least radius of gyration	Working Stress in tons/sq inch of net section		
	Both ends hinged	One end hinged One end fixed	Both ends fixed
20	3.5	4.0	4.5
30	3.0	3.5	4.0
40	2.5	3.0	3.5
50	2.0	2.5	3.0
60	1.5	2.0	2.5
70	1.0	1.5	2.0
80	0.5	1.0	1.5

TABLE NO.6.5b L.C.C. requirements for W.I. Columns 1909

Ratio of actual length L to least radius of gyration	Working Stress on tons/sq inch of section		
	Both ends hinged	One end hinged One end fixed	Both ends fixed
20	2.67	3.33	4.00
40	2.33	3.00	3.67
60	2.00	2.67	3.33
80	1.67	2.33	3.00
100	1.33	2.00	2.67
120	0.67	1.67	2.33
140	0.00	1.33	2.00
160		0.67	1.67
180		0.00	1.00
200			0.33
210			0.00

TABLE NO.6.5c L.C.C. requirements for mild steel columns 1909

Ratio of actual length L to least radius of gyration	Working Stress in tons/sq inch of section		
	Both ends hinged	One end hinged One end fixed	Both ends fixed
20	4.0	5.0	6.0
40	3.5	4.5	5.5
60	3.0	4.0	5.0
80	2.5	3.5	4.5
100	2.0	3.0	4.0
120	1.0	2.5	3.5
140	0.0	2.0	3.0
160		1.0	2.5
180		0.0	1.5
200			0.5
210			0.0

TABLE 6.6 Column stresses to Moncrieff formula

Ratio L/r	Working Stress in tons/sq inch		
	Both ends hinged	Both ends fixed	Both ends flat
20	6.50	6.65	6.65
40	5.93	6.50	6.50
60	5.03	6.27	6.27
80	4.01	5.93	5.93
100	3.09	5.52	5.52
106	2.86	5.38	5.38
107	2.82	5.35	5.35
120	2.38	5.03	4.25
140	1.86	4.52	3.12
160	1.48	4.01	2.39
180	1.20	3.52	1.89
200	0.99	3.09	1.53

TABLE 6.7 Column stress to BS449 1937

Slenderness ratio c = effective L / min. r	Axial stress pc in tons/sq inch	Axial stress pc in N/mm2
20	7.17	110.7
30	6.92	106.9
40	6.64	102.6
50	6.30	97.3
60	5.89	91.0
70	5.41	83.6
80	4.88	75.7
90	4.33	66.9
100	3.81	58.8
110	3.34	51.6
120	2.93	45.3
130	2.58	39.8
140	2.28	35.2
150	2.02	31.2
160	1.81	28.0
170	1.62	25.0
180	1.46	22.5
190	1.33	20.5
200	1.21	18.7
210	1.10	17.0
220	1.01	15.6
230	0.93	14.4
240	0.86	13.3

TABLE NO.6.8 Column stress to BS449 1948

Slenderness ratio c = effective L / min. r	Axial stress pc in tons/sq inch	Axial stress pc in N/mm2
20	8.03	124.0
30	7.54	116.5
40	7.06	109.0
50	6.57	101.5
60	6.09	94.1
70	5.66	87.4
80	5.12	79.1
90	4.62	71.4
100	4.13	63.8
110	3.67	56.7
120	3.26	50.3
130	2.89	44.6
140	2.57	39.7
150	2.30	35.5
160	2.06	31.8
170	1.86	28.7
180	1.68	25.9
190	1.52	23.5
200	1.39	21.5
210	1.27	19.6
220	1.17	18.1
230	1.08	16.7
240	0.99	15.3
250	0.92	14.2
300	0.65	10.0
350	0.49	7.6

6.6.6 Column stresses to BS449 after 1948

These are sufficiently recent as to be readily available if required.

6.7 Eccentric Loads on Columns

Whilst the allowable column stresses already discussed at length include a small allowance for "accidental eccentricity", they are primarily concerned with centrally applied loads, or loads balanced about the centroid of the section. Loads not applied at the centroid, ie eccentric thereto, produce bending stresses as well as axial stresses which can materially reduce the carrying capacity of the column.

Early literature dealing with eccentric loads on columns appears to be sparse. Goodman, however, dealing with cast iron columns condemns the "barbarous" practice of loading columns on side brackets which "reduces the load the column can carry to one tenth, or even one twentieth what it would carry if centrally loaded".

The fundamental principle of stress due to eccentricity is given in Figure 6.1.

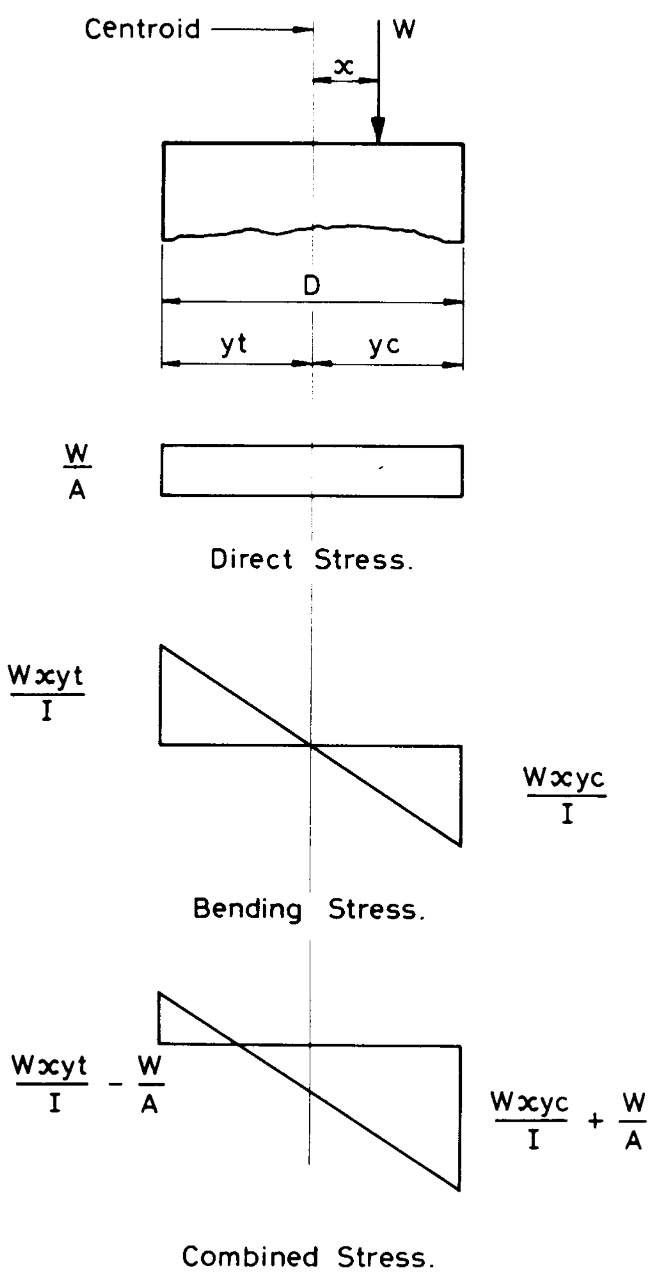


Figure 6.1 Stress due to Eccentricity.

W = Load
x = Eccentricity of load about centroid
A = Area of section
I = Moment of Inertia about axis through centroid
D = depth of section
y_t and y_c = distances to extream fibres from centroid
BM = Wx

Note: The classic expression is written:–

$$\text{Combined stress} = \frac{W}{A} \pm \frac{BMy}{I}$$

When considering mild steel and wrought iron the maximum stress ie direct + bending is the critical one to watch. With cast iron however, when the bending stress exceeds the direct stress tension occurs on part of the section, and since the strength of cast iron in tension is so poor this can be critical.

The engineers prior to the twentieth century, appeared to limit the combined stress to the allowable stress produced by the application of the column formula which they favoured. This was very conservative. However, since the quality of the material, and other factors, were far from consistent, it is recommended that this practice should be observed when dealing with cast and wrought iron columns.

For steel columns, where the material generally is more reliable, the allowable stresses for both axial load and for bending should be used, and whilst there have been many variations, including the method given in BS449 1937, the basic combination given by the formula:–

$$\frac{f_c}{p_c} + \frac{f_{bc}}{p_{bc}} \not> 1$$

where f_c is the axial stress given by W/A and f_{bc} is the compressive bending stress given by BMy/I is considered to offer a practical approach to determining the combined effect of axial and bending stresses.

6.8 High Strength Steels

All the information given for steel in this section is based upon the material being ordinary mild steel to BS15. In 1934 however BS548 was issued covering a steel with higher tensile strength than BS15 steel, and the allowable stresses were increased by approximately 50% to suit this steel (except for column stresses where the increases depended on the slenderness ratio).

