20. I.A. Bartenev, *Konstrukzii Russkoj Architektury XVIII-XIX v.v.* (Leningrad, 1982), pp72-8.
21. M.Z. Taranovskaya, *Karl Rossi: Architektor, Gradostroitel Khudoznik*, (Leningrad, 1980), p.149.
22. Y.V. Gaydarov '150 let Spustia Issledovanie Metallicheskich Konstruhzij Zdanija Teatra', *Architektura i Stroitel 'stvo Leningrada* (1973), n.1., p.24.
23. S.G. Fedorov, D.Y. Gouzevitch, 'Proekt Pervogo v Rosii Kupol'nogo Pokrgtija s Vantobym Podkrepleniem', *Issledovanija Prostranstvennych Konstrukzij* (LenZNIIEP, Leningrad, 1985), pp.105-10.
24. ZGIA SSSR, 206-2-382 (Payment for a steam engine for Novaja Ladoga made by Clark, 1831-37).
25. ZGIA SSSR, 37-9-683 (Information on gun-powder and cannon manufacture collected by Clark on his foreign travels, 1832).
26. In the beginning of 1830 many of the foreign engineers left St Petersburg (Lamé, Clapeyron – 1831, Traitteur – 1832, P. Bazaine – 1835).
27. N.I. Olkhovskij *Opsanie Zeleznch Balok i Stropil Ustroennych v Zimnem Dvortze pri Vozobnevleni ego*, offprint from Volume X of the *Mining Journal* (St Petersburg, 1839).
28. S. Fedorov. Sprengwerkdacher des Winterpalasts in St Petersburg: 1838-1842. (Zum Werdegang der Idee zugbeanspruchter Mettallkonstruktionen in der Europaishen ingenieur-technichen Praxis des 19. Jahrhunderts). Vom Holz sum Eisen: Weitgespannte Konstruktionen des 18. und 19. Jahrhunderts, Universitat Stuttgart, SBF 230, 1991, pp.57-95.
29. L.M. Baranovitch *Istorija Vosstanovlenija Zimnego Dvortza i Zarstrovanie Imperatora Nicolaja I 1838-39 (St. Petersburg, 1857)*. M.E. Saltykov-Shchendrin State Library Manuscript, Inventory 380, file 105, pp.39-41.
30. The palace of the great princess Maria Nicholaevna, built by A.I. Stakenschneider 1839-44. Stakenschneider graduated from the St Petersburg Academy of Fine Arts (1822), and from 1825 worked with Monferrand on the construction of St Isaac's Cathedral. In 1837-8 he made a study trip to France, Italy and Great Britain. He was the architect of many major houses of the period 1830-60, as well as public buildings such as railway stations.
31. ZGIA SSSR, 482-3-136 (Reimbursement to the heirs of Clark for works at Mariinskij Palace, 1842-86).
32. ZGIA SSSR, 482-3-136, pp.10-11.
33. After his dismissal, Clark's position as Director of the Alexandrovskij Ironworks was taken by Col. Fullon of the Corps of Marine Engineers. In the late 1840s the factory was taken over by the railway department and its production totally reorganised. In Soviet times the factory was subject to high security, so until now local archive material has not been accessible to researchers.
34. ZGIA SSSR, 482-3-136, p.23, verso.
35. ZGIA SSSR, 44-1-472, p.7.
36. Clark was awarded the normal pension for officers of his rank.
37. ZGIA SSSR, 560-35-882, p.14 (Concerning the deposits of Matthew Clark in the State Treasury, 1887).
38. The total cost of the metal structures made for the Winter Palace by the Alexandrovskij Ironworks in 1838-9 was 4,104 million roubles.

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The Design of Structural Ironwork 1850-1890: Education, Theory and Practice

STANLEY SMITH

The mid-nineteenth century was a period when a series of changes took place in the construction industry, especially in that part of the industry concerned with the design and erection of iron structures. Apart from the introduction of new materials, and the need for new building types, there were influential changes that occurred in the way designers evisaged the scope of their work in this field which led to an increasing specialisation of activity and the proliferation of professional organisations intended to serve the interests of specific groups. In addition, alternative views were developing about the provision of education and training for designers and what should be offered to new entrants to the engineering design professions. Another major area of activity was the attempt to apply the principles of scientific investigation to explain the performance of structures and to develop theories that could be used as the basis for design.

It has been suggested that changes in the practice of engineering generally had by 1890 led to the development of a 'scientific engineering', founded on the application of science and mathematical analysis.[1] By considering the writings and comments of some of the mid-century designers this paper attempts to establish if such a development took place in the practice of structural design in the second half of the nineteenth century. To do this, attention has been focused on four specific areas. First, on the specialisation that took place within the civil engineering profession, coupled with the growth of provincial engineering societies; second, on the published material intended to assist structural designers, its content and intended readership; third on the attitudes towards education and training that were expressed by designers in public and finally, on mid-nineteenth century views about the importance of practice in relation to theory.

Specialisation and Structural Design

Today a structural designer can be defined with general agreement as 'one who is competant to design stable and economical structures of different kinds to meet the requirements for which the structures are needed.' But it was not until 1908 that there was a specific professional institution to pursue the interests of the structural engineer.[2] In the nineteenth century, structural design of ironwork formed part of the wider activities of the civil engineer, whose needs were catered for by the Institution of Civil Engineers, founded in 1818. It was not until attempts were made to obtain a Royal Charter in 1828, that it was considered necessary to define what an engineer was or did. The Council requested Thomas Tredgold to prepare such a description and this was entered in the minutes on 4th January, 1828 and eventually, in an abridged form, included in the Charter. The work of the civil engineer was seen as concerned with, 'The art of directing the great sources of power in nature for the use and convenience of man', and as described by Tredgold, the improvement of the means of communication, the protection of property from natural forces and the control and manipulation of water.[3]

By 1866, when John Fowler gave his Presidential Address, his list of the activities of a civil engineer was much more specific and comprehensive than Tredgold's and listed seven categories of work, ranging from inland communications, works relating to public health, harbours and mining, to machinery and shipbuilding. His selection demonstrated how far the specialisation in engineering design had progressed. Fowler was also much more specific about what an engineer's duties involved, stated as 'design, prepare drawings, superintend and carrying out of the works', not as in Tredgold's description, 'the art of directing the forces of nature'.[4] The Fowler list defined much more clearly those fields where the design of spanning structures was likely to occur, a reflection of the increasing importance of this type of work for the engineer, especially in connection with new building types.

