Proceedings of the First International Congress on Construction History, Madrid, 20th-24th January 2003, ed. S. Huerta, Madrid: I. Juan de Herrera, SEdHC, ETSAM, A. E. Benvenuto, COAM, F. Dragados, 2003.

Robert Stephenson and planning the construction of the London and Birmingham Railway

Michael M. Chrimes

> It was the first of our great metropolitan railroads, and its works are memorable examples of engineering capacity. They became a guide to succeeding engineers; as also did the plans and drawings . . . When Brunel entered upon the construction of the Great Western line he borrowed Robert Stephenson's plans, and used them as the best possible system of draughting. From that time they became recognised models for railway practice. To have originated such plans and forms, thereby settling an important division of engineering literature, would have made a position for an ordinary man. In the list of Robert Stephenson's achievements such a service appears so insignificant as scarcely to be worthy of note.
>
> (Jeaffreson 1864, 1: 213).

Jeaffreson's modest final accolade highlights the significance of the London and Birmingham Railway. Robert Stephenson's appointment as its Engineer of the on 19 September 1833 (Directors 1833) marked a new stage in the general development of civil engineering in the British Isles. This paper will consider Stephenson's appointment in the context of civil engineering at that time, and the experience available within the profession. It will focus on how he organised the construction of the railway, and its impact on civil engineering generally.

In the early 1830s civil engineering was a profession moving to maturity (BDCE; Chrimes 2003a; Skempton 1996a; Watson). The term had been coined by John Smeaton about seventy-five years earlier and, following its foundation in 1818, the Institution of Civil Engineers had secured a Royal Charter in 1828. There had been skills shortages in civil engineering in years of high demand, and it remained difficult to obtain adequate training in the profession. It was not until the 1820s that the majority of practioners had received training explicitly as civil engineers, and not until 1841 that the Institution of Civil Engineers were to insist on this of its Members. By the standards of the time Robert Stephenson with his training and university education, was well prepared.

At the time of the construction of the Liverpool and Manchester Railway in the late 1820s there were many people around with more experience of civil engineering than the Stephensons. By 1833 the success of locomotive traction had changed the situation dramatically, and put the services of the Stephenson school of engineers in high demand. Robert Stephenson was free of other commitments and the Railway's Directors may also have felt Robert's youth might make it easier to tailor him to their needs.

The Route

Early proposals for a railway between London and Birmingham were projected by William James (1820) and (Sir) John Rennie (1825–26) and followed a more westerly route than that proposed for a rival company by Francis Giles in the late 1820s (Chrimes 2003b). It was Giles' route which formed the basis of that developed by Robert Stephenson (1831–1833). Once the route had been identified surveying teams made surveys indicating the property ownership along the line in preparation for a Parliamentary bill. This failed to be enacted in 1832, largely due to opposition from property interests but was successful the following year. At that time most civil engineering works in Britain were privately financed, and required a parliamentary act before they could proceed. The London and Birmingham's Act was passed in May 1833.

PROJECT ORGANISATION

The Act represented a license to proceed —with the detailed surveying as a prelude to the purchase of land with raising capital, constructing the works, and operating the railway itself.

Over the previous seventy-five years three generations of engineers had met similar challenges and developed established procedures for carrying out civil engineering works, but rarely on the same scale. With major linear works of the London–Birmingham type the greatest obstacle to completion had often proved not the engineering challenges of the route, but rather raising the capital necessary. This had stalled works on Smeaton's Forth–Clyde Canal, Brindley's Oxford Canal, Rennie's Kennet and Avon Canal, and Jessop's Grand Junction Canal, as well as a whole host of lesser works (see table 1). More recently the Liverpool and Manchester Railway had sought an Exchequer loan for its works.

The timing of the London-Birmingham Act was fortunate in that the operating success of the Liverpool-Manchester Railway emboldened investors, the passage of the Reform Act promised political stability, and the economic cycle was on an upturn. As work proceeded circumstances began to change, wages and thus costs rose, and in the late 1830s there was a mini-economic crisis, which affected Brunel's work on the GWR; by then the London-Birmingham Railway had opened. One challenge, therefore, was to construct the railway as quickly as possible to enable investors to see a return on their capital before they lost heart.

As originally presented to Parliament , the line was 111 miles in length from Camden Town, London, to Curzon Street, Birmingham, with gradients nowhere exceeding 16ft per mile (1:330), and involved 12 million cubic yards of excavation and nearly 11 million cubic yards of embankments, as well as 6 viaducts, some 300 bridges and three long tunnels. It was on a scale rarely matched before or since. For comparison one can refer to table 1 for canal works, and table 2 below for other major civil engineering projects.