In 1941 BS968, High Tensile Steel (Fusion Welding Quality) was issued. This was a quality of steel designed to overcome problems which had been encountered in welding steel to BS548. The allowable stresses were higher than for Mild Steel to BS15 but less than those to BS548.

All these steels, mild steel, high tensile steel, fusion welding quality steel, and extra high strength steel are all covered in BS4360 which replaces BS15, BS548, BS968 etc and appropriate allowable stresses to suit are given in BS449, 1969 and 1970. They will not be examined further in this publication.

SECTION NO. 7 Developments in Fabrication and Design

7.1 Introduction

A historical publication of this nature would be incomplete without some reference to changes in design, fabrication and erection techniques which have occured during the period under review.

Perhaps the most important fundamental change was the introduction of framing a structure, ie the provision of beams and columns bolted together to act as a skeleton to support the walls and floors and thus transfer the loads direct to suitable foundations.

For a long time after iron and steel were introduced into building construction the method of use consisted almost entirely of beams supported on brickwork or on intermediate columns, and there was no interconnection other than simple bolting to maintain the members in position.

Of course there were exceptions such as the historic arch supporting the roof of St Pancras Station, and other similar structures. But in the main, simply supported beams were the main uses of the materials, with columns introduced to break up long spans.

It is claimed that the first completely steel framed building in the British Isles was a furniture store at Stockton-on-Tees designed and constructed in the year 1900 by Redpath Brown and Co Ltd. This consisted of beams and columns bolted together, though in America site riveting was extensively used for joining the components of a structure together.

The basic difference between riveted and bolted connections should be clearly understood. Driving hot rivets expanded them to fill the holes and thus produced a non-slip connection, whilst ordinary bolts in clearance holes gave connections with a certain amount of slip and hence these could not be regarded as rigid.

Site riveting was not a common practice in this country though some engineers did insist on non-slip connections, and as an alternative to site riveting the use of close tolerance bolts was accepted. This consisted of using turned barrel bolts in holes marginally (3/1000" to 5/1000") larger. As it was impossible to align holes to this degree of accuracy they were drilled to a smaller diameter and reamed out to the required size after the parts had been assembled.

Before proceeding to a discussion of more recent developments in fabrication and design etc a review of bolts and bolted connections is given in section 7.2. Subsequently sections 7.3 to 7.7 inc. refer to a selected number of changes viz:—

- 7.3 Electric Arc Welding of steelwork
- 7.4 Use of High strength friction grip bolts
- 7.5 Rigid frame analysis
- 7.6 Plastic methods of design
- 7.7 Computer Analysis

7.2 Riveted and Bolted Connections

Experience has shown that it is often the connections rather than the members themselves that may form the weak link in the chain. It is often difficult to identify the bolt and nut material from the markings on them, even if they exist.

The first of the British Standards for black bolts was BS28 issued in 1932 which was eventually replaced by BS916 in 1953. This was superseded by the current standard BS4190 in 1967 which was introduced to cover the International Standards Organisation (ISO) range of bolts.

Similarly high tensile bolts, which were generally close tolerance bolts, were first covered by BS1083 in 1942 which was subsequently superseded by the current standard BS3692 in 1967.

During the intervening years several British Standards were produced with respect to the various threads eg Whitworth, Fine, Unified Course and Fine etc and also to the type of bolt head eg cup, countersunk square etc.

Details of the fasteners currently produced are available in BCSA's publication "Structural Fasteners and their application."

In the Table 7.1 are listed the allowable stresses, in tons/sq.in for rivets and bolts in accordance with various editions of BS449. Mild steel (MS) was always to BS15 and high tensile steel was to BS548 with the exception of the 1959 edition when it changed to BS968.

If the stresses in the bolts in a connection are at a critical level, then it may be better to simply replace the existing bolts with those of known quality.

The nominal diameter of the shank of an existing rivet may be found by dividing the diameter of the cup head by 1.6 and similarly that of an existing bolt by dividing the distance across the flat surfaces of the head by 1.5.

7.3 Electric Arc Welding of Steelwork

The welding together of two pieces of metal is quite an old process, though the method of carrying out the work has changed. Welding of structural steelwork probably dates from about the year 1900, this being done first by the oxy-acetylene process.

Construction by this process was very limited, though properly carried out the results could be quite sound and durable. A canopy at the Manchester Works of Redpath Brown and Co Ltd, constructed about 1902, was supported on a series of welded lattice girders and remained in use for some fifty years until dismantled to make way for a new development.

Electric Arc Welding commenced to infiltrate into the United Kingdom in the mid 1920's though its adoption was very slow. Apart from the capital cost of new equipment to carry out the process, the changes necessary in design and detailing to suit the new technique were slow to be developed.

Initially electric are welding was used to replace riveting in the fabrication of components and connections. It was not at first fully appreciated that it was not economic to weld on an angle cleat — if welding was being used the angle must be replaced by a plate.

The outbreak of war in 1939, and the need to fabricate quickly components for the war effort such as bridge parts etc accelerated the development of arc welding though it was not until after the cessation of hostilities that it was possible to lay down special welding shops.

Over the years since the war major improvements in arc welding techniques has meant that most major components of large steel structures are fabricated by this means. Little site fabrication however is done this way probably because of the difficulties in quality control and inspection.

Initially, electric arc welding was restricted to mild steel and even then specially prepared electrodes were required to ensure that the strength of the parent metal was not reduced. Subsequently, however, developments in the manufacture of electrodes, and in welding techniques has meant that all grades of steel can now be arc welded without difficulty.

It should be noted that the welding of cast iron requires special attention to the selection of electrodes and the preheating of the parent metal and therefore **it is not recommended** that welding should be used to connect to existing cast iron members.

In broad terms, any welded fabrications found and dating before 1930/35 are almost certain to be gas welded, and later electric arc welded.

TABLE NO.7.1 ALLOWABLE STRESSES IN RIVETS AND BOLTS in tons/sq inch

Detail	Rivets			Bolts		
	Type	MS	HT	Type	MS	HT
1932						
Tension	Shop	5		≯0.75"φ	5	
	Site	4		<0.75"φ	0	
Shear	Shop	6		Turned	6	
	Site	5		Black	4	
Bearing	Shop	12		Turned	12	
	Site	10		Black	8	
1935 & 1937						
Tension	Shop	5	7.5	≯0.62"φ	5	7.5
	Site	4	6	<0.62"φ	0	0
Shear	Shop	6	9	Turned	6	9
	Shop	5	7.5	Black	4	6
Bearing	Shop	12	18	Turned	12	18
	Site	10	15	Black	8	12
1948						
Tension	Shop	5	7.5	≯0.75"φ	6	9
	Site	4	6	<0.75"φ	5	7.5
Shear	Shop	6	9	Turned	6	9
	Site	5	7.5	Black	4	6
Bearing	Shop	12*	18*	Turned	12*	18*
	Site	10	15*	Black	8	12*
		* increase by 25% when in double shear				
1959						
Tension	All	6.0	9.0	≯1.12"φ	8.0	12.0
				≯0.87"φ	7.0	10.5
				<0.87"φ	6.0	9.0
Shear	Power Shop	6.5	9.0	Turned	6.0	9.0
	Power Site	6.0	8.5	Black	5.0	7.0
O	Hand	5.5	7.5			
Bearing	Power Shop	19.0	27.0	Turned	19.0	27.0
	Power Site	17.5	25.0	Black	12.5	$
	Hand	16.0	23.0			

O All values reduced by 20% when in single shear

$ Value not given, approx. 17.5 prorata.

Note:- MS = Mild Steel
HT = High Tensile Steel

7.4 Use of High Strength Friction Grip Bolts

Connections made with HSFG bolts rely upon the friction between faying surfaces induced by torque in the bolts. Because of this the question of holes for the bolts reducing the effective area of a member does not arise.

This type of connection must not be confused with High Strength Bolted connections where the bolt acts in shear or bearing similar to an ordinary black bolt, but with increased allowable stresses.

High strength friction grip bolts were first introduced in this country about 1950 but it was not until after the ISE Jubilee Symposium in June 1959 that their use became widespread.

The main function of these bolts initially was to replace close tolerance fitted bolts for non-slip connections. These were expensive to install as the holes had to be drilled undersize and then be reamed out to the exact size after assembly of the parts. Carrying out such work on site was also slow.

Of course, site riveting met the same need, but very little site riveting has ever been carried out in this country, though its use was widespread in America.

The main danger with HSFG connections is in loosing the friction by loosening the bolts. To avoid this danger some engineers required the thread of the bolt to be "clinched" after the required torque had been applied.

