Properties and Assessment of Historical Structural Steelwork

Author: *Kevin Cowie*
Affiliation: *Steel Construction New Zealand Inc.*
Date: *3rd July 2009*
Ref.: *MAT1005*

Key Words
Historical steelwork, old steelwork, retrofit, appraisal, rehabilitation, assessment,

Introduction
The refurbishment or 'adaptive re-use' of existing buildings currently forms a significant part of the workload for many architects and engineers. The structural engineer will be required to make an appraisal of the existing steelwork in these buildings. This article provides sources of information for identifying the properties and making an assessment of the historical structural steelwork.

Steel Section Sizes, Dimensions and Properties
Up until the mid 1960s a lot of structural steel used in New Zealand was sourced from the United Kingdom (UK). A small amount of structural steelwork was sourced from United States of America (USA). For steel from the UK a very useful publication is the *Historical Structural Steelwork Handbook* (Bates, 1984). This publication is available to view on the British Constructional Steelwork Association website, www.steelconstruction.org . The handbook contains numerous extremely useful tables for properties of steel beams and other sections dating from 1972 back to 1887.

Properties for British Standard steel beams produced to BS 4 – 1932 is provided in Figure 4. For steel from USA the AISC Design Guide 15 (Brockenbrough, 2002) provides properties of beams and columns steel sections from 1887 to 2000.

Typical Pre-1976 Steel Building Systems Used in New Zealand
Use of Iron and Steel in Existing Buildings
A good summary of the use of iron and steel in structures from 1780 to the present day is given in (Bussell, 1997). For a New Zealand context the relevant period is from 1900. Figure 1 shows the main period of use of various materials. Existing New Zealand building with ferrous material will mostly be steel. This was the preferred material for structural members in buildings from 1880 onwards. The exception is columns, especially gravity columns functioning as vertical props for the floor. Cast iron was used for these through to just after 1900 and cast iron columns are found in some of the oldest New Zealand buildings (NZSEE, 2006). They are typically "chunky" with thick sections, often ornate or complex profile fluted or plain hollow circular or cruciform columns. Their surface is typically pitted with small blowholes. More detailed visual characteristics are given in Table 7.1 of (Bussell, 1997).

Moment-resisting Frames
Details for typical moment resisting frames are described in (NZSEE, 2006). Beams were typically rolled steel joist (RSJ) sections. These are I-sections in which the inside face of the flanges are tapered relative to the outside face, at a slope of around 15%. This makes the flanges thicker at the root radius than at the tips. The flange slenderness ratios of RSJ sections are always compact when assessed to NZS 3404:1997 (SNZ, 1997). These beams were typically encased in concrete for fire resistance and appearance, with this concrete containing nominal reinforcement made of plain round bars or, sometimes, chicken wire.

Disclaimer: SCNZ and the author(s) of this document make no warrantee, guarantee or representation in connection with this document and shall not be held liable or responsible for any loss or damage resulting from the use of this document