Table 1. Some Major Canal Works - 1760–1830

Project	Engineer	Years	(Engineering) Costs
Oxford Canal I	Brindley and Simcock	1769-1778	£200,000
Oxford Canal II	Barnes	1786-1798	£ 56,000
Oxford Canal III	Vignoles	1828-1834	£170,000
Forth and Clyde Canal I	Smeaton and Mackell	1768-1777	£164,000
Forth and Clyde Canal II	Whitworth	1785-1791	£140,000
Kennet and Avon Canal	Rennie	1794-1810	£860,000
Grand Junction Canal I	Jessop	1793-1805	£ 1.5m
Grand Junction Canal II	Barnes	1797-1805	See above
Grand Union Canal? III	H Provis and Bevan	1810-1814	£290,000
Caledonian Canal	Jessop and Telford	1803-1823	£855,000

Table 2. Major British Civil Engineering Projects - 1600–1830

Project	Engineer	Years	Costs	Approx. Value
Great Bedford Level	Vermuyden	1650-1656	£250,000	170m
Westminster Bridge	Labelye	1738-1750	£198,000	100m
Trent and Mersey Canal	Brindley and Henshall	1766-1777	£300,000	150m
West India Docks	William Jessop	1800-1806	£515,000	160m
Bristol Harbour	William Jessop	1804-1810	£470,000	140m
Plymouth Breakwater	The Rennies	1812-1850	£ 1.5m	400m
Sheerness Dockyard	The Rennies	1813-1830	£ 1.6m	400m
London Bridge	The Rennies	1824-1831	£425,000	105m
Liverpool and Manchester Railway	George Stephenson	1826-1830	£600,000	150m
London and Birmingham Railway		1833	£ 2.5m (original estimate)	450m

To guide him Stephenson had his own experience and observations on projects in which his father had been involved. He could also build on the precedents set by previous generations of engineers. In this the work of Smeaton was particularly significant. In the early 1830s there was little available in the way of engineering textbooks to draw upon (Skempton 1987) and Smeaton's published reports provided practical illustrations of engineering (Smeaton 1814). Stephenson later acknowledged Smeaton's influence: *«Smeaton is the greatest philosopher in our profession this country has yet produced»* (Smiles 1861: 2, 86)

Smeaton's Forth-Clyde Canal provided a model management structure for linear works. The project organisation of the London–Birmingham Railway mirrored this model. The route was divided into divisions under assistant engineers, with sub-assistant engineers and overseers responsible for the day-to-day supervision of shorter sections (Table 3). Each division involved a number of contracts, based on what was considered reasonable capital resources for a contractor. Generally a balance of cuttings and embankments was sought in each contract to minimise the need to haul over long distances. Separate contracts were drawn up for some major works and later works such as station buildings. Before contracts could be issued estimates were prepared to assess tenders properly, specifications and drawings prepared for inspection by contractors to enable them to price their work, and detailed land surveys carried out to enable land purchases to proceed. All this required staff, an opportunity for Stephenson to bring in experienced and trusted individuals who would share his workload.

Appointment of Staff

Stephenson's experience provided him with the opportunity to judge in general terms the qualities of staff he would require. Although many of George Stephenson's associates were tied up elsewhere, Robert was largely able to rely on people already known to him and experienced in railway work for senior appointments. The week following his own appointment, on 26 September, Stephenson made his first recommendations for engineering appointments: John Dixon and William Crosley as assistant engineers, and S. Bennett, J. C. Birkenshaw, E. Dixon and C. Fox as draughtsmen to work at the London end (Directors 1833). The next day he recommended T. L. Gooch as Assistant engineer, with John Brunton junior, at the Birmingham end (Birmingham 1833).

Stephenson was unsuccessful in his recommendation concerning John Dixon, who remained with the

Liverpool and Manchester Railway. . Further negotiations regarding salaries, and the appointment of George Watson Buck and Frank Forster as additional Assistant Engineers, followed in the next 3 months. This team of Assistant Engineers were to be in charge of construction until April 1837 when Thomas Gooch went to take charge of the construction of the Manchester and Leeds Railway . The management structure for construction can be seen in table 3. The engineering staff on the line eventually, in late 1837, numbered 55 (CEAJ 1837), and details of known names and appointments can be seen in table 4.

Of those not known to him personally Buck and Crosley had considerable experience of construction, and Buck also had a reputation for his structural use of iron (BDCE 2002). Fox's engineering experience was of a more mechanical nature, and he clearly had a commanding presence (Conder 1983, 11–12). Generally Stephenson's management technique was to appoint young aspirant engineers to junior positions, entrusting them with more responsibility and independence as they proved themselves. He later wrote to Brunel, speaking specifically of G. H. Phipps:

> I have always met that by reposing the utmost confidence in him taking care of course that my principles of conducting operations were adhered to . . . (Stephenson 1838)

Table 3.