As this type of fastener is relatively recent in adoption it is unlikely to crop up often in buildings being renovated. If however it should be found excessive care must be used to make sure that the viability of the joint should not be destroyed.

7.5 Rigid Frame Analysis

Whilst rigid frame construction was extensively used for arches, portal frames etc from quite an early date it did not become generally applied to building frames for two main reasons viz:—

(i) Difficult to analyse in detail
(ii) Difficult to make fully rigid connections.

For a long time multi-storey steel building frames were designed to empirical rules ie they were designed as pin jointed for vertical load and as fixed jointed for horizontal loads from the wind.

The design as pin jointed for vertical loads avoided the use of statically indeterminate methods, and the analysis for the horizontal loads could be carried out using one of a variety of recognised approximate methods.

To design even a small building frame as fully rigid by any of the recognised methods such as strain-energy, slope deflection etc was so laborious as to be avoided except in exceptional cases. The use of approximate methods such as Hardy Cross method of moment distribution etc did simplify the work a little but even this method was avoided whenever possible.

Developing fully rigid connections using rivets or bolts also presented many problems and even though the advantages of rigid construction were fully appreciated very few examples were to be found.

The Steel Structures Research Committee, which was established jointly by the Government and the Steel Industry, developed a semi-rigid method of design where the stiffness of simple connections and their effect on the interaction between beam and column were assessed and exploited. Even this method met with little use in practice.

The widespread use of welding, and to a lesser extent HSFG bolting, made rigid frame construction easier to attain (though not without cost) and several frames erected during the last twenty years are in this form.

7.6 Plastic Methods of Design

Plastic methods of design developed by Professor J.F. Baker and his colleagues, during and after the war of 1939/45 exploit fully the continuity in a structure where the formation of a plastic hinge can result in the redeposition of moment, and thereby ulitise more fully the strength of the construction.

Whilst the plastic theory has been extensively applied to portal frame construction there are a limited number of multi-storey building frames designed in this manner, possibly due to the difficulty in determining the positions where plastic hinges will form, though research is continuously in progress at Manchester University and elsewhere to simplify the application of the plastic theory to multi-story frames.

7.7 Computer Analysis

The development of the electronic computer led to the preparation of computer programmes to solve the problems of multi-storey rigid frames which had for so long inhibited their adoption.

The first practical programme of this nature was written to suit the Ferranti Mercury Computer, and is described in the Steel Designer's Manual 3rd Edition 1966.

Basically the programme was limited to a frame of twenty joints but by an overlap system many more joints could be accommodated.

The first major multi-storey frame-work designed using the computer method of analysis, and constructed with site welded joints was the Littlewoods Headquarters Building in Liverpool which was eighteen storeys in height, constructed in 1963.

7.8 General

These short notes are intended to indicate that care must be taken if altering or renovating a more recent structure say about 25 years or less in age, to ensure that the methods of design and construction are fully understood so that there are no adverse results due to interaction or load transfer.

Guidance on the design of individual elements of a structure and the connections between them to the current British Standard BS449 Part 2 1969 is given in BCSA publications 'Structural Steelwork — Design of Components' and 'Manual on Connections'.

SECTION NO. 8 Continental Sections

8.1 Introduction

It is known that around the turn of the century, and, in some instances, up to the late 1930's, steel sections were imported from various parts of Europe, in particular from France, Belgium and Luxembourg.

Whilst most of the Continental exporters were prepared to roll and supply British Standard Sections once these were established, quite a large quantity of standard continental beams were also used in this country.

This section is therefore devoted to providing basic information about these continental sizes together with an indication of the extent of the availability from various countries.

From reference to various continental handbooks a fair proportion of the information required is obtainable from a handbook published by the French steelmaker Longwy in 1928. This did not imply a new range of sizes dating from 1928, the sizes were produced much earlier than that and were well established in the year 1900.

Handbooks from other countries with dates ranging from 1913 to 1934 indicate the supply of sections to the French sizes. It can be assumed therefore that these sizes are typical of standard continental beams. This is confirmed by reference to another French producer's handbook dated 1905.

In addition to the standard beams, R.A. Skelton and Company produced a range of Broad Flange Beams which were in imperial sizes, and aimed at the United Kingdom market. A substantial quantity of these beams were known to have been imported between 1920 and 1950, and details extracted from Skelton's 1921 Handbook are given.

8.2 French Sections

As mentioned, these are standard continental sections based on the sizes of beams produced from a very early date.

From about 1845 to 1860 all such beams produced in France were in wrought iron but from 1860 some beams were in steel made by the Bessemer converter, and from 1870 by the Siemens Martin process.

After 1900, the sections produced were almost entirely in steel, though some wrought iron was used until about 1915.

The tables given, numbered 8.1 to 8.4 inclusive are taken from Longwy's handbook dated 1928. In the catalogue published by Descours Cabaud and Cie in 1905 many of the sizes shown are included. The catalogue also lists others, with narrower or wider flange widths. Unfortunately, no technical data is available for these sections, but it is stated that all sections could be obtained in iron or steel.

8.3 Italian Sections

Reference to extracts from an Italian handbook – date unknown – shows a much wider range of wide flange sections than those produced by Longwy in France which are shown in Table 8.2.

These consisted of light profiles DIL, and normal profiles DIN, and it is apparent from the tabulated properties that the two series were separate rather than one being derived from the other.

Table 8.5 gives the properties of the light or reduced DIL profiles and Table 8.6 the properties of the normal DIN profiles.

The same handbook lists standard continental profiles ranging from 80 x 42 to 500 x 185, only the basic and **not** the larger derived sections which were produced by opening the rolls.

The properties of these standard continental beams numbering 32 in all – are obtainable from Table 8.1 already presented.

8.4 Luxembourg Sections

Luxenbourg, depending almost entirely upon exports of its steel products, has always rolled sections of sizes to suit its customers.

Reference to a handbook published by Columeta Luxenbourg (now Arbed–Belval) in 1934 lists standard continental sections ranging from 80 x 42 to 550 x 200, again the basic sections only – not the derived – and the properties are similar to those in Table 8.1.

The table of wide flange profiles also differs to the extent that two smaller sections ie 100 x 100 and 120 x 120 are included and the upper limit is 400 x 300. For convenience Table 8.7 has been prepared to show the properties of the two smallest profiles, the balance of the table to repeat Table 8.6.

8.5 Belgium Sections

Reference to a handbook dated about 1930 shows that standard continental sections ranging from 80 x 42 to 550 x 200 were produced in Belgium.

Unlike the French however a **lighter** version of all sections from 100 x 49.5 to 560 x 198 were also produced. Sufficient technical detail of continental sections has already been provided and therefore no information is given of these reduced profiles.

Belgium also produced a few special light beams with narrow flanges viz:–

100 x 44 x 7.35kg	(3.94ins x 1.73ins)
120 x 44 x 8.98kg	(4.73ins x 1.73ins)
140 x 50 x 10.7kg	(5.51ins x 1.97ins)
160 x 50 x 11.9kg	(6.30ins x 1.97ins)
180 x 55 x 14.4kg	(7.09ins x 2.17ins)
200 x 60 x 17.0kg	(7.87ins x 2.36ins)

and also produced wide flange DIL and DIN sections as already tabulated.

8.6 German Sections

Extracts from a German handbook dated 1913 lists 39 standard continental profiles ranging from 80 x 42 x 5.95kg/m to 550 x 200 x 167.21 kg/m. Whilst the specified mass/m shows slight variations the properties of these beams can be considered as similar to corresponding properties for the basic sections in Table 8.1.

It can be stated here that in Europe the root radii for beam sections is not standardised and varies slightly between countries and makers. This variation has little effect on section properties but can make a small difference in mass/m.

The same German handbook also list 36 wide flange sections, 18 in the normal series similar to Table 8.6 and 18 in the reduced series similar to Table 8.5. In both series the sizes range from 180 x 180 to 475 x 300 but as the thicknesses of web and flange do not match those given for the Italian sections the properties of the German sections can not be considered as comparable with the Italian sections. Unfortunately no detailed properties are available for the German sections.

Notes relative to tables 8.1 to 8.4 inclusive

Tables 8.1, 8.2 and 8.3 Joists

(a) The sizes are metric based but for convenience the imperial equivalent of both depth and width is given.

(b) In tables 8.1 and 8.3 two widths are given for each depth of section, the second width in each case being obtained by opening the rolls.

(c) All beam sections were rolled with 14° taper flanges.

Table 8.4 Channels

Two widths are given for each depth of channel, again the second is obtained by opening the rolls.