Another measure of the changes in the practice of design can be seen in the content and format of papers presented to the professional institutions over the years. The learned institutions had papers read on structural design matters, but it was the papers read at the Institution of Civil Engineers and at the Mechanicals, often reprinted at length in the technical press, that had the widest influence.[5]

A very typical presentation in the late forties was that by Turner, on the roof his firm had designed and erected at Lime Street Station, Liverpool.[6] This was a factual description of the structure, involving no theoretical explanation, and was followed by a discussion that concentrated on the economics of such a roof, the type of covering and the practicalities of this class of work. This approach was very common, and continued until the eighties, as can be seen in the description of the Clyde Bridges, given in 1880, where the author B.H. Blyth considered that all his audience were interested in was a description of the solution, one that could be the basis for a later scheme.[7] The Turner paper is also interesting for the light it throws on the approach to design of people such as William Fairbairn and Joseph Locke, who when asked to check the safety of the structure, gave answers that appear to have been based very much on past experience, not calculation.

By the early 1850s practising engineers were presenting papers that started to contain descriptions of the theoretical basis for their design, such as Barton's paper in 1854 on the stress in the web of beams as used at the Boyne Viaduct. It is interesting to note that Fairbairn's paper on tubular bridges in 1849 contains very little mathematical analysis, but the ensuing discussion, which continued over several subsequent meetings, included contributions from most of the theoreticians who were connected with the Institution of Civil Engineers.[8] In the sixties and seventies papers such as Calcott Reilly's on uniform stress and those by continental engineers like Gaudard contained some theoretical analysis.[9]

Papers of the Turner type continued to be published, but with the passage of time became more wide-ranging and reflected the continuing specialisation of interests about practical aspects of design. This was so in the case of the papers presented in 1863 and 1867 on the Charing Cross and Cannon Street bridges and roofs respectively (Fig. 1), and that on St Pancras station in 1870, all of which contained, in addition to practical information about construction, discussion of the economics of the methods chosen and the basis of the design adopted.[10] Later papers, like Baker's in 1879 on the strength of beams, contained a great deal of theoretical material, whilst still intended for the practical man, and in this in-

stance reflected concern about how such factors as wear, daily use and exposure could affect design decisions[11] Other papers with a theoretical content attempted to summarise the state of knowledge in a subject, and present it in a way that made it possible to apply it in practical situations. Papers by Gaudard and Bender on wind forces in the 1890s are a good example of this type.[12] However the continuing publication of papers that concentrated on the practical aspects of the design and construction of ironwork suggest that for many this was the approach required. Theoretical descriptions, with the very criticial refutations of the theories stated in the following discussion, may have suggested that theories could not provide the answers to practical problems.

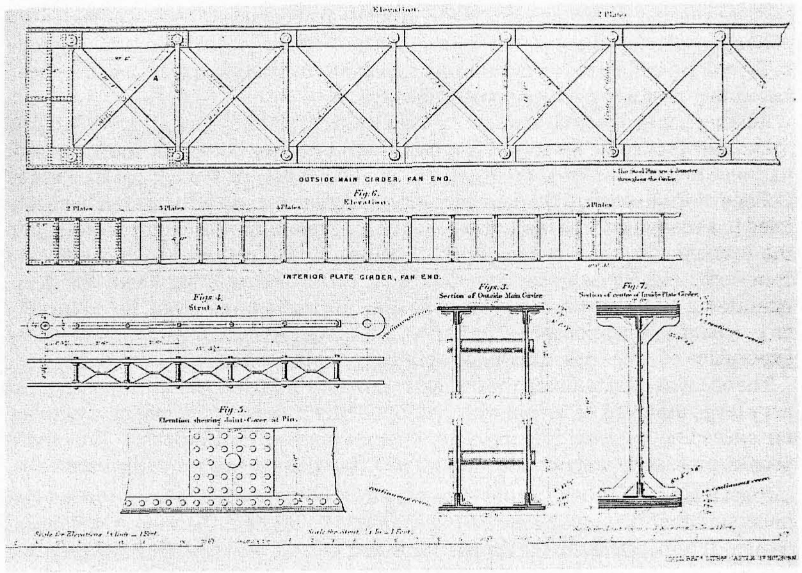

Fig. 1: Details of Charing Cross Railway Bridge, (from *Min. Proc. Inst. Civ. Eng.* 22, 1863).

For those engineers who were not members of the London-based institutions, or who lived too far away to attend, there grew up in the mid-century a whole series of societies and institutes, descended from the literary and philosophical associations and mechanics institutes of the earlier part of the century. These organisations were often open to all and frequently required no formal educational requirements for entry; a recommendation from an existing member was more important. In 1888 *Spon's Engineers Price Book* listed 14 such groups, ranging from the Society of Engineers, with 450 members, the North East Coast Institute of Engineers and Shipbuilders, with 600 members, to South Staffordshire and East Worcestershire Institute of Mining and Mechanical Engineers, with only 70. The total membership of all these societies was about 3500, at a time when the membership of the Institution of Civil Engineers was 7500.[13]

At the meetings of these societies the papers that were read had a very practical content compared to those given at the Institution of Civil Engineers. An interesting example was that given in 1877 to the Liverpool Society of Engineers by C. Graham Smith (an Associate Member of the Civils) entitled 'Wrought Iron Girder Work'. The first paragraph set the tone of the paper by saying, 'Strains in Ironwork. In treating this subject it is not here proposed to consider the abstract questions involved in the various methods of arriving at the theoretical strains on the different portions of girder work'. The paper discussed in some detail the technical problems of the engineer, on site and in the office, in attempting to cope with the problems of thermal movement, definitions of elasticity, the arrangement of members to meet strains, (used throughout to mean stress in present day terms), the differing qualities of iron and methods of testing.

