Engineering design books in the inter-war years

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There are books for practising professionals that deserve to be categorized as textbooks because of the way they are used and reflect the practices of their day. This note is about books produced for structural engineers during the inter-war years. It describes the way in which they reflect the competition between the principal structural materials: steel and reinforced concrete. It is work in progress because a full analysis of the contents of these has not yet been carried out. Nevertheless the preliminary work raises some interesting questions.

The engineer's sources

In the course of their education and subsequent careers engineers will use a number of books that deal with basic theory, handbooks for regular use, and the codes of practice that embody the publicly approved methods of design, although the divisions between these categories are not always clear cut. The work on basic theory on my own shelves is Pippard and Baker's *The analysis of engineering structures* (the 1950 reprint of the 1943 2nd edition), which I acquired as a student. There is a long history of such books going back into the nineteenth century when they had titles such as *Mill construction*, but in spite of the practical bias suggested by their titles they dealt more with the theoretical than the practical aspects of design. These are textbooks for students but may be kept as reference books as the theoretical ideas they contain change very little.

It is the more basic handbooks, or manuals, that are used like textbooks during an engineer's career because they contain design examples showing how basic engineering theory and the provisions of codes of practice are to be applied in particular cases. Of these handbooks I have a 1964 (6th edition) of Reynolds's *Reinforced concrete designers' handbook*, and a copy of the commentary on CP114 (the contemporary code of practice for reinforced concrete) by Scott, Glanville and Thomas (2nd edition, 1965). These were the books that I used in my early career. There was, and still is, a *Steel designers' manual* and a more recently published manual on masonry design, neither of which I have. However I have all three editions of *Timber designers' manual* (1976, 1984 and 2002), the US Department of Agriculture Handbook 72, *Wood as a structural material*, and two American timber construction manuals. I am a specialist timber engineer and therefore have all editions of the codes for structural timber design. Engineers also need such codes of practice that cover their area of design and the basic codes defining the loads which are to be applied to structures. Many will also keep some manufacturers' manuals dealing with the properties of their products, which also need to be kept up to date.

The changing building industry

> I'll tell this tale, which is strictly true,
> Just by way of convincing you,
> How very little, since things were made,
> Things have altered in the building trade.
>
> Kipling, *A truthful song*

In spite of Kipling's unflattering image of the building industry there was a major change in the first half of the twentieth century when the construction of commercial and public buildings ceased to comprise masonry walls with timber floors and partitions; instead steel and concrete frames were used. Steel frames carried patent concrete floors and partitions. What made life simple for the design engineer was the adoption of standard steel sections and the publication of these in 1904 as one of the early British Standards. As public authorities had for centuries exercised control over building as a matter of public safety, the legislation had also to develop along with these technologies. In Britain the important step was the so-called Steel Frame Act of 1909, in fact an amendment to the London Building Act, which provided the first regulations for steel frame buildings but also gave the London County Council (LCC) powers to draw up regulations for the design of reinforced concrete.

In the early years of the century reinforced concrete was characterised by a multitude of patent systems. Structures were largely designed by contractors, who were either the patent holders themselves or licencees of the patent holders. This was not to the liking of the architectural profession who, together with other professional bodies, set up the Joint Committee on Reinforced Concrete to devise design rules that would enable independent professionals to design in this material. The rules produced were eventually incorporated into the LCC regulations in 1915, but by then the Great War prevented this having much immediate effect on building. The important years of development were therefore those between the wars, which is why this study is limited to those dates.

The inter-war books

The first task in comparing the books on these materials is to assemble a comprehensive list, simplified by searching the British Library catalogue for key words in the titles. For steel the terms used were: 'steel frame', 'steel design' and 'steelwork'. This netted a reasonably short list which, eliminating a text for architectural students and all the American books, is shown in Table 1. Even this short list may be over long. The book by Faber is an introductory text while Etchells's book is more promotional than it is useful and only merits inclusion because of a technical section on filler-joist floors. The most significant is Cocking's book, first published in 1917 but with a second edition within the given time frame and, like the later book by Lee, very much a handbook related to the current regulations.