TABLE NO.8.7 — BEAM SIZES ROLLED IN LUXEMBOURG ABOUT 1900/1934

METRIC UNITS — WIDE FLANGES

Size D x B	Mass/m	Imperial Equivalent D x B	Imperial Equivalent Mass/ft	Thickness Web	Thickness Flange	Area	Moment of Inertia X - X	Moment of Inertia Y - Y	Radius of Gyration X - X	Radius of Gyration Y - Y	Section Modulus X - X	Section Modulus Y - Y
mm	kg	ins	lbs	mm	mm	cm2	cm4	cm4	cm	cm	cm3	cm3
100x100	20.50	3.94x 3.94	13.78	6.5	10.0	26.1	447	167	4.1	2.5	89.3	33.4
120x120	26.90	4.72x 4.72	18.08	7.0	11.0	34.3	864	317	5.0	3.0	114.0	52.9
140x140	34.63	5.51x 5.51	23.27									
150x150	37.15	5.91x 5.91	24.96									
160x160	45.81	6.30x 6.30	30.78									
180x180	51.62	7.09x 7.09	34.69									
200x200	64.94	7.87x 7.87	43.64									
220x220	71.54	8.66x 8.66	48.07									
240x240	87.39	9.45x 9.45	58.72									
250x250	91.08	9.84x 9.84	61.80	ALL PROPERTIES REPEAT TABLE 8.6								
260x260	94.77	10.24x10.24	63.68									
280x280	112.71	11.02x11.02	75.74									
300x300	120.87	11.81x11.81	81.22									
320x300	134.48	12.60x11.81	90.37									
340x300	136.52	13.39x11.81	91.74									
360x300	150.30	14.17x11.81	101.00									
380x300	152.50	14.56x11.81	102.48									
400x300	163.68	15.75x11.81	110.00									

8.7. Skelton Broad Flange Beams

These beams, shown in the Skelton handbook No 17A dated 1921 in Imperial dimensions and with Imperial properties can be considered to be equivalent to the DIN beams given in Table 8.6, and slight variations in mass/m can be accounted for by the root radii.

Six extra sizes of beam are included in the Skelton range viz:—

170 x 170 x 48.57 kg/m
190 x 190 x 54.39 kg/m
210 x 210 x 68.16 kg/m
230 x 230 x 74.78 kg/m
270 x 270 x 98.26 kg/m
290 x 290 x 116.67 kg/m

If necessary, properties of these sections can be assumed by interpolation between the size above and the size below.

8.8 General Remarks

From the various tables and other comments given so far in the Section certain conclusions can be drawn:—

1. From quite an early date a range of standard narrow or normal flange beam sizes existed on the Continent, some or all of which were produced by the major steel and iron companies and many of which were imported and used in the United Kingdom.

Whilst the handbooks consulted are all dated after 1900 — the earliest being 1905 — it is understood that the sections were in existence in 1900.

2. Many continental producers rolled special sections, perhaps for regular customers, similar to the special sections rolled in Britain for the National Coal Board.

3. Most Continental producers rolled wide flange sections but these were not standardised to the same extent as the narrow flange beams.

4. Again, it would appear from a perusal of numerous European handbooks that whilst a standard Continental range of channel sizes existed many makers in the various countries introduced variations. Hence as in Table 8.4 the French manufacturers offered a derived range of channels as well as the standard range.

5. Many European steel makers rolled sizes to suit the standards of the countries to which they exported as well as their own sizes.

6. Details of current steel qualities, section sizes and design codes for most continental countries can be found in the BCSA publication 'International Structural Steelwork Handbook'.

7. Current Continential practice is to roll IPE beams to Euronorm 19.57 and HE beams to Euronorm 53.62. Full versions of these Euronorms are available from BSI if required.

TABLE NO. 8.1 BEAM SIZES ROLLED IN FRANCE BY LONGWY ABOUT 1900

METRIC UNITS NORMAL PROFILES (P.N.)

See separate page for notes

Size D x B	Mass/m	Imperial Equivalent Size D x B	Mass/ft	Thickness Web	Flange	Area	Moment of Inertia X - X	Y - Y	Radius of Gyration X - X	Y - Y	Section Modulus X - X	Y - Y
mm	kg	ins	lbs	mm	mm	cm2	cm4	cm4	cm	cm	cm3	cm3
80x42	5.95	3.15x1.65	4.00	3.9	5.9	7.58	77.7	6.28	3.20	0.91	19.4	2.99
80x48	9.72	3.15x1.89	6.53	9.9	5.9	12.38	103.3	10.21	2.89	0.91	25.8	4.25
90x46	7.06	3.54x1.81	4.74	4.2	6.3	8.99	117.0	8.76	3.61	0.99	26.0	3.81
90x51	10.59	3.54x2.01	7.12	9.2	6.3	13.49	147.4	12.82	3.31	0.98	32.7	5.03
100x50	8.34	3.94x1.97	5.60	4.5	6.8	10.63	170.0	12.20	4.00	1.07	34.0	4.86
100x56	13.05	3.94x2.20	8.77	10.5	6.8	16.63	220.0	18.30	3.64	1.05	44.0	6.54
110x54	9.66	4.33x2.13	6.49	4.8	7.2	12.31	238.0	16.20	4.40	1.15	43.2	5.99
110x59	13.98	4.33x2.32	9.39	9.8	7.2	17.81	293.4	22.50	4.06	1.12	53.3	7.61
120x58	11.13	4.72x2.28	7.78	5.1	7.7	14.18	327.0	21.40	4.80	1.23	54.5	7.38
120x64	16.78	4.72x2.52	11.28	11.1	7.7	21.38	413.4	30.90	4.40	1.20	68.9	9.64
130x62	12.62	5.12x2.44	8.48	5.4	8.1	16.08	435.0	27.40	5.20	1.30	66.9	8.85
130x67	17.72	5.12x2.64	11.91	10.4	8.1	22.58	526.5	36.50	4.83	1.27	81.0	10.90
140x66	14.32	5.51x2.60	9.62	5.7	8.6	18.24	572.0	35.20	5.60	1.39	81.7	10.70
140x72	20.91	5.51x2.83	14.05	11.7	8.6	26.64	669.2*	48.60	5.01*	1.35	101.3	13.49
150x70	16.01	5.91x2.76	10.76	6.0	9.0	20.39	734.0	43.70	6.00	1.46	97.8	12.50
150x76	23.07	5.91x2.99	15.50	12.0	9.0	29.39	902.8	59.30	5.54	1.42	120.3	15.61
160x74	17.90	6.30x2.91	12.03	6.3	9.5	22.80	933.0	54.50	6.40	1.55	116.6	14.70
160x79	24.18	6.30x3.11	16.25	11.3	9.5	30.80	1103	70.20	5.98	1.51	137.9	17.70
170x78	19.77	6.69x3.07	13.28	6.6	9.9	25.19	1165	66.50	6.80	1.62	137.0	17.10
170x84	27.78	6.69x3.31	18.67	12.6	9.9	35.39	1410	88.90	6.31	1.58	166.0	21.20
180x82	21.88	7.09x3.23	14.70	6.9	10.4	27.87	1444	18.30	7.20	1.71	160.4	19.80
180x88	30.36	7.09x3.46	20.40	12.9	10.4	38.67	1735	106.4	6.70	1.66	192.8	24.20
190x86	23.95	7.48x3.39	16.09	7.2	10.8	30.51	1759	97.20	7.59	1.78	185.1	22.60
190x91	31.40	7.48x3.58	21.10	12.2	10.8	40.00	2045	120.4	7.15	1.73	215.1	26.50
200x90	26.24	7.87x3.54	17.63	7.5	11.3	33.43	2139	117.0	8.00	1.87	214.0	25.90
200x96	35.66	7.87x3.78	23.96	13.5	11.3	45.43	2539	147.8	7.48	1.80	254.0	30.80
210x94	28.47	8.27x3.70	19.13	7.8	11.7	36.27	2558	137.0	8.40	1.94	243.6	29.30
210x99	36.71	8.27x3.90	24.67	12.8	11.7	46.77	2943	166.7	7.93	1.89	280.3	33.70
220x98	31.02	8.66x3.86	20.84	8.1	12.2	39.51	3055	163.0	8.79	2.03	277.7	33.30
220x104	41.38	8.66x4.09	27.81	14.1	12.2	52.71	3587	203.4	8.25	1.96	326.1	39.10
230x102	33.46	9.06x4.02	22.48	8.4	12.6	42.63	3605	188.0	9.20	2.10	313.4	36.90
230x107	42.49	9.06x4.21	28.55	13.4	12.6	54.13	4112	226.3	8.72	2.04	357.5	42.30
240x106	36.17	9.45x4.17	24.31	8.7	13.1	46.08	4239	220.0	9.59	2.19	353.3	41.5
240x112	47.48	9.45x4.41	31.91	14.7	13.1	60.48	4930	271.2	9.03	2.12	410.8	48.4
250x110	38.98	9.84x4.33	26.19	9.0	13.6	49.65	4954	255.0	9.99	2.27	396.3	46.4
250x115	48.79	9.84x4.53	32.79	14.0	13.6	62.15	5605	300.4	9.50	2.20	448.4	52.2
260x113	41.83	10.24x4.45	28.11	9.4	14.1	53.29	5735	287.0	10.37	2.32	441.1	50.8
260x119	54.08	10.24x4.69	36.34	15.4	14.1	68.89	6614	357.9	9.80	2.28	508.7	60.2
270x116	44.89	10.63x4.57	30.16	9.7	14.7	57.18	6623	325.0	10.76	2.40	490.5	56.0
270x121	55.48	10.63x4.76	37.28	14.7	14.7	70.68	7453	382.8	10.27	2.33	552.0	63.3
280x119	47.89	11.02x4.69	32.18	10.1	15.2	61.01	7575	363.0	11.14	2.44	541.0	61.0
280x124	58.88	11.02x4.88	39.57	15.1	15.2	75.01	8489	405.0	10.64	2.32	606.4	65.3
290x122	50.81	11.42x4.80	34.14	10.4	15.7	64.73	8619	403.0	11.54	2.49	594.4	66.1
290x127	62.20	11.42x5.00	41.80	15.4	15.7	79.23	9635	472.8	11.03	2.44	664.4	74.5