The information about testing is full of detail about the preparation of samples, both for site and workshop tests, and a great deal of comment obviously the result of long experience of inspecting ironwork. The details of defects likely to originate in the rolling mill due to worn rolls, or inaccurate cutting of plates must have been extremely useful to inexperienced engineers.[14]

Another paper of a similar practical type was that given by Hamilton W. Pendred in October 1883 at the Society of Engineers. This Society, although London based, had been founded in 1854 as the Putney Club, intended for ex-students of the Putney College of Engineering. Its members originally were those who had not been articled to a member of the Institution of Civil Engineers and so could not easily join the Institute. The title of the paper, 'Designs, Specifications and Inspection of Ironwork', clearly describes its content. Plentiful information about the practicalities of ironwork detailing, riveting and fabrication was given, based largely on personal observation and experience. This paper was intended for those whose experience of preparing drawings, detailing and inspection were limited.[15]

The occupational tables in the census returns in the latter part of the century list very large numbers of people who described themselves as engineers, a number far exceeding the total membership of the recognised institutions.[16] Thus these people, plus those without educational qualifications in the provincial societies, formed a large group who would have very little opportunity of learning about and understanding the application of the more mathematical theories of structural design. It appears likely that in the 1880s and 1890s it was still common practice for design to be based on a set of standard rules of thumb, and it was very unlikely that structural design theory was widely used. The effect of the need for a wider use of theory, and the separation of functions that has been described, meant that the education of engineers had to respond to changing circumstances and to be divided into different streams, each dependant on the activity in which the student was to be engaged.

Published Information for the Engineer

Another measure of how far the new theoretical knowledge was applied in practice is to be found in the published material available to the student and practitioner which set out the result of new research in an easily accessible manner.

When the first volume of the Todhunter and Pearson, *History of the Theory of Elasticity and the Strength of Materials* was published it listed several thousand articles, papers, memoirs and books on the subject, written between 1650 and 1886.[17] Although many were not of direct use to the designer, a large number were.

What is difficult to establish is how many practitioners would have been able to see them, and in case of those originally published in a foreign language, the ability to translate them. Some of the English articles had appeared in the *Transactions of the Royal Society*, the *Proceedings* of the Institution of Civil Engineers and of the Mechanicals, and were reprinted in the technical press, but it would appear that the extent of their circulation would have been limited.

From the mid-century onwards there was a variety of printed material intended to supply the designer with the information he needed, and this can be divided into four main groups. There were text books, intended for both students and practitioners; books that contained detailed illustrations of structures, intended as examples to be copied; manufacturers' handbooks; and finally the encyclopaedic pocket books.

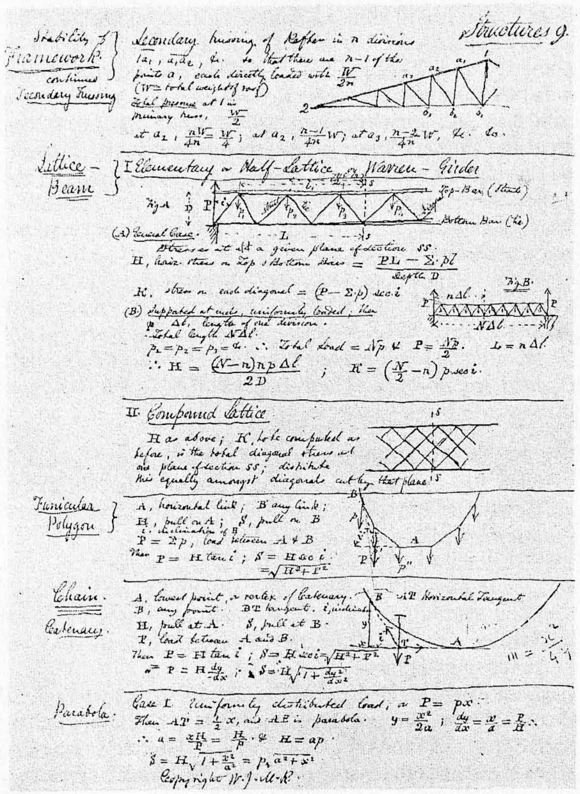

Fig. 2: A page from the lithographed notes prepared by W.J. McQuorne Rankine for the use of his Glasgow studens in the 1850s (Civil Enginering Library, Imperial College, London).

Most of the books in the first category, which were intended to provide some theoretical basis for study, were written by people who were teachers, and who were the main contributors to the discussions at the institutions that explored the mathematical analysis of structures. These included such people as Anderson, Pole, Tate, Unwin, Stoney and Reilly. Frequently their books were based on a series of lectures; in Anderson's and Unwin's case, those given at the Royal Engineering School at Chatham.[18] Of this group of publications perhaps the most famous was Rankine's *Manual of Civil Engineering*, published in 1862.[19] The *Manual*, and other books that Rankine wrote about statics and mechanical engineering, were based on the notes and lectures given to students at Glasgow University, and present the most comprehensive attempt to provide in one volume all the knowledge required by the civil engineer (Fig. 2).[20]