© Steel Construction New Zealand Inc. 2009

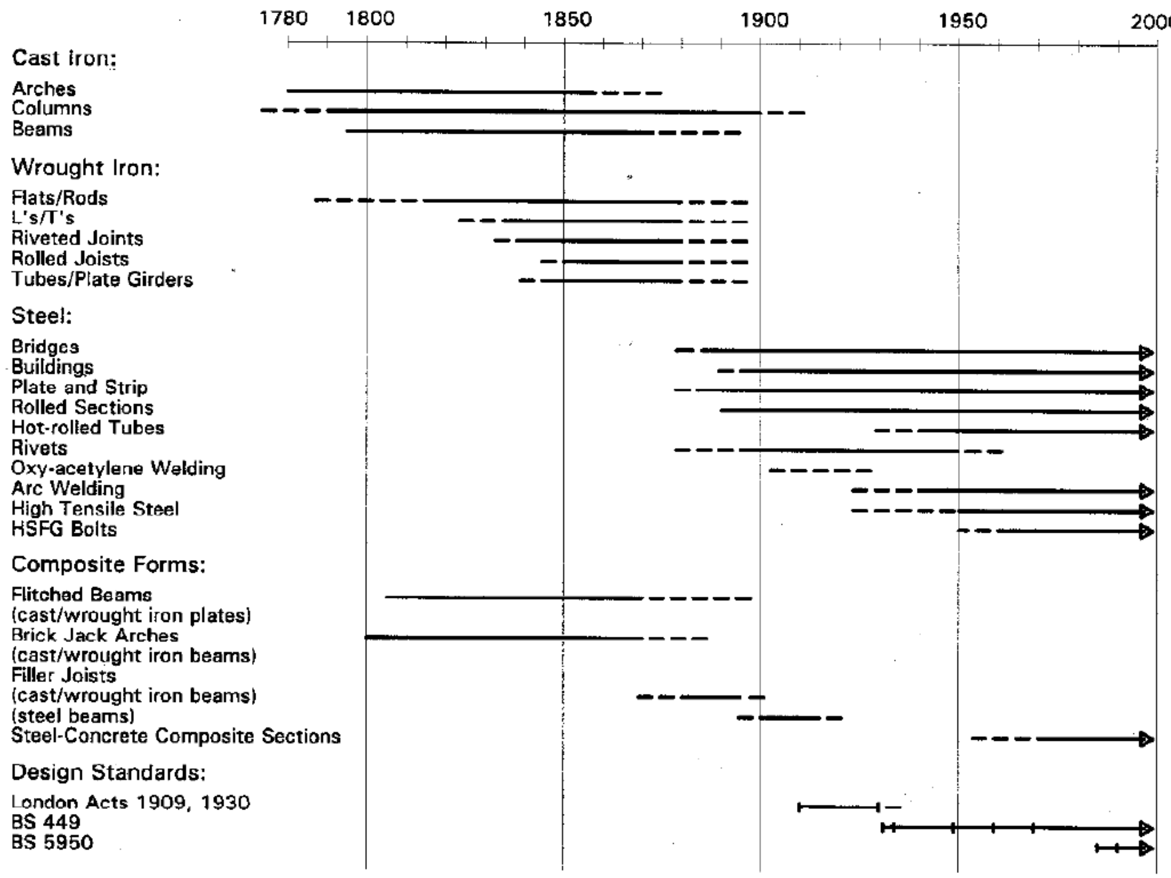


Figure 1: Main periods of the Structural use of Cast Iron, Wrought Iron and Steel (Bussell, 1997)

Columns formed from hot-rolled sections used either hot-rolled steel columns (RSC) or box columns formed by connecting two channels, toes out, with a plate to each flange. The columns were encased in lightly reinforced concrete containing nominal reinforcement made of plain round bars. Compound box columns were also formed from plates, joined by riveted or bolted angles into a box section and encased in concrete.

Beam to column connections in the earlier moment frames typically comprised semi-rigid riveted or bolted connections. The RSJ beam flanges were bolted to Tee-stubs or angles bolted to the column flanges or to lengths of RSJ bolted to side extensions of the column plate. The RSJ beam web was connected by a double clip angle connection to the column flanges. These joints generally involved the use of rivets up to 1950 and high strength friction grip (HSFG) bolts after 1960, with a changeover from rivets to bolts from 1950 to 1960. Beam to column connections from about 1940 onwards were also arc welded.

Splices in columns typically involved rivet (pre 1950) or bolted (post 1950) steel sections.

Braced frames are very briefly discussed in (NZSEE, 2006) and the publication covers only concentrically braced framing (CBF), either x-braced CBFs or V-braced CBFs.

Expected Yield and Tensile Strengths of Steels. Fasteners and Weld Metals

The expected yield and tensile strengths of historical steel are provided in Figures 2 and 3. Figure 2 contains information on UK steelwork. Figure 3 contains information on American steelwork. For further information on American steelwork refer to (Brockenbrough, 2002).

© Steel Construction New Zealand Inc. 2009

Property (values in N/mm² unless noted)	Typical value (or range of values)	Notes
Ultimate tensile strength:		
BS 15: 1906	432-494	BS 15 covered mild steel
BS 15: 1912-1941	432-509	
BS 15: 1948-1961		
Rivet bar	386-463	
Other	432-509	
BS 548: 1934-1942		BS 548 covered high tensile
Rivet bar	463-540	steel
Other	571-664	
BS 968: 1941	As BS 548: 1934	BS 968 covered weldable high
BS 968: 1943	509-633	tensile steel
BS 968: 1962	494-602	
Yield strength:		
BS 15: 1948-1961	225-235	
BS 15: 1961-1968	230-250	No change in UTS.
BS 548: 1934-1942	293-355	No requirements for rivet bar;
BS 968: 1941	As BS 548: 1934	values depended on steel
BS 968: 1943	293-324	thickness, being lower for
BS 968: 1962	340-355	thicker sections
Elongation at failure (%):		
BS 15: 1906-1941		
Rivet bar	25 (min.)	
Other	20 (min.)	
BS 15: 1948-1961		
Rivet bar	26-30	Cold bend test
Other	16-24	
BS 548: 1934-1942		
Rivet bar	22-27	
Other	14-18	
BS 968: 1941-1943		
Plates	14-18	
Sections and bars	14-22	
BS 968: 1962		
Standard test pieces	15-23	