Station	Miles	Principal Works	Engineering Staff Sub-Assistant*	Assistant
Euston	0			
Camden Town Depot	1	Retaining walls		Charles Fox
		Primrose Hill Tunnel	F. Young	
Watford	18	Watford Embankment and Colne Viaduct	T. Jenkins	George W. Buck
		Watford Tunnel	Captain Cleather	
Tring	32	Tring Cutting	S. S. Bennett	
[Denbigh Hall]	48		E. Jackson	William Crosley
Wolverton	52	Wolverton Embankment and Viaduct	T. Gandall	
	58			
Blisworth	63	Blisworth Cutting	G. H. Phipps	Frank Forster and G. H. Phipps
Weedon	70			
	79	Kilsby Tunnel	C. Lean	
Rugby	83		H. Lee	
		Avon Viaduct	J. Brunton	Thomas Gooch and Frank Forster
Coventry	94			
		Beechwood Tunnel	B. L. Dickinson	
Birmingham	112	Rea Viaduct		(after April 1837)

Table 4. London and Birmingham Railway - Engineering Staff

Name	Date of Appointment	Annual Salary	Role
George Aitchison	January 1834 January 1837	£150 £270	Clerk Architect intermediate stations
Bagster	1836		Superintendent of station layouts
William Baker			Pupil of G. W. Buck
J. Bennett?			
S. S. Bennett	1833 1835	£200	Draughtsman Sub-Assistant Engineer, Tring
J. J. Berkley	(1837)		Pupil of G. P. Bidder
George Parker Bidder	17 September 1834		Assistant in drawing office
John Cass Birkenshaw	November 1833 May 1834 19 November 1834	£200 £400	Draughtsman, staking out London area Drawings, etc., Birmingham Division Manager, Primrose Hill direct labour
P. Browne	?1837?		Assistant?, Coventry
John Brunton	 11 October 1833	 £250	Assists in preliminary surveys Sub-Assistant Engineer, Birmingham Division, Avon Viaduct
William Brunton	1830-1831		Surveyor/Resident, London end
George Watson Buck	December 1834	£600	Assistant Engineer, 'B' (Watford Division)
Budden	May 1834 1836	£100	Office Assistant
D. Carter	1836		Draughtsman, Coventry, Clerk of Works, Euston Station
Charles Frederick Cheffins			Assisted with drawings
Captain Cleather	October 1834	£200	Sub-Assistant Engineer, Nash Mills, Tring
Francis R. Conder	1834		Pupil of Charles Fox
William Crosley	1833		Assistant Engineer, 'C' Division
William Crosley (junior)	1833 (6 April 1836)		Pupil (Assistant) of father, in drawing office
Bernard L Dickinson			Sub-Assistant Engineer, Birmingham September 1835 1837
Edward Dixon	1832 September 1833 7 February 1834	 £200	Assisted in surveys Draughtsman Sub-Assistant Engineer
R. Dixon			Draughtsman
Robert Benson Dockray	December 1835 1837 7 March 1838	 £300	Assistant Sub-Assistant Engineer Resident Engineer, Birmingham Division
Mark Faviell (junior)	?1835		Sub-Assistant Engineer
Frank Forster	1 November 1833 December 1833 April 1837	£500 £600	Assistant Engineer, Weedon Assistant Engineer, Birmingham
George Foster	5 May 1834 1837		Draughtsman, St John's Wood Assistant, Coventry office
Fowler	1837		Assistant, Coventry office
Charles Fox	1833 1834 1835 August 1837	£200	Draughtsman Sub-Assistant Engineer, Watford Assistant Engineer, Euston Extension Resident Engineer, London–Wolverton
John Gandell	2 September 1835		Sub-Assistant Engineer, Wolverton

Table 4. (Continuation)