In the reviews of these books in the technical press there were frequent complaints that they were too theoretical in content, did not display the approach to design required by the practical man, and neglected to discuss those non-quantifiable aspects of construction detail that could have a profound effect on the solution selected.[21] Two volumes that escaped such criticisms, and indeed were highly praised at the time, were those by F.W. Sheilds on *The Strains on Structures of Ironwork* and J.H. Latham's *The Construction of Wrought Iron Bridges including the practical application of the principles of mechanisms to wrought iron girder work.*[22] These two books were both clearly set out, easy to follow, and contained a wealth of practical detail about connection methods, the qualities of material, and problems of fabrication. In the preface to his book, Sheild commented on one of the designer's problems:

> *'I have found great difficulty however in gaining a complete knowledge of the strains of several parts of iron frames as the works of previous authors, though displaying great talent and research have left much indetermined and obscure, which is necessary to the design of such structures.'*[23]

This is a view taken up by Latham in the Preface to his book, where he notes the almost total division of the practical from the theoretical in mid-century engineering, but pleads for both to be considered together saying, 'Yet it is only by their union that perfection can be obtained.'[24]

Criticisms of the theoretical content of textbooks suggest that the editors of journals saw their readership as consisting essentially of 'practical men' who would not be willing to attempt to assimilate new theories about design. Even an author such as Sheilds recognised that new research findings were not easily accessible to the practising engineer.

One writer whose works were of a practical nature, and who published extensively in mid-century, was William Fairbairn. His books appeared between 1850 and 1870, a period that included the publication of Rankine's books, but his style and content were in distinct contrast to Rankine.[25] Although Fairbairn contributed papers to the learned societies as well as writing books, it was the latter that reached the widest audience. His earliest book, *Useful Information for Engineers*, was in the mould of the engineering pocketbook. Perhaps his most famous was *On The Application of Cast Iron and Wrought Iron to Building Purposes*, first published in 1854 and reprinted and revised several times. The fourth edition in 1870 received very adverse reviews in *Engineering* which commented. 'If the 1870 edition was to be as useful as the 1854 edition it needed greater revising.'[26] This is in strong contrast to the reviews of Fairbairn's books published twenty years earlier. The main criticism appeared to be based on the use of what were considered to be out of date examples, such as the factory at Saltaire, the Spey Bridge and other tubular bridges, which were no longer accepted as appropriate structural forms. This volume, like others written by Fairbairn, contained much material reprinted from other sources. Because of their straightforward, non-mathematical approach his works were always easily understood by practical engineers. But although the style of writing was acceptable, the use of twenty year old examples, non-representative of the latest practice, meant that this works gradually lost approval.[27]

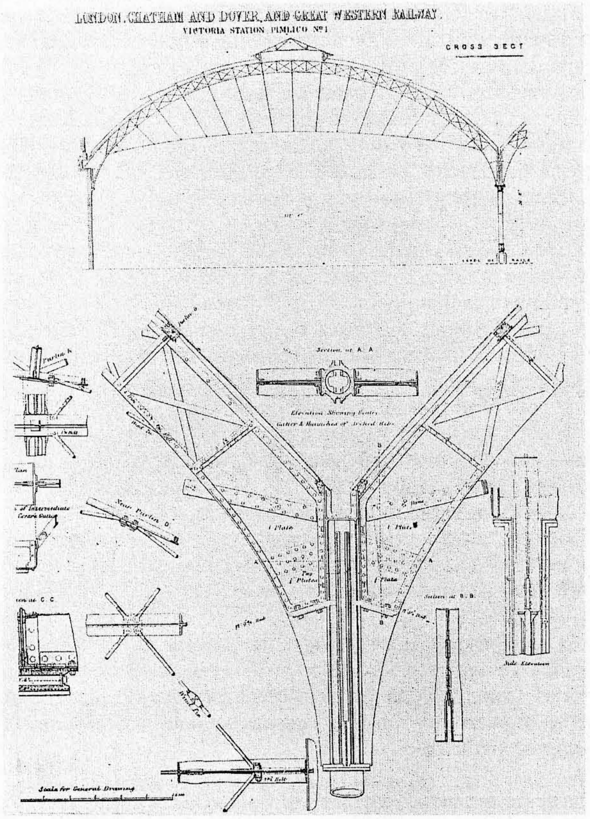

Fig. 3: John Fowler's roof for Victoria Station, a typical illustration from William Humber's *Record of the Progress of Modern Engineering* (1863).

The second group of books, those intended as direct aids to finding complete solutions, are exemplified by the various volumes written by William Humber, which came out between 1858 and 1870. All were large format volumes containing beautifully engraved and lithographed plates, accepted by contemporaries as an accurate record of the structure as built (Fig. 3).[28] Other books of this type by Dempsey and Grover contained, in addition to illustrations, tables of information about volumes of soil, and weights of materials.[29] Later in the century, when graphic statics had become an accepted technique, several books appeared, such as Olander's *A New Method of Graphic Statics*, where detailed drawings of a structure were accompanied by a worked example of the appropriate graphic analysis.[30] Volumes by Timmins and Tarn contained similar information, often presented so that one diagram could be used for varying loads and spans.[31]

The prevalence of books of this type and texts on draughtsmanship by people such as Binn, Bently and Charnock, with details of structural connections and simple calculations to determine the size of members, suggest that they were all intended for a readership, in the classroom or the office, with mathematical abilities that were limited.[32] It would appear that in the craftsman tradition these readers were prepared to copy from the examples of successfully completed structures, and not attempt to derive solutions from first principles.

It is difficult to judge the extent of the use of the third group of books, the manufacturer's handbooks, as so few have survived. One of the best known, Matheson's *Works in Iron* (from Andrew Handyside and Co.), seems to have been intended for the 'practical engineer' judging by its non-mathematical content.[33] The *Viaduct Handbook* from the Crumlin Iron Works, and Hutchinson's *Girder Making and Bridge Building*, were written in a similar style.[34] The first handbook of standard rollings was that published by Dorman Long in 1887 and was basically a catalogue. It was not until 1892 that a design manual, in the modern sense, was published by Redparth Brown and Co.[35] This contained safe load tables, provided on the assumption that there were very few engineers who would be able to produce calculations to justify the size of the beam to be used.