Figure 2: Typical Properties of Structural Steel from the UK 1906 - 1968 (Bussell, 1997)

Time period	Application	Minimum yield stress (MPa)	Minimum tensile strength (MPa)
< 1900	Buildings Rivets	240 205	400 340
1900–10	Buildings Rivets	240 205	410 340
1910–25	Buildings Rivets	190 170	380 330
1925–32	Buildings Rivets	210 170	380 314
1932–50	Buildings Rivets	225 195	410 355
1950–76	Buildings (mild steel)	250	410
	Buildings (HT steel)	350	480

Source: Ferris (year?).

Figure 3: Minimum Material Properties for Steels and Rivets Manufactured in the USA (NZSEE, 2006)

© Steel Construction New Zealand Inc. 2009

Assessment of Tensile Strength by Hardness Test

Older steels have an inherently greater variability than modern steels. Simple in-situ non-destructive test testing such as hardness tests may be used to provide an approximate tensile strength but will not give an indication of fracture toughness. There is a relationship between material hardness and tensile flow stress, which is the average of the yield and UTS. A hardness test on its own should not be relied on as a direct measure of strength. (NZSEE, 2006) gives an approximate relationship between the *Vickers Hardness Test* and tensile strength as:

$$f_u = 3.09 H_v + 21.2$$

where H_v = Vickers Hardness from test

This expression is valid for $100 \leq H_v \leq 300$, corresponding to $330 \leq f_u \leq 950$ MPa. Any materials with $H_v > 135$ should be investigated more thoroughly by tensile sampling.

References

Bates, W., Historical Structural Steelwork Handbook, British Constructional Steelwork Association Ltd, London, England, 1984 (This publication is available for download from the BCSA website: www.steelconstruction.org)

Brockenbrough, R., AISC Rehabilitation and Retrofit Guide, Steel Design Guide Series 15, American Institute of Steel Construction, United States of America, 2002

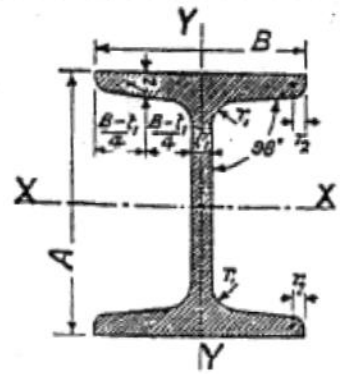
Bussell, M., Appraisal of Existing Iron and Steel Structures, SCI Publication 138, Steel Construction Institute, Ascot, England, 1997

NZSEE, Assessment and Improvement of the Structural Performance of Buildings in Earthquakes, Recommendations of a NZSEE Study Group on Earthquake Risk Buildings, New Zealand Society for Earthquake Engineering, 2006 (This publication is available for download form the NZSEE website: www.nzsee.org.nz)

SNZ, Steel Structures Standard, NZS3404 Part 1:and2 1997 (Incorporating Amendment 1 and 2), Standards New Zealand, Wellington, October 2007

© Steel Construction New Zealand Inc. 2009

BRITISH STANDARD STEEL BEAMS.
(B.S. 4—1932)