300x125	54.16	11.81x4.92	36.39	10.6	16.2	68.99	9785	449.0	11.91	2.55	652.3	71.9
300x131	68.29	11.81x5.16	45.89	16.8	16.2	86.99	11135	538.1	11.31	2.49	742.3	82.1
320x131	61.00	12.60x5.16	40.99	11.5	17.3	77.71	12493	554.0	12.68	2.67	780.8	84.6
320x136	73.56	12.60x5.35	49.43	16.5	17.3	93.71	13858	642.4	12.16	2.62	866.1	94.5
340x137	68.04	13.39x5.39	45.72	12.2	18.3	88.68	15670	672.0	13.45	2.79	921.7	98.1
340x142	81.39	13.39x5.59	54.69	17.2	18.3	103.7	17307	775.0	12.92	2.73	1018	109.2
360x143	76.13	14.17x5.63	51.16	13.0	19.5	96.98	19576	817.0	14.21	2.90	1088	114.2
360x148	90.26	14.17x5.83	60.65	18.0	19.5	115.0	21520	938.5	13.68	2.86	1196	126.8
380x149	83.98	14.96x5.87	56.43	13.7	20.5	107.0	23978	972.0	14.97	3.01	1262	130.4
380x154	98.89	14.96x6.06	66.45	18.7	20.5	126.0	26264	1113	14.44	2.97	1382	144.5
400x155	92.43	15.75x6.10	62.11	14.4	21.6	117.8	29173	1160	15.74	3.14	1459	149.6
400x160	108.13	15.75x6.30	72.66	19.4	21.6	137.8	31839	1317	15.20	3.09	1592	164.7
425x163	103.82	16.73x6.42	69.76	15.3	23.0	132.3	36956	1433	16.71	3.29	1739	175.8
425x168	120.51	16.73x6.61	80.98	20.3	23.0	153.5	40154	1623	16.17	3.25	1890	193.3
450x170	115.27	17.72x6.69	77.46	16.2	24.3	146.8	45888	1722	17.68	3.42	2039	202.5
450x175	132.93	17.72x6.89	89.32	21.2	24.3	169.3	49685	1959	17.13	3.40	2208	223.9
475x178	127.81	18.70x7.01	85.88	17.1	25.6	162.8	56410	2084	18.61	3.58	2375	234.1
475x183	146.46	18.70x7.20	98.42	22.1	25.6	186.6	60875	2343	18.06	3.54	2563	256.1
500x185	140.79	19.69x7.28	94.61	18.0	27.0	179.4	68736	2470	19.57	3.72	2749	267.0
500x190	160.41	19.69x7.48	107.79	23.0	27.0	204.4	73944	2765	19.02	3.67	2958	291.1
550x200	166.65	21.65x7.87	111.98	19.0	30.0	212.3	99054	3486	21.60	4.05	3602	348.6
550x205	188.24	21.65x8.07	126.49	24.0	30.0	239.8	105990	3866	21.02	4.02	3854	377.2
600x215	199.27	23.62x8.46	133.90	21.6	32.4	253.9	138960	4553	23.39	4.24	4632	423.5
600x220	222.82	23.62x8.66	149.73	26.6	32.4	283.9	147960	5180	22.83	4.27	4932	470.9

Note:- * Assumed values only

TABLE NO 8.2 BEAM SIZES ROLLED IN FRANCE BY LONGWY ABOUT 1900

METRIC UNITS VERY BROAD FLANGES (TLA)

See separate page for notes

Size D x B	Mass/m	Imperial Equivalent Size D x B	Mass/ft	Thickness Web	Flange	Area	Moment of Inertia X - X	Y - Y	Radius of Gyration X - X	Y - Y	Section Modulus X - X	Y - Y
mm	kg	ins	lbs	mm	mm	cm2	cm4	cm4	cm	cm	cm3	cm3
180x180	48.43	7.09x 7.09	32.54	8.5	13.6	61.70	3611	1109	7.65	4.24	401.2	123.0
200x200	57.56	7.87x 7.87	38.68	9.0	14.5	73.32	5294	1597	8.50	4.67	529.4	160.0
220x220	64.84	8.66x 8.66	43.57	9.0	15.0	82.60	7359	2202	9.44	5.16	669.0	200.0
240x240	76.00	9.45x 9.45	51.07	10.0	15.9	96.80	10218	3028	10.27	5.60	851.5	252.0
250x250	82.50	9.84x 9.84	55.44	10.5	16.5	105.1	12066	3575	10.71	5.84	965.2	286.0
260x260	90.66	10.24x10.24	60.92	11.0	17.6	115.5	14308	4244	11.13	6.06	1101	326.0
300x300	119.40	11.81x11.81	80.23	12.5	20.0	152.1	25187	7409	12.87	6.98	1679	494.0

TABLE NO. 8.3 BEAM SIZES ROLLED IN FRANCE BY LONGWY ABOUT 1900

METRIC UNITS SPECIAL PROFILES

See separate page for notes

Size D x B	Mass/m	Imperial Equivalent Size D x B	Mass/ft	Thickness Web	Flange	Area	Moment of Inertia X - X	Y - Y	Radius of Gyration X - X	Y - Y	Section Modulus X - X	Y - Y
mm	kg	ins	lbs	mm	mm	cm2	cm4	cm4	cm	cm	cm3	cm3
100x42	7.09	3.94x1.65	4.76	4.0	6.5	9.03	138.2	6.8	3.91	0.87	27.6	3.24
100x51	14.15	3.94x2.01	9.51	13.0	6.5	18.03	213.2	14.1	3.44	0.88	42.6	5.53
120x44	8.18	4.72x1.73	5.50	4.3	6.5	10.43	224.2	8.2	4.64	0.88	37.3	3.72
120x48	11.95	4.72x1.89	8.03	8.3	6.5	15.23	281.8	10.3	4.30	0.82	46.9	4.29
140x47	10.38	5.51x1.85	6.98	4.5	7.9	13.23	390.8	12.4	5.43	0.97	55.8	5.28
140x51	14.78	5.51x2.01	9.93	8.5	7.9	18.83	482.3	16.5	5.06	0.94	68.9	6.47
160x50	12.68	6.30x1.97	8.52	5.5	8.3	16.16	598.2	14.6	6.08	0.95	74.8	5.84
160x55	18.93	6.30x2.17	12.72	10.5	8.3	24.16	768.9	20.9	5.64	0.93	96.1	7.60
250x100	37.28	9.84x3.94	25.05	10.0	12.5	47.50	4478	178.9	9.71	1.94	358.2	35.78
250x105	47.10	9.84x4.13	31.65	15.0	12.5	60.00	5128	191.2	9.24	1.78	410.2	36.42