The final type of printed material considered here is the compendium or engineer's pocket book. Volumes of this type have been available for many years and went through a large number of editions. *The Practical Mechanics Workshop Compendium* by Templeton had fifteen editions in twenty-five years, and Molesworth's *Pocket Book of Useful Formulae and Memorandum* had its thirty-third edition in 1938.[36] The intended reader can be deduced from the comment in the Preface to Molesworth, which said:

> *Complex and difficult formulae have been as far as possible avoided, and in many cases, to the formulae have been added an easy approximate rule. Throughout the book there is scarcely a formula which cannot be mastered by anyone possessing little more than a mere knowledge of arithmetic'.*

Much of the comment in the journals and books talked of the need to copy what had been done before, and much of the information available, as described above, was presented in a form that made this possible. With design dependant on the use of factors to control the size of members, coupled with the use of small scale tests,

design education had only to develop the skills of draughtsmanship and an understanding of the disposition of structural members to succeed.

The approach adopted by many of these books suggests that until the end of the century the intended readership was not expected to be very familiar with complicated mathematical processes. The fact that some, such as Baker's *Long Span Railway Bridges*, were published in weekly parts in the technical press implies that they were intended for the aspiring artisan, hoping to improve his level of expertise.[37] As William Hutton wrote in the Preface to the fifteenth edition of Templeton's:

> *'... as the recognised text book and well worn and thumb marked Vade Mecum, of several generations of intelligent and aspiring workmen, it has the reputation of being the means of raising many of them in their position in life'.*[38]

One further source of information for the designer was the technical journal. By the mid-century the weekly technical paper was an established part of the engineering scene. The earliest magazines, *The Artizan*, *The Builder* and the *Mechanic's Weekly*, all catered for the general technician and constructor. *The Civil Engineer and Architect's Journal*, the *Engineer*, and *Engineering* were intended more specifically for the engineering design professions (Fig. 4).[39]

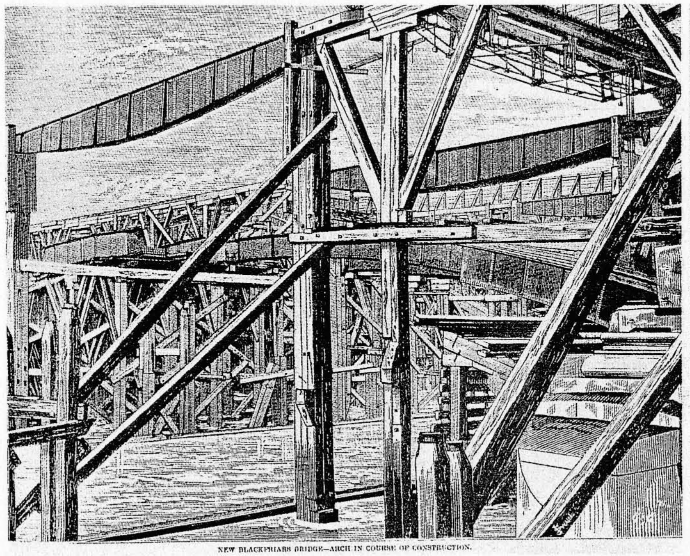

Fig. 4: The construction of Blackfriars Bridge (from the *Engineer*, February 18, 1876).

Education and Training

The ability of the practitioner of 1885 to make use of the research that was by then available can to some extent be measured by considering the content and quality of the education and training that was provided for the student twenty-five years earlier. By the mid-sixties the quality of the education for the engineer was the concern of many in the professions and was discussed by several of the Presidents of the Institution of Civil Engineers.

It was partly this concern that led the Institute to undertake a survey of training during 1868 and 1869. The results were published in a report in 1870, which expressed the Institution view that the education and training provided in the United Kingdom was the best in the world. The preface to the detailed information about courses gives a valuable statement of how the engineer of the time saw his profession and the preparation required for it. It endorsed the view that the education of an engineer should follow that adopted by other trades, namely a four year apprenticeship, and that this would provide the opportunity for the student 'to acquire competency'. It was considered that theoretical knowledge was not 'absolutely necessary', but the good pupil was expected to undertake private study to remedy any lack of theoretical knowledge. The report made very clear that it was considered that practical experience would compensate for any deficiencies in theoretical attainments.[40]

That this was not the universal view is apparent from the contribution made by Fleeming Jenkins in an appendix to the Report. Jenkins was at the time Professor of Engineering at Edinburgh, so was no doubt expressing the academic view of the situation. He described how at the age of eighteen the pupil was accepted, although a nuisance in the office, because of the fee; that the majority were ignorant of algebra, could not apply a simple formula from the pocket books, and that 'their arithematic is very shaky and a knowledge of physics, geology or the higher mathematics is wonderfully rare'. A further paragraph describes how little they were taught and how they picked up the minimum of information, only enough to enable them to do a limited class of work. As a contributor to *Engineering* pointed out, 'all the pupil in the office learnt was how to smoke cigars'.[41]

There was no mention in the report of what was considered to be the proper course of study, or type of education. This was perhaps because John Fowler had attempted to do this in his Presidential Address in 1866. He had described the training of the engineer under four headings.

1. General instruction or a liberal education.
2. Special education as preparation for technical knowledge.
3. Technical knowledge.
4. Preparation for conducting practical matters.