For reinforced concrete the search terms were: 'reinforced concrete' and 'concrete construction'; and here the results were rather different (see Table 2). There was an average of about two books per year published throughout the period in question. This list was reduced from the full search results by weeding out books that dealt with such topics as bridge design and all the American books, leaving forty, either general books or books on reinforced concrete building frames, not counting second or third editions. Moreover this list does not include a number of publications produced by the Concrete Institute, each of which deals with very particular aspects of the subject, such as concrete mix design. With several times the number of books on steel design this disparity calls for some explanation.

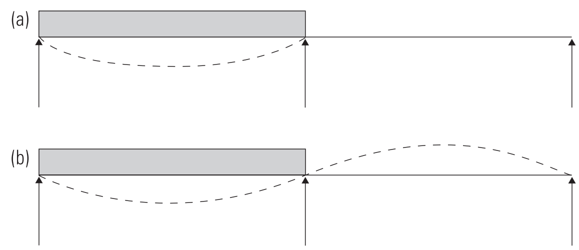
There are a number of possible reasons for this disparity in numbers: relative popularity of the two materials; relative complexity in design; relative rapidity with which the technologies developed and the relative newness of the technologies in a developing professional climate.

The relative popularity of the two materials

The most obvious explanation for this might be that reinforced concrete was more extensively used than steel but in fact the reverse is true. This in itself needs some explanation as Marian Bowley[1] has pointed out that a reinforced concrete frame was cheaper than a steel frame. She notes that the difference in price might not be apparent to the clients, that steel was heavily promoted but, perhaps most significant, that it was far easier to design.

Relative difficulty in design

There are two aspects to design: determining the forces on individual members and the sizing of those members to carry those forces. For steel design, beams were treated as simply supported, i.e. a load on one beam does not affect the stresses in adjacent beams. The same is not true of reinforced concrete where beams are connected to each other. This is illustrated by diagrams showing the deflection of concrete and steel beams (Figure 1) and had the effect that more than one loading case had to be considered when designing a concrete frame. The analysis of concrete structures was simplified when Hardy Cross published a new method of analysis.[2]



1. (a) The deflection of a pair of steel beams with one span loaded sown by the dotted line. (b) The deflection of a two-span concrete beam with one span loaded. The dotted line shows that the unloaded span is affected.

Determining the size of a steel beam can be childishly simple; the problem being to select a beam that will result in an acceptably low working stress. The relationship between load, span and bending had been known since the nineteenth century, as had that between the stress and the properties of the section. The bending on the beam is, in many cases, the product of the load and span divided by 8. Dividing this result by its section modulus gives the stress in the chosen beam, which simply has to be lower than the allowable stress. The working stress was set by regulations and the properties of the steel sections were given in the British Standard and reproduced in many reference books. It was then a matter of applying the formula to find the required section properties and making a selection from a table. All the designer needed from the handbook was information on the ways in which design was constrained (or informed) by the regulations and on what might be called good practice.

Such a simple method could not be used for the design of reinforced concrete. The stresses in the concrete and the reinforcing steel depend upon the size and shape of the section and amount of reinforcement introduced. The designer had to select all these as well as specify the strength of the concrete mix. It

1 Marian Bowley, *The British building industry: four studies in response and resistance to change* (Cambridge University Press, 1966).

2 Hardy Cross, *Continuous frames of reinforced concrete* (Wiley, 1932).

Table 1
Books on steel frame design

1920	Beck, Ernest G. *Structural steel work*. Longmans.
1924	Waldram, Percy J. *Structural design in steel frame buildings.* Batsford.
	Atkin, Harry. *Constructional steelwork.* Chapman and Hall.
1925	Cocking, Walter Cyril. *The calculations for steel-frame structures designed to comply with the requirements of the London County Council (general powers) Act 1909 with notes on the application of theory to practical design.* Scott, Greenwood & Son, 2nd rev. edn. (1st edn. 1917).
1927	Swift, G. A. *Steel works buildings*. Association of Engineering and Shipbuilding Draughtsmen.
	Faber, Oscar. *Constructional steelwork simply explained*. OUP (2nd edn 1937).
1933	Etchells, E.F. (ed.). *Modern steelwork: a review of current practice in the employment of structural steel-work in buildings and bridges.* British Steelwork Association.
	Lee, D H. *The use of steelwork in buildings under the LCC Code of Practice and the British Standard Specification no 449–1932.* Spon.
1937	Smith, H. P. *Structural steelwork for buildings.* Crosby Lockwood.
1939	Hale, Robert S. *Welded steel construction.* Pitman.