TABLE NO. 8.4 CHANNEL SIZES ROLLED IN FRANCE BY LONGWY ABOUT 1900

METRIC UNITS NORMAL PROFILES

See separate page for notes

Size D x B	Mass/m	Imperial Equivalent Size D x B	Mass/ft	Thickness Web	Flange	Area	Distance to N.A. from back	Moment of Inertia X - X	Y - Y	Radius of Gyration X - X	Y - Y	Section Modulus X - X	Y - Y min.
mm	kg	ins	lbs	mm	mm	cm2	cm	cm4	cm4	cm	cm	cm3	cm3
80x45	8.64	3.15x1.77	5.80	6.0	8.0	11.00	1.48	106.0	19.9	3.10	1.35	26.5	6.57
80x50	11.78	3.15x1.97	7.92	11.0	8.0	15.00	1.51	127.3	28.7	2.91	1.38	31.8	8.22
100x50	10.60	3.94x1.97	7.12	6.0	8.5	13.50	1.58	206.0	29.7	3.91	1.48	41.2	8.67
100x55	14.52	3.94x2.17	9.76	11.0	8.5	18.50	1.58	247.7	41.9	3.66	1.50	49.5	10.69
120x55	13.35	4.72x2.17	8.97	7.0	9.0	17.00	1.63	364.0	43.9	4.63	1.61	60.7	11.33
120x60	18.06	4.72x2.36	12.14	12.0	9.0	23.00	1.64	436.0	59.7	4.35	1.61	72.7	13.68
140x60	16.01	5.51x2.36	10.76	7.0	10.0	20.40	1.79	605.0	63.5	5.45	1.76	86.4	15.07
140x65	21.51	5.51x2.56	14.45	12.0	10.0	27.40	1.76	719.5	85.1	5.12	1.76	102.7	17.96
160x65	18.84	6.30x2.56	12.66	7.5	10.5	24.00	1.88	925.0	87.1	6.21	1.91	115.6	18.84
160x70	25.12	6.30x2.76	16.88	12.5	10.5	32.00	1.84	1095	114.3	5.85	1.89	137.0	22.15
180x70	21.98	7.09x2.76	14.77	8.0	11.0	28.00	1.96	1354	115.5	6.95	2.03	150.4	22.91
180x75	29.05	7.09x2.95	19.52	13.0	11.0	37.00	1.92	1597	148.8	6.57	2.00	177.4	26.66
200x75	25.28	7.87x2.95	16.99	8.5	11.5	32.20	2.00	1911	150.7	7.70	2.16	191.1	27.65
200x80	33.13	7.87x3.15	22.26	13.5	11.5	42.20	2.00	2244	191.1	7.29	2.13	224.4	31.85
220x80	29.36	8.66x3.15	19.73	9.0	12.5	37.40	2.18	2690	199.7	8.48	2.31	244.5	34.31
220x85	38.00	8.66x3.35	25.53	14.0	12.5	48.40	2.12	3133	250.0	8.05	2.27	284.9	39.18
240x85	33.21	9.45x3.35	22.32	9.5	13.0	42.30	2.27	3598	252.0	9.22	2.44	299.8	40.44
240x90	42.63	9.45x3.54	28.65	14.5	13.0	54.30	2.21	4174	311.4	8.77	2.39	347.8	45.86
260x90	37.92	10.24x3.54	25.48	10.0	14.0	48.30	2.40	4823	323.0	9.99	2.59	371.0	48.93
260x95	48.12	10.24x3.74	32.34	15.0	14.0	61.30	2.34	5555	395.2	9.52	2.54	427.3	55.20
280x95	41.84	11.02x3.74	28.12	10.0	15.0	53.30	2.56	6276	404.9	10.85	2.76	448.3	58.43
280x100	52.83	11.02x3.94	35.50	15.0	15.0	67.30	2.48	7190	493.9	10.34	2.71	513.6	66.94
300x100	46.16	11.81x3.94	31.02	10.0	16.0	58.80	2.74	8026	500.9	11.68	2.92	535.1	69.00
300x105	57.93	11.81x4.13	38.93	15.0	16.0	73.80	2.63	9151	608.1	11.14	2.87	610.1	77.26

TABLE NO.8.5 BEAM SIZES ROLLED IN ITALY ABOUT 1900

METRIC UNITS REDUCED PROFILES DIL (WIDE FLANGES)

Size A x B	Mass/m	Imperial Equivalent D x B	Imperial Equivalent Mass/ft	Thickness Web	Thickness Flange	Area	Moment of Inertia X - X	Moment of Inertia Y - Y	Radius of Gyration X - X	Radius of Gyration Y - Y	Section Modulus X - X	Section Modulus Y - Y
mm	kg	ins	lbs	mm	mm	cm2	cm4	cm4	cm	cm	cm3	cm3
140x140	31.3	5.51x 5.51	21.03	4.5	12.0	39.9	1473	549	6.1	3.7	210	78
150x150	35.0	5.91x 5.91	23.52	4.75	12.5	44.6	1898	704	6.5	4.0	253	94
160x160	38.8	6.30x 6.30	26.07	5.0	13.0	49.4	2398	888	7.0	4.2	300	111
180x180	47.7	7.09x 7.09	32.05	5.5	14.0	60.7	3745	1362	7.9	4.7	416	151
200x200	56.6	7.87x 7.87	38.03	6.0	15.0	72.1	5522	2002	8.8	5.3	552	200
220x220	67.2	8.66x 8.66	45.16	6.5	16.0	85.6	7948	2843	9.6	5.8	723	258
240x240	77.7	9.45x 9.45	52.21	7.0	17.0	99.0	10975	3921	10.5	6.3	915	327
250x250	83.3	9.84x 9.84	55.98	7.25	17.5	106.1	12775	4561	11.0	6.6	1022	365
260x260	90.0	10.24x10.24	60.48	7.5	18.0	114.7	14940	5281	11.4	6.8	1149	406
280x280	102.1	11.02x11.02	68.61	8.0	19.0	130.1	19693	6960	12.3	7.3	1407	497
300x300	115.5	11.81x11.81	77.61	8.5	20.0	147.1	25611	9012	13.2	7.8	1707	601
320x300	122.5	12.60x11.81	82.32	9.0	21.0	156.1	30744	9463	14.0	7.8	1922	631
340x300	129.7	13.39x11.81	87.15	9.5	22.0	165.2	36529	9914	14.9	7.7	2149	661
360x300	136.9	14.17x11.81	91.99	10.0	23.0	174.4	43009	10364	15.7	7.7	2389	691
380x300	144.4	14.96x11.81	97.03	10.5	24.0	183.9	50226	10815	16.5	7.7	2644	721
400x300	151.9	15.75x11.81	102.07	11.0	25.0	193.5	58224	11266	17.3	7.6	2911	751
425x300	160.1	16.73x11.81	107.58	11.5	26.0	203.9	68836	11718	18.4	7.6	3239	781
450x300	168.5	17.72x11.81	113.23	12.0	27.0	214.6	80680	12169	19.4	7.5	3586	811
475x300	176.9	18.70x11.81	118.87	12.5	28.0	225.4	93829	12620	20.4	7.5	3951	841
500x300	186.3	19.69x11.81	125.19	13.0	29.0	237.3	108742	13074	21.4	7.4	4350	872
550x300	197.8	21.65x11.81	132.92	13.5	30.0	252.0	138461	13527	23.4	7.3	5035	902
600x300	209.8	23.62x11.81	140.98	14.0	31.0	267.2	172989	13980	25.4	7.2	5766	932

TABLE NO.8.6 BEAM SIZES ROLLED IN ITALY ABOUT 1900

METRIC UNITS NORMAL PROFILES DIN (WIDE FLANGES)