This course of study was based on the assumption that part one would be completed by the age of fourteen, the second after two years in an office, to be followed by a four or five year apprenticeship with an engineer to acquire the technical knowledge and practical experience outlined in the last two items.[42]

For the student in 1870 who did decide to undertake a formal course of study, the Institution report described ten courses that were available. Three, at the Royal School of Mines, the Royal School of Naval Architecture and Owens College did not award degrees. Of the seven university courses, two were in London, one in Edinburgh, one in Glasgow and three in Ireland. All covered to differing degrees subjects germaine to structural engineering, and all were of different lengths. The course in Glasgow required one year of four to be spent in an office, and the three year course at Cork provided, it was said, all the training required before setting up in practice.[43]

Throughout the latter half of the nineteenth century a series of investigations were made into the provision of technical education, as well as into the general availability of primary, secondary and higher education. What all these reports make clear, from the Yolland Report on *Engineering Education in the Army* to the seven reports of the *Royal Commission on Scientific Instruction* 1872-77, was that there was very little science or technical study conducted at any level, and that entrants to the professions and the armed forces were particularly ignorant in those areas involving science and mathematics that were considered important.[44]

By 1878, when the Livery Companies' Committee reported on technical education, in addition to the London based courses listed above they were able to describe classes at thirteen other institutions, ranging from Crystal Palace School of Practical Engineering to that at the South London Working Men's College.[45] These all seem to have been colleges that provided education for the artisan or the technician grade office assistant. Paradoxically, if the articled pupil received no formal tuition, the office draughtsman, if attending one of these courses, may well have been better informed about some of the technical matters discussed in the office.

Much of the evidence in the Livery Companies' Committee's Report notes how unsatisfactory apprenticeship could be with respect to any breadth of experience.

> *'... and the greater his skill in this one article the more chance there will be that he will be kept in it, both because he can earn more and also because he becomes more and more expert at this one speciality'.*

The Report goes on to note, in relation to 'abstract theory', that this should be obtained during the apprenticeship but:

> *'The practical fact however is, that such instruction is not given to apprentices except in rare instances.'*[46]

By the late 1880's, notwithstanding the defects in the system, the venerable William Pole could state:

> *'... this practical course furnished the most direct and expeditious entry to the professions. It was not the custom to consider any scientific knowledge as particularly necessary'.*[47]

Even those such as Fleeming Jenkins, who as Professor of Engineering was certain to be in favour of more formal tuition, were equivocal on this point. In his address to the B.A.A.S. in 1871, Jenkins pointed out how in the past good sense and long practice had provided the answers to simple problems, but in the seventies problems were more complex and the help of science and theory were required for their solution. However he went on to say:

> *'The business of the school is to teach those things which practice as an art will not teach a man.... one kind of knowledge of the properties of materials can only be acquired, by actually handling them.... Colleges cannot give him this; he must serve an apprenticeship, in fact if not in form.'*[48]

Theory, Science and Practice

What becomes clear from the evidence presented in these various reports is how the theoretical, scientific and technical education available in Continental colleges exceeded the scope and content of that available in the United Kingdom. The European courses were far more comprehensive and usually longer; an academic engineering qualification led to government posts and bettered social status, and was it seen as vitally important to the engineer. Many commentators, such as Jenkins, Calcott Reilly and Latham appreciated that continental engineers were going to be better prepared to confront new problems and derive solutions for them from first principles.[49]

This lack of formal technical education was very much the outcome of the English attitude to the provision of education and its content.[50] It was the result of several different influences: on one hand primary and secondary education was left to private enterprise, on the other the teaching of technical subjects was considered undesirable for reasons ranging from the wish to not raise the worker's aspirations, to the possible revealing of the firm's secrets.[51] It was also a reflection of two other attitudes that existed at the time. First, the anti-intellectual view of science and technical education, that was reinforced in the building industry by a widespread respect for the craftsman.[52] Secondly, the widely held mid-century opinion that all progess up to that time was soley due to the efforts of the 'practical man', the man on the job, whose education had been acquired on the shop floor, on the site, or in the office.[53]

It is clear that the need for a theoretical scientific education was understood in the 1870s and 1880s, but papers such as William Anderson's, given to the Junior Society of Engineers in 1887 at South Kensington, (where there was science teaching), with its plea that engineers should study nine sciences, suggests that at the time these were not part of the normal curriculum. Although Anderson's list is perhaps over ambitious, it presents a distinct contrast to that of Fowler twenty years earlier, where the emphasis was on the practical skills, but it still illustrates that those in practice in the nineties had not had the opportunity to acquire any substantial scientific knowledge in their youth.[54]

If it is assumed that the universities were the most likely source of scientific knowledge for engineers, the limited number of people on university engineering courses suggests that such knowledge was not very widespread. It would appear that in 1870 about 35% of those who described themselves as scientists or engineers attended university, about 200 in all, and the majority of these were scientists not engineers. Even in 1914, out of a total university population of 33,000, only 1622 (roughly 5%) were taking engineering courses. Outside the traditional centres, Cambridge, Edinburgh and Glasgow, the numbers in the civic universities were still very small, 800 in 1880, 3,300 in 1893, with only 93 graduating in that year. Because of the way the totals are aggregated there is no way of establishing how many were studying engineering, not science, but it seems that the number of engineering students was very small.[55]

One of the first things that Rankine attempted to do when appointed professor at Glasgow in 1855, was to define engineering knowledge and its relation to practice. He described as follows what he saw as the three parts of knowledge:

> *'Mechanical knowledge may obviously be distinguished into three kinds; purely scientific knowledge, purely practical knowledge and that intermediate knowledge which relates to the application of scientific principles to practical purposes, and which arises from understanding the harmony of theory and practice.'*[56]

This was the theme taken up by J.H. Latham in 1858, in the preface to his book, where he attempted a definition of the 'theoretical man' and the 'practical man', based on the use of analysis, the activity which most mathematical techniques are used for in structural design. He saw analysis for the practical man being used to classify events 'actually passing before the eyes', and for the theoretical man being used to draw out the facts so that 'the bearing they have on the object in view may be connectedly stated in sentences whose logic is easily seen...'. He went on to say, with regret, that the reasoning of mathematics and the experience of the workshop 'are rarely considered as in union, but rather as opposed to one another'.[57]