Note: All published in London.

Table 2
Books on reinforced concrete

1918	Andrews, Ewart S. *Elementary principles of reinforced concrete construction:* 2nd edn. Scott, Greenwood (1st edn. 1915, 3nd edn. rev.1924).
1919	Faber, Oscar and P. G. Bowie. *Reinforced concrete design. Vol. 1, Theory.* Edward Arnold, 1919 [2nd edn. 1924].
	Williamson, James. *Calculating diagrams for design of reinforced concrete sections.* Constable.
1920	Adams, Henry. *Reinforced concrete construction in theory and practice: an elementary manual for students and others.* Longmans.
	Cassell's reinforced concrete. Waverley Book Co.
	Concrete Institute. *Standard specification for reinforced concrete work*
	Faber, Oscar. *Reinforced concrete design. Vol II, Practice.* Edward Arnold.
	Twelvetrees, Walter Noble. *A treatise on reinforced concrete, etc*. Pitman.
	Marsh, Charles F., *Concise treatise on reinforced concrete.* Constable.
	Institution of Structural Engineers. *A standard specification for reinforced concrete work.*
	Cantell, Mark Taylor. *Reinforced concrete construction.* Spon (2nd edn. 1921).
1921	Andrews, Ewart Sigmund. *Detail design in reinforced concrete, with special reference to the requirements of the reinforced concrete regulations of the London County Council, etc.* Pitman.
	Gammon, John C. *Reinforced concrete design simplified.* Crosby Lockwood.
	Piggott, Joseph T. *Reinforced concrete calculations in a nutshell. With 1909 LCC regulations.* Spon.
	Twelvetrees, Walter Noble. *Concrete and reinforced concrete:* Pitman.
	Simplified methods of calculating reinforced concrete members, Second edition, revised and enlarged, etc.: Pitman (1st edn. 1909).
1922	Faber, Oscar. *Reinforced concrete simply explained.* Oxford Technical Publications (2nd edn. 1926).
	Hudson, R J. H., *Reinforced concrete. A practical handbook, etc.* Chapman & Hall.
	Marsh, Charles F. and William Dunn. *Manual of reinforced concrete.* Constable.
1924	Faber, Oscar. *Simpleexamples of reinforced concrete design.* Humphrey Milford, (2nd edn., Oxford University Press, 1929).
	Manning, George Philip. *Reinforced concrete design, etc.* Longmans (2nd edn. 1936).
	Andrews, Ewart Sigmund. *Regulations of the LCC relating to reinforced concrete and steel framed buildings.* Batsford.
1925	Lakeman, Albert. *Elementary guide to reinforced concrete, etc.* Concrete Publications.
	Morgan, R. Travers. *Tables for reinforced concrete floors and roofs.* Chapman and Hall.
	Crabtree, H. V. *The elements of reinforced concrete design.* Association of Engineering and Shipbuilding Draughtsmen.
	Scott, A. A. H. *Reinforced concrete in practice,* 2nd edn., revised. Scott Greenwood (1st edn. 1915).
1927	Butler, Maurice, *Diagrams of reinforced concrete construction and fireproof floors:* M. Butler: Watford.
	Cantell, Mark Taylor. *Practical designing in reinforced concrete.* Spon.
1930	Glanville, W H. and F. G. Thomas. *Studies in reinforced concrete.* Building Research Board.
	Scott, Ernest A. *Arrol's reinforced concrete reference book.* Spon.
1932	Manning, G. P. *Construction in reinforced concrete: an elementary book for designers and students.* Pitman.
	Institution of Structural Engineers. *Draft regulations concerning the design of flat slab floors in reinforced concrete.*
1933	Adams, Haddon Clifford. *The elements of reinforced concrete design.* Concrete Publications.
	Building Research Board. *Report of the reinforced concrete structures committee of the building research board, with recommendations for a code of practice for the use of reinforced concrete in buildings.*
1934	Scott, W. L. *Explanatory handbook on the code of practice for reinforced concrete.* Concrete Publications, (2nd edn. revised, 1939).
1936	Probst, E. *Principles of plain and reinforced concrete construction.* Edward Arnold.
1937	Caughey, Robert Andrew. *Reinforced concrete:* Chapman & Hall.
	Young, J. McHardy. *Reinforced concrete:* Crosby Lockwood.
1938	Reynolds, Charles Edward. *Practical examples of reinforced concrete design: in accordance with the Code of Practice for the use of reinforced concrete in buildings (1934) and the London County Council Building by-laws (1938):* Concrete Publications.
	Institution of Structural Engineers, *Report on reinforced concrete for buildings and structures.*
1939	Grundy, R. F. B. *The essentials of reinforced concrete design.* Chapman & Hall.