Web Flange

Size. A × B. Ins.	Wt. per foot lb. (approx.).	Sectional Area. sq. in.	Standard Thickness Inches.		Radii Inches.		Moments of Inertia. (In.)⁴		Radii of Gyration. (In.)		Section Moduli. (In.)³	
			t_1. web	t_2. flange	r_1.	r_2.	About XX.	About YY.	About XX.	About YY.	About XX.	About YY.
3×1½	4	1·18	0·16	0·249	0·25	0·12	1·66	0·13	1·19	0·33	1·11	0·17
3×3	8·5	2·52	0·20	0·332	0·37	0·18	3·81	1·25	1·23	0·70	2·54	0·83
4×1¾	5	1·47	0·17	0·239	0·27	0·13	3·66	0·19	1·58	0·36	1·83	0·21
4×3	10	2·94	0·24	0·347	0·37	0·18	7·79	1·33	1·63	0·67	3·89	0·88
4¾×1¾	6·5	1·91	0·18	0·325	0·27	0·13	6·73	0·26	1·88	0·37	2·83	0·30
5×3	11	3·26	0·22	0·376	0·37	0·18	13·68	1·45	2·05	0·67	5·47	0·97
5×4½	20	5·88	0·29	0·513	0·49	0·24	25·03	6·59	2·06	1·06	10·01	2·93
6×3	12	3·53	0·23	0·377	0·37	0·18	20·99	1·46	2·44	0·64	7·00	0·97
6×4½	20	5·89	0·37	0·431	0·49	0·24	34·71	5·40	2·43	0·96	11·57	2·40
6×5	25	7·37	0·41	0·520	0·53	0·26	43·69	9·10	2·44	1·11	14·56	3·64
7×4	16	4·75	0·25	0·387	0·45	0·22	39·51	3·37	2·89	0·84	11·29	1·69
8×4	18	5·30	0·28	0·398	0·45	0·22	55·63	3·51	3·24	0·81	13·91	1·75
8×5	28	8·28	0·35	0·575	0·53	0·26	89·69	10·19	3·29	1·11	22·42	4·08
8×6	35	10·30	0·35	0·648	0·61	0·30	115·06	19·54	3·34	1·38	28·76	6·51
9×4	21	6·18	0·30	0·457	0·45	0·22	81·13	4·15	3·62	0·82	18·03	2·07
9×7	50	14·71	0·40	0·825	0·69	0·34	208·13	40·17	3·76	1·65	46·25	11·48
10×4½	25	7·35	0·30	0·505	0·49	0·24	122·34	6·49	4·08	0·94	24·47	2·88
10×5	30	8·85	0·36	0·552	0·53	0·26	146·23	9·73	4·06	1·05	29·25	3·89
10×6	40	11·77	0·36	0·709	0·61	0·30	204·80	21·76	4·17	1·36	40·96	7·25
10×8	55	16·18	0·40	0·783	0·77	0·38	288·69	54·74	4·22	1·84	57·74	13·69
12×5	32	9·45	0·35	0·550	0·53	0·26	221·07	9·69	4·84	1·01	36·84	3·88
12×6	44	13·00	0·40	0·717	0·61	0·30	316·76	22·12	4·94	1·30	52·79	7·37
12×6	54	15·89	0·50	0·883	0·61	0·30	375·77	28·28	4·86	1·33	62·63	9·43
12×8	65	19·12	0·43	0·904	0·77	0·38	487·77	65·18	5·05	1·85	81·30	16·30
13×5	35	10·30	0·35	0·604	0·53	0·26	283·51	10·82	5·25	1·03	43·62	4·33
14×6	46	13·59	0·40	0·698	0·61	0·30	442·57	21·45	5·71	1·26	63·22	7·15
14×6	57	16·78	0·50	0·873	0·61	0·30	533·34	27·94	5·64	1·29	76·19	9·31
14×8	70	20·59	0·46	0·920	0·77	0·38	705·58	66·67	5·85	1·80	100·80	16·67
15×5	42	12·36	0·42	0·647	0·53	0·26	428·49	11·81	5·89	0·98	57·13	4·72
15×6	45	13·24	0·38	0·655	0·61	0·30	491·91	19·87	6·10	1·23	65·59	6·62
16×6	50	14·71	0·40	0·726	0·61	0·30	618·09	22·47	6·48	1·24	77·26	7·49
16×6	62	18·21	0·55	0·847	0·61	0·30	725·05	27·14	6·31	1·22	90·63	9·05
16×8	75	22·06	0·48	0·938	0·77	0·38	973·91	68·30	6·64	1·76	121·74	17·08
18×6	55	16·18	0·42	0·757	0·61	0·30	841·76	23·64	7·21	1·21	93·53	7·88
18×7	75	22·09	0·55	0·928	0·69	0·34	1151·18	46·56	7·22	1·45	127·91	13·30
18×8	80	23·53	0·50	0·950	0·77	0·38	1292·07	69·43	7·41	1·72	143·56	17·36
20×6½	65	19·12	0·45	0·820	0·65	0·32	1226·17	32·56	8·01	1·31	122·62	10·02
20×7½	89	26·19	0·60	1·010	0·73	0·36	1672·85	62·54	7·99	1·55	167·29	16·68
22×7	75	22·06	0·50	0·834	0·69	0·34	1676·80	41·07	8·72	1·36	152·44	11·73
24×7½	95	27·94	0·57	1·011	0·73	0·36	2533·04	62·54	9·52	1·50	211·09	16·68

Figure 4: British Standard Steel Beams BS 4 - 1932 (Unknown Source)

© Steel Construction New Zealand Inc. 2009