One result of Rankine's efforts, and those of others, to use a more scientific approach was the change in the 1850s and 1860s to the use of stress as a design parameter, in place of a breaking load. In 1869 the credit for this change in girder design was given by W.C. Unwin to J.H. Latham, when he said the latter was:

> *'...the first to abandon completely the formulae for breaking weight and to proportion girders simply to the actual stress due to the load, and his work is still probably the best treatise in our language on wrought iron bridges'.*[58]

Although a change of attitude was taking place, it seems that for most engineers at the time, the design of structures was based on the assumption that the best course of action was to copy an example that had successfully performed the function required. Much of the comment in the journals and books talked of the need to copy what had been done before, and much of the information available was presented in a form that made this possible. With design dependant on the use of factors to control the size of members, coupled with the use of small scale tests, design education had only to develop the skills of draughtsmanship and an understanding of the disposition of structural members to succeed.

One indication of the attraction of techniques based on craft skills, such as draughtsmanship, can be seen in the way the use of graphic statics was taken up in the design office in the last decades of the century, in preference to mathematically based design techniques. As steel became more widely used, it became important to be able to define the stress in individual structural members, to ensure the economical use of an expensive material, and the technique described by Karl Culmann in his book, *Die Graphische Static* (1866), enabled this to be done.[59] It was of course a design tool that required the minimum of theoretical knowledge and was dependant on draughting skills.[16]

Today the practice of design is seen as requiring a theoretical background before a solution to a large scale problem can be produced. However design is a skill, exercised in a climate of knowledge derived from a variety of sources, which requires practice for its development. It was this additional requirement that was described by Zerah Colborn in *Engineering* in 1869, in an editorial entitled 'Experience in Design', where he said:

> *'Engineers are often called upon to design structures, the proper pro-*

portions of which cannot possibly be determined by any process of mathematical investigation, no matter how refined or labourous'[60]

The whole article highlights the difficulties of design, where the quality of the material and distribution of members can falsify decisions based on exact calculation a similar point was made by Rankine:

'In practical science the question is – 'what are we to do' – a question that involves the necessity of the immediate adoption of some working rule'.

He went on to accept that technology could not wait for the result of scientific research, that designers had to make decisions on the best data available, and that prompt and sound judgement in such cases was the characteristic of the 'practical man'.[61]

Although as the extracts quoted above show, the combination of theory and practice was seen as desirable, change was slow. Benjamin Baker, in his Presidential Address to the British Association for the Advancement of Science, made a strong plea for the application of scientific principle, and of Rankine's 'Intermediate Knowledge'. This was intended to qualify the student '... to plan a structure or mechanism for a given purpose, without the necessity of copying some existing example, and to adapt his designs to situations to which no existing example offers a parallel'.[62]

To the foreign engineer the situation in Britain was hard to understand. As Gustav Eiffel pointed out in 1888:

'The English engineers have almost bypassed calculations, and they fix dimensions of their members by trial and error, and by experiment... and small scale models'.[63]

This view was reiterated in 1892 when William Anderson gave the first Forrest Lecture to the Institution of Civil Engineers:

'...this country is not keeping pace with its neighbours, and we shall, in the future, have to pay more attention to abstract science and its application to practice, than we have been so far in the habit of doing...'.[64]

Notwithstanding these attempts to get new ideas about structural design adopted, all the technical journals were very critical of books about theory and judging from the tone and content of the editorials about design, they considered that their readers were more interested in the practicalities of fabrication and erection. Several editorials commented on the way the man on the site could, by the distortion and overstressing of components during erection, completely nullify the assumptions and intentions of careful calculation.

Conclusion

It is apparent that people involved in the design, fabrication and erection of iron and steel structures in the nineteenth century, did not see their activities as the

result of a combination of either science, theory, practice or technology. For them applied science, although a term used by people such as Rankine, did not have its present-day meaning. For the mid-century designer all these concepts were separated, and his interest in theory was only for its power to forecast future events, or future performance. This is clear from a quotation from Bender's text book of 1877:

'...the thinking bridge engineer, who in the school or practice has learned to sift rubbish, both analytical and graphical, from the few principles of natural philosophy which are really needed... will decide for himself when... the application of the theory of the continuous girders can lead to any economy in construction'.[65]

It must be remembered that the best developed theories that involved the performance of structures were those concerned with the properties of materials, especially elasticity, and their use in structural design was limited. Even when analytical methods were available it is clear that few designers were prepared to use them. In engineering, a major part of practice is design, which is essentially action, and action requires a decision to do one thing rather than another; but action is based on intentions, on a design achieving the desired aim, which in much of construction involves what often appears to be subjective choices about form, geometry and style. But in artisan technology, which it is suggested was the basis for much of engineering and structural design, these choices were based on action which had a logical basis and an intuitive one. The latter would be better defined as communication by tacit knowledge, being understood without being expressed, and was to a large extent controlled by craft rules and respect for past examples, and did not depend on any scientific knowledge.[66]

The general level of understanding, and the concentration of science on those disciplines where observations could affect the classification and understanding of natural phenomena, meant that the 'practical man' had little use for science or theory. This was the view that Huxley put forward in 1850, when he wrote:

'... practical men believed that the idol whom they worship – rule of thumb – has been the source of the past prosperity, and will suffice for the future welfare of the arts and manufactures. They were of the opinion that science is speculative rubbish; that theory and practice have nothing to do with one another; and the scientific habit of mind is an impediment, rather than an aid, in the conduct of ordinary affairs'.[67]

and that same view would seem to be just as prevelent in 1890 as in 1850.