Size D x B	Mass/m	Imperial Equivalent D x B	Mass/ft	Thickness Web	Flange	Area	Moment of Inertia X - X	Y - Y	Radius of Gyration X - X	Y - Y	Section Modulus X - X	Y - Y
mm	kg	ins	lbs	mm	mm	cm2	cm4	cm4	cm	cm	cm3	cm3
140x140	34.63	5.51x 5.51	23.27	8.0	12.0	44.1	1552	550	5.9	3.5	217	79
150x150	37.15	5.91x 5.91	24.96	8.0	12.0	47.3	1897	670	6.3	3.8	253	90
160x160	45.81	6.30x 6.30	30.78	9.0	14.0	58.4	2634	958	6.7	4.1	329	120
180x180	51.62	7.09x 7.09	34.69	9.0	14.0	65.8	3833	1363	7.6	4.6	426	151
200x200	64.94	7.87x 7.87	43.64	10.0	16.0	82.7	5952	2136	8.5	5.1	595	214
220x220	71.54	8.66x 8.66	48.07	10.0	16.0	91.1	8052	2843	9.4	5.6	732	258
240x240	87.39	9.45x 9.45	58.72	11.0	18.0	111.3	11686	4152	10.2	6.1	974	346
250x250	91.08	9.84x 9.84	61.20	11.0	18.0	116.0	13298	4692	10.7	6.4	1064	375
260x260	94.77	10.24x10.24	63.68	11.0	18.0	120.7	15050	5278	11.2	6.6	1158	406
280x280	112.71	11.02x11.02	75.74	12.0	20.0	143.6	20722	7324	12.0	7.1	1480	523
300x300	120.87	11.81x11.81	81.22	12.0	20.0	154.0	25759	9007	12.9	7.6	1717	600
320x300	134.48	12.60x11.81	90.37	13.0	22.0	171.3	32249	9910	13.7	7.6	2016	661
340x300	136.52	13.39x11.81	91.74	13.0	28.0	173.9	36942	9910	14.6	7.5	2173	661
360x300	150.30	14.17x11.81	101.00	14.0	24.0	191.5	45122	10813	15.4	7.5	2507	721
380x300	152.50	14.96x11.81	102.48	14.0	24.0	194.3	50949	10813	16.2	7.5	2682	721
400x300	163.68	15.75x11.81	110.00	14.0	26.0	208.5	60642	11714	17.1	7.5	3032	781
425x300	166.43	16.73x11.81	111.84	14.0	26.0	212.0	69483	11714	18.1	7.4	3270	781
450x300	181.84	17.72x11.81	122.19	15.0	28.0	231.6	84223	12619	19.1	7.4	3743	841
475x300	184.78	18.70x11.81	124.17	15.0	28.0	235.4	95122	12620	20.1	7.3	4005	841
500x300	200.44	19.69x11.81	134.69	16.0	30.0	255.3	113177	13525	21.1	7.3	4527	902
550x300	206.72	21.65x11.81	138.91	16.0	30.0	263.3	140342	13527	23.1	7.2	5103	902
600x300	226.80	23.62x11.81	152.40	17.0	32.0	288.9	180829	14435	25.0	7.1	6028	962
650x300	233.47	25.59x11.81	156.88	17.0	32.0	297.4	216783	14437	27.0	7.0	6670	962
700x300	254.36	27.56x11.81	170.92	18.0	34.0	324.0	270290	15346	28.9	6.9	7723	1023
750x300	261.42	29.53x11.81	175.67	18.0	34.0	333.0	316256	15349	30.8	6.8	8434	1023
800x300	268.49	31.50x11.81	180.42	18.0	34.0	342.0	366386	15351	32.7	6.7	9160	1023
850x300	291.67	33.46x11.81	195.99	19.0	36.0	371.6	443890	16267	34.6	6.6	10444	1084
900x300	299.12	35.43x11.81	201.00	19.0	36.0	381.1	506040	16270	36.4	6.5	11245	1085
950x300	306.58	37.40x11.81	206.01	19.0	36.0	390.6	572953	16273	38.3	6.5	12062	1085
1000x300	314.04	39.37x11.81	211.03	19.0	36.0	400.1	644748	16276	40.1	6.4	12895	1085

SECTION NO. 9 Miscellaneous

9.1 Introduction

A publication of this nature would be incomplete without some information dealing with unusual applications of steel construction, and also if advice on how to use the contents was omitted. This section will be devoted to some notes on the following:—

9.2 Concrete encased steelwork
9.3 Asymmetrical sections
9.4 Identification of material
9.5 Relationship between past and present

9.2 Concrete encased steelwork

Four particular examples of concrete encasement are considered.

9.2.1. Grillage beams

Grillage beams solidly encased in mass concrete must behave as a composite construction and this was recognised from the early days when it was permitted to design grillage beams for stresses as much as 50% greater than normal stresses.

9.2.2 Filler joist floor construction

Before the introduction of precast and patent concrete floors extensive use was made of small beams at regular spacing either fully encased or with the soffit uncased forming very durable and satisfactory floorings.

Records show that such filler joist floors existed before the year 1900 and in some early examples cast iron sections are known to have been used.

The stiffening effect of the concrete slab was recognised by permitting an increased stress on the steel sections provided that these were designed to carry the load without assistance from the concrete, a favourate method being to allow 1 ton/sq inch increase in bending stress for each 1 inch of concrete cover over the top flange up to a maximum of 3 inches.

When regulations in the form of BS449 1932 were issued this rule of thumb basis was altered in favour of design as a concrete beam with the combined moment of inertia of the steel and surrounding concrete but later issues of BS449 reverted to the original concept.

9.2.3. Beams supporting floor slabs

Beams supporting reinforced concrete floor slabs were often encased in concrete for fire protection, such casing being cast integral with the floor. Again, the stiffening effect of such encasement was appreciated so that in BS449 1935 an increase in the bending stress on such beams was allowed. However, before such increase was permissible a number of conditions had to be met, and then the increase was so small few designers were prepared to use the concession.

9.2.4. Concrete encased columns

In all of the three previous cases the steel beams were subjected to bending as the main function. In the case of columns however the principal condition is axial compression. Concrete is an excellent material in compression though poor in bending and tension, hence adequate recognition of the compressive assistance of concrete encasement to columns was an early priority.

As early as 1914 Redpath Brown and Company Ltd decided to initiate investigations into this question. In the absence of suitable test equipment they offered to supply a testing machine to the National Physical Laboratory.

The outbreak of the first World War stopped the manufacture of the machine and it was not until 1922/1923 that the machine was completed and the tests carried out on a series of steel sections as columns both uncased and cased.

Mr J Mitchell Moncrieff CBE reported on the tests, the results, subsequently published in 1924 by Redpath Brown and Co Ltd., showed the considerable assistance in carrying capacity the concrete gave to the bare steel. However it was not until 1948, some 24 years later that clauses were written into the design specifications to permit an even modest assistance from the concrete casing to steel columns.

In the 1950's Dr Oscar Faber OBE conducted a new series of tests which were reported in the Structural Engineer in 1956. Again the test results proved that far greater reliance could be placed on the concrete casing than is officially permitted.

These brief notes show that many engineers were aware from a very early date that concrete encasement materially assisted the carrying capacity of steel sections, in particular of steel columns and it is therefore possible that some structures exist where, before regulations were introduced, the engineer made some allowance for concrete casing. Since, however, such casing would not be reinforced in the manner prescribed in later specifications it should be ignored in assessing the carrying capacity of any structure apart from the floors. However, since the contribution of the concrete casing can be significant, if considered desirable this can be fully examined and its value determined.

9.3 Asymmetrical Sections

The only examples which can be found of rolled asymmetrical beam sections is in a 1925 French handbook, and these sections were limited in both number and size. Obviously, these were produced for special applications.

In this country two main applications of asymmetric sections can be found. These inevitably are built up sections, and the two applications are considered as follows:—

9.3.1 Wall beams

In early construction uncased steel beams were often used to carry brick walls, and a common detail was as shown in Fig.9.1.

In these and similar details the added strength provided by the steel plate was usually ignored and the whole of the load was carried by the steel beam.

9.3.2 Crane Gantry Girders

Because of the nature of the load to be carried ie vertical load from the weight of the crane plus the load plus impact allowance, coupled with horizontal load applied adjacent to the top flange from cross-surge, unless horizontal stiffening girders were used the girders were built-up asymmetric sections.

Fig 9.2 shows some of the different types frequently used in general workshop construction.

For steel mill buildings etc much more complicated shapes were developed, generally consisting of plate girders with asymmetric flanges, and with the development of metal arc welding welded sections replaced riveted sections, but inevitably with the top flange much larger than the bottom flange.

Many of the Structural Steelwork Handbooks which have been issued from time to time list the design properties of some asymmetrical sections but the permutations are such that it is impossible to repeat this information here. Often, the section under review is not one of those listed and it is necessary to calculate the properties from first principles. This is best done by using the tabular method, an example of this being given in the BCSA publication "Structural Steelwork — Design of Components".

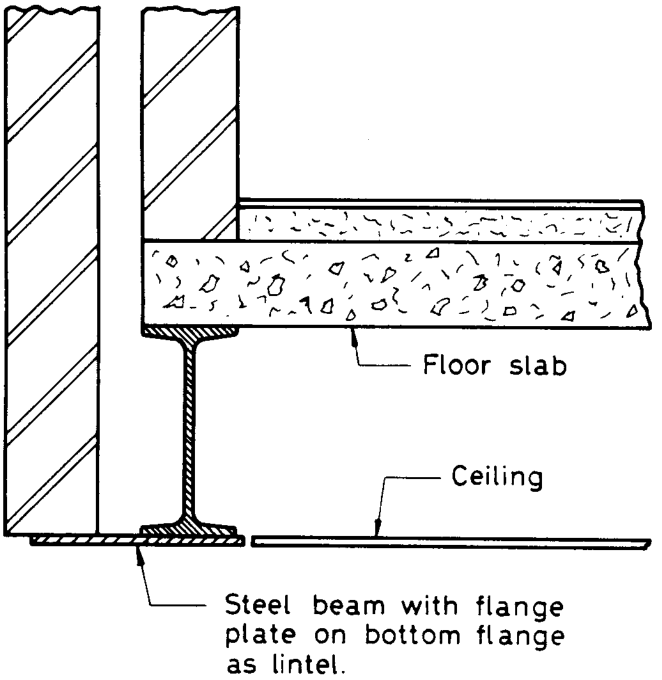


Figure 9.1 Uncased Steel Lintel.