Published in London except where noted otherwise.

was then a matter of trial and error because altering the quantity of steel affected the properties of the section, which in turn affected the working stresses. Given the complexities involved in concrete design it is no wonder that a more extensive range of books was needed. To make life as simple as possible for the designer, some contained a range of charts, tables and diagrams whose purpose was to help navigate through these rather difficult waters, such contents sometimes explicitly mentioned in the titles of the books.

Technological development

Developments in steel construction were relatively few. Rolling technology developed to improve the range of sizes and the properties of the steel sections available. This simplified design as it reduced the occasions on which engineers needed to make up their own sections by riveting small sections together. It was only late in the inter-war period that welding was introduced and that the current methods of design were being questioned. Neither of these developments had much effect till after the war. In contrast concrete was a far from settled technology. There was much debate about which was the better of the alternative methods providing adequate shear strength in beams, an issue resolved by theoretical work of Oscar Faber. Floor construction could be simplified by the use of flat-slab construction, which had been widely used in the United States but only adopted in Britain in the late 1920s. What one might consider most fundamental of all was the design of the basic material, the concrete mix. Concrete was made on site to the engineer's specification and the choice of materials and proportions of the mix was a subject of research and development.

Nevertheless, it is not certain that keeping engineers up to date was contributing to the large number of books. This is where more work is needed, but a suspicion that books might be lagging behind theoretical developments is raised by the issue of concrete strength, surely a fundamental aspect of design. The strength of concrete depends upon the water content of the mix and at first it was not clear whether dry, or stiff, mixes were preferable to wet mixes that were easier to place. In the years immediately after the First World War, Duff Abrams published the results of research in America that demonstrated the significance of water:cement ratio and one might have at least expected this to find its way into American textbooks. However the first edition of Urquhart and O'Rourke,[3] an American book, which was sufficiently popular to be reprinted several times up to the Second World War, made only passing reference to this issue and was never revised to incorporate the results of Abrams's work. If this is a common pattern it seems likely that books were not up to date so that engineers might have been working with out of date methods.

If basic textbooks did not keep engineers up to date there were alternative sources that did. There was the series of publications on special subjects produced by the Concrete Institute but much more important was the journal *Concrete and constructional engineering* that regularly ran technical articles on design methods. It was almost certainly this and the journals of the professional institutions that specialist designers relied upon to keep them informed rather than the basic textbooks. Perhaps this was partly because theory might be ahead of practice; the use of the stiff concrete mixes required by theory had to wait for development in the technology for vibrating concrete so that such mixes could be easily placed.

The developing professional climate

Given the relative popularity of the two materials, it is difficult to account for the much greater production of books on concrete on the grounds of either its greater complexity or developments of the technology. The other factor to be taken into account is the development of structural engineering as an independent profession. Initially, much structural design was carried out by contractors in a process that is today called 'design-and-build'. This was an unsatisfactory method and there was a growing pressure in the 1920s for independent structural engineers to be appointed to design the structure before the work was put out to tender.

It was not to be until after WWII that it became fairly common practice for a consulting engineer to be engaged for the design of a building's structure, a process that I have discussed elsehere.[4] Nevertheless, one might imagine Owen Williams's knighthood for his work as consulting engineer on the Empire Exhibition (1924) could have encouraged others to see the possibilities of this method of working; moreover the buildings he designed were of an overtly concrete architecture. If consulting engineers were to be able to offer a full service to their architect clients then they would need to be *au fait* with what might well be an up and coming material. It seems likely that it was the need for engineers to

3 Leonard Church Urquart and Charles Edward O'Rourke, *Design of concrete structures (*McGraw Hill, 1923).

4 David Yeomans,'Collaborating with consulting engineers', in Louise Campbell, (ed), *Twentieth-century architecture and its histories,* Society of Architectural Historians of Great Britain, 2000, 125–51.

make themselves familiar with this relatively new but complex material that accounts for the demand for these books.

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