In the mid nineteenth century it was often assumed that physical science had an explanation for the observed behaviour of a phenomena and an exact theory that permitted the application of the general to the particular, providing a correct explanation of what had taken place. Frequently however when designs were based on theory, the theory was wrong and in a scientific setting the result would have been unacceptable. Fortunately in technology generally, and in construction in particular, rough and ready theories supplied quick estimates of orders of magnitude, and the traditional methods of construction and connection adopted, successfully in the majority of instances, masked the incorrect results of theoretical assumptions.[68] In this type of situation the view of a writer such as Layton is correct, when he comments that in the mid-nineteenth century there was very little of what the twentieth century would describe as applied science.[69]

This suggests that the premise put forward by some historians of technology, that the last half of the nineteenth century, in Britain, was a time when there were extensive developments in structural theory and scientific engineering are unfounded, and that the need to design large span structures did not create a demand for theories to explain structural performance.[70] Although by 1890 there had been an extensive body of research carried out into structural performance and the theoretical design of beams and trusses by continental engineers working in university and technical high school laboratories, the comments of practising designers do not suggest that the general view of the use of theory in design had changed much between 1840 and 1890.

The relative importance in relation to each other of science and technology, theory and practice, is still the subject of an extensive literature, in which numerous writers in the 1960s and 1970s, have attempted to resolve the question and to produce and acceptable philosophy of technology.[71] More recent writers have attempted to place the problem, as far as structural design is concerned, within the context of the design process. Thus whilst emphasising the creative aspects of design they have related the work of the practical man to the theoretical developments of the time and the range of problems to be solved.[72] However, there are still writers who are prepared to argue, as does Michael Forres, that all eighteenth and nineteenth century technical developments were the result of the efforts of the practical man.[73]

The preceding discussion demonstrates that for most of the professions in the construction world, the terms science, technology and theory had limited significance and that in the United Kingdom, perhaps in contrast to the rest of Europe, the 'practical man' remained highly respected. That this was true in education and design, as well as on site and in the workshop, is confirmed by a brief perusal of the biographies of late nineteenth century engineers, which show that in all aspects of their education and career, the practical was considered important.

The majority in the design professions had received an education that had been dominated by a craft approach to design, where respect for practical experience and tradition were paramount. This coupled with the scepticism for any contribution that academic study or science could make, ensured that many considered that practical experience and knowledge learnt in the workplace were more useful than anything else.

Nevertheless, by the end of the century, the general climate of ideas was slowly changing, and engineers and designers were aware that in many activities, even if not their own, science and theory had a contribution to make in providing explanations and developing analysis. This is apparent in the more theoretical content of the papers that were read to the institutions and that appeared in the technical press.

Although by 1890 there was a proliferation of institutions intended to serve the interests of a variety of engineering specialisms, it is apparent that the evidence does not substantiate the claim that there was an established discipline of scientific engineering. However changes were occuring and the dominance of the practical man, with his craft approach to education, design, and practice were being challenged. In design, as in many professions, the small size of the majority of practices has ensured that this preference for the practical or the craftsman approach has endured into the present century and can still be heard in discussions about professional education.

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Abstracts of Periodical Literature

SIMON PEPPER

GIDEON BIGER AND NILI LIPHSCHITZ, **Regional Dendrohistory and Timber Analysis: The Use of Wood in the Buildings of Nineteenth-Century Jaffa,** *Mediterranean Historical Review*, 6, 1 (June 1991), pp. 86-104. In an arid country, such as Palestine, the use of wood as a building material is closely related to other historical factors. The identification of the wood species used for construction in nineteenth-century Jaffa enabled the authors to trace the geographical origin of this material (to Asia Minor) and to explain the changes which followed the appearance of the steamship off the coast of Palestine, the presence of foreign colonies, changes in building styles, and building activity around the port of Jaffa. The authors suggest that timber analysis could be applied elsewhere to establish the phases of urban development.

DAVID BROOKE, **The 'Great Commotion' at Mickleton Tunnel, July 1851,** *Journal of the Railway and Canal Historical Society*, XXX Pt 2, 145 (July 1990), pp.63-67. The history of the construction and operation of the British railway system in the nineteenth century contains several episodes in which established companies used physical force to deter potential rivals. What distinguished the seizure of Mickleton Tunnel in 1851 was the presence at the head of one of contending parties of the great engineer, I.K. Brunel, who here came within a hair's breadth of ruining a reputation already tarnished by his high-handed actions in 1837 (when the progress of the GWR had been threatened by recalcitrant landowners). In his efforts to remove a tunnelling contractor whose delays threatened progress on the Oxford, Worcester and Wolverhampton Railway, Brunel marshalled an army of 2,000 navvies to throw the contractor off the site, and the ensuing riotous confrontation was only controlled by magistrates with a large force of armed police.

DAVID BROOKE, **The Criminal Navvy in the West Riding of Yorkshire,** *Journal of the Railway and Canal Historical Society*, XXX Pt 7, 150 (March 1992), pp.365-72. The labour forces (and their employers, see above) of civil engineering projects acquired a reputation for disorderly behaviour during the construction of canals. This paper draws on the West Yorkshire archives, Wakefield, for its data on the crime waves and attempted preventive measures that accompanied works on canal, railway and tunnelling projects, as well as the civil disorders that so often afflicted the towns which formed the base areas for major nineteenth century construction enterprises.

CAROLINE A. BRUZELIUS, ***ad modum franciae:*** **Charles of Anjou and Gothic Architecture in the Kingdom of Sicily,** *Journal of the Society of Architectural Historians*, L, 4 (December 1991), pp.402-420. The ruined abbeys of S. Maria di Realvalle and S. Maria della Vittoria in southern Italy attest to the use of French Gothic architecture as part of a policy of cultural and political domination over the kingdom conquered by Charles of Anjou in 1266. The Angevin registers document