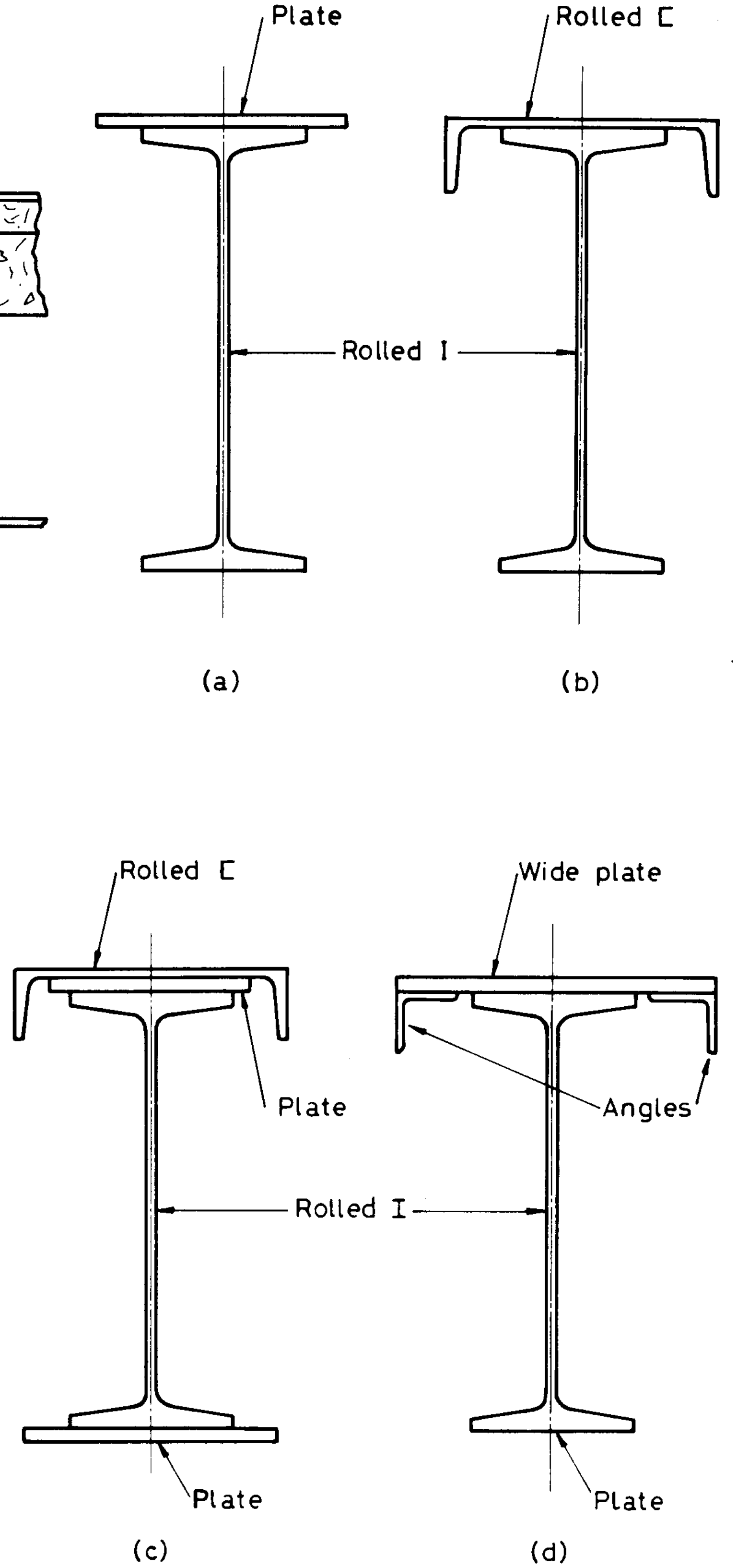


Figure 9.2 Built up Gantry Girders.

9.4 Identification of material

The situation will often occur when examining old construction that it is necessary to determine the material used in order to select the proper working stresses.

Identification of cast iron should present no problems for several reasons viz:—

(a) The shape of the member will not conform to any special class ie in the case of a cast iron beam the section will almost without exception be asymmetric, whilst a cast iron column will have connection material cast on.

(b) Evidence of the mould will almost certain exist in the form of a joint line.

(c) The surface of the member will be pitted and not relatively smooth as with roll marks.

Distinguising between wrought iron and steel can be more difficult. However it may be sufficient to assume the quality of the material using a time factor as follows:—

(i) If it is known that the structure existed before 1890 it is almost certain that the material is wrought iron and appropriate wrought iron stresses used.

(ii) If the structure was built after 1910 and member sizes conform to BS4 it should be safe to assume mild steel stresses.

(iii) Between 1890 and 1910 either wrought iron or mild steel could apply and unless very conservative stresses are adopted the material quality should be determined.

If a definate answer is required small borings could be made on locations remoted from the positions of maximum shear and bending and the metal extracted sent for chemical analysis. Since wrought iron is substantially free from carbon the presence of this element in measurable quantity indicates that the material is steel not wrought iron.

9.5 Relationship between past and present

The object in producing this manual is to assist engineers and others concerned with the renovation or reinstatement of old buildings. If this object is to be achieved then hints on how to apply the contents are advisable.

In order to arrive at recommendations it is first necessary to reconsider briefly the significant changes which have taken place during the period covered. These concern material, loadings and stresses.

9.5.1 Material

During the last 100 years or so vast improvements have taken place in the manufacture and quality of steel. Therefore it must be assumed that old steel cannot be used with the high stresses permitted today without a detailed analysis of the material being undertaken.

9.5.2 Loadings

Apart from wind loading, knowledge gained with respect to imposed loading has meant that most requirements have been reduced from those in use at the beginning of the period under review.

With increased knowledge from experiment and observation, conclusions have been reached which suggest that early structures were under-designed for the effect of wind load. It should be appreciated however that such structures were far more robust than modern structures.

9.5.3 Stresses

Working stresses have increased in line with improvements in quality, except in so far as the behaviour of certain elements under loading conditions is better understood, leading to more stringent requirements for lateral restraint etc.

9.6 Recommendation for Design

Bearing in mind the above changes the following recommendations are made:

1. Imposed loads suitable to the proposed use of the structrue should be taken in accordance with modern practice.
2. Where current design methods may not be appropriate, eg design of a cast iron column, then members should be checked using the working stresses and design methods applicable to the time of original construction.
3. Where current design methods may be appropriate eg a laterally unrestrained beam, then members should be checked with BS449: Part 1: 1970 or BS449: Part 2: 1969

   (a) using the working stresses applicable to the material at the time of original construction.

   (b) revised working stresses based on a detailed material analysis.

It should be appreciated that these views are the authors own and it is essential that the engineer carrying out the investigation satisfies any appointed authority.

For further guidance on the survey and appraisal of existing building structures readers are recommended to refer to the Institution of Structural Engineer's publication "Appraisal of Existing Structures".

SECTION NO. 10 Bibliography

10.1 Bibliography

During the preparation of this manual the author has made reference to a wide range of publications. Readers wishing to pursue particular aspects are referred to the following publications although copies of the earlier books are becoming increasing difficult to obtain:—

Strains in girders — Hunter — 1872
Notes on building construction — Rivington — 1879
Encyclopedia of architecture — Papworth — 1881
Handbook of machinery — Appleby — 1903
Mechanics applied to engineering — Goodman — 1918
Wind stresses in buildings — Fleming — 1930
Theory & design of structures — Andrews — 1932
Constructional Steelwork — Faber — 1954
History of building regulations in London — Knowles and Pitt — 1972

The above list of textbooks gives the authors name and the date of the edition consulted. In many cases the volume was first published at a much earlier date than the one given.

In addition to text books reference has been made to a wide range of British Standards from the time they were first issued. These include:—

BS1	BS28	BS968	CP3 Chap V
BS4	BS449	BS1083	CP113
BS6	BS548	BS3692	
BS15	BS916	BS4360	

Some of these are now withdrawn or re-numbered.

Reference has also been made to Reports on Steelwork for Buildings issued by the Institution of Structural Engineers, to the LCC By-Laws and other official publications.

Finally, the author has made access to Strucutural Steelwork handbooks published by BCSA, Constrado and many of the major steelwork manufacturers and fabricators both in this country and abroad.

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