Name	Date of Appointment	Annual Salary	Role
Thomas Longridge Gooch	October-November 1831 1832 11 October 1833 December 1833	 £500 £600	Surveys of route Estimates and further surveys Assistant Engineer, Birmingham District (Coventry)
Conrad Hanson	4 October 1837	£150	Office Assistant
William Hanson	1836?	£ 50	Office Assistant October 1837
George Harris	[1837]		Pupil of Charles Fox
Thomas Elliot Harrison	1830-1831		Assistant on surveys
David Hodgson	August 1837		Assistant, Wolverton
Edward Jackson			Sub-Assistant Engineer
Timothy Jenkins			Sub-Assistant Engineer
King			Assistant to Aitchison
Charles Leam	1 August 1834 1835	 (£400 from June 1836)	Draughtsman Sub-Assistant Engineer, Kilsby Tunnel
Peter Lecount	1832 May 1834	 £150	Traffic forecasts Clerk, Engineer's Department Sub-Assistant Engineer, Birmingham Division
Hedworth Lee	1835 1837		Draughtsman Sub-Assistant, Weedon
William Price Marshall	1835		Draughtsman
Sturges Meek	1833 December 1836		Pupil of George Stephenson Sub-Assistant Engineer
George Mackay Miller	1833?		Draughtsman
M. Monteleagre			Sub-Assistant Engineer
John Nash	1834	c.£150	Overseer
Paul Padley	September 1833		Stakes out line
Perry	[c.1837]		Assistant, Berkhamstead
George Henry Phipps	1833 1835	£200	Draughtsman Sub-Assistant Engineer, Weedon
Robert Rawlinson	December 1834?		Assistant at Blisworth, 1836
John Reid			Sub-Assistant Engineer
Luke Richardson	1836		Overseer
J. Riches	[1837]		Assistant, Coventry office
James Routh	[1830s]		Pupil/Assistant to G. P. Bidder
William Routh			
William Rudge			Assistant, Coventry office
J. Sharpe			Clerk of Works, Camden Station
Thomas Macdougall Smith	1830s		Assistant
Herbert Spencer	10 November 1837	£80	Pupil of Charles Fox
Robert Stephenson	1830-1833 September 1833	 £1,500	Joint Engineer, Parliamentary planning Engineer-in-Chief
Stokes			Draughtsman, St John's Wood
Francis Thompson	December 1838		Assistant architect
Richard Townsend	1837		Sub-Assistant Engineer, Tring
Francis Mortimer Young	1833 10 December 1834	 £200	Draughtsman, Coventry office Sub-Assistant Engineer, Primrose Hill Tunnel

The team's first task was to stake out the actual line of the railway. The Act allowed deviation within a band 100 yards wide and gave railway staff authority to enter property to fix the route. Stephenson believed that by employing experienced engineers he could save on land surveying costs (London, 26 9 1833); it would also give his senior staff first hand acquaintance with the route. He himself had walked the line 12 times by May 1834 (Conder 1983, 14).

Levels were taken every chain (22 yards) along the line, enabling the preparation of sections, and thus quantities. Trial shafts were sunk at several locations to obtain additional information on the strata to that gathered prior to the Act, and providesamples for the contractors. These investigations led to a modification of the design slopes, and a consequent increase in costs.

As the route was fixed by the engineers in the field, contract drawings could be made and specifications drawn up. Common sense suggested that contracts should be let at the London and Birmingham ends first as there traffic was likely to be greatest and could generate income to offset against expenditure (Rastrick 1833). Thereafter, the most difficult contracts namely those at Tring and Kilsby Tunnel were prepared so delays there would not hold up the opening of the whole line. Table 6 indicates the details of the contracts, and when they were awarded.

The process was apparently straightforward, but from contemporary sources it is clear Stephenson was short-staffed in early 1834. His staff included, aside from himself, 4 assistant engineers, several of whom had pupils (table 4), and 4 sub-assistants, and 8 known office staff. It took two man-days to prepare a drawing and 2,000 drawings had to be prepared for the line, the equivalent of more than 10 man years work (Lecount 1839). Stephenson himself spent at least three days on the Rea viaduct for which three drawings were prepared, He personally supervised the drawings, and was also responsible for the specifications (Stephenson 1834). Although Brunton speaks of two shifts of 20 drawing office staff, this must surely refer to a later period. He claimed to have worked twenty hours (i.e., 2 man-day) shifts with only one night's sleep for a fortnight, personally delivering the Birmingham drawings for the inspection by the directors on 4–5 July 1834 (Brunton 1930, 36). One suspects others were as busy. Pupils were probably all drafted in to meet deadlines and additional draughtsmen taken on at short notice.

This meant that there was an initial «crisis» on the critical path; the human resource dictated how quickly contracts could be let and work commenced. The Birmingham directors expressed their disquiet at the delay in starting work at their end of the line (Birmingham, 16 5 1834) Pressure became more acute as work began on site requiring supervision, and preparations for an extension act to Euston from Camden began in the autumn of 1834.

Selecting the Contractors

Once the specifications and contract drawings had been prepared the contracts could be put out to tender. A senior engineer consulted by the Company, John Urpeth Rastrick, recommended putting the contract out to tender in large lots, since «extensive contracts . . . become worth the attention of men of capital who should they unfortunately find that they have taken the work for too small an amount, or should the seasons become unfavourable for the execution thereof, so that they may run the risk of losing money by the contract they will still go on and complete the work sooner than suffer the least imputation on their character or respectability . . . whereas when work is let in little petty contracts they are generally taken by men of no capital whose security is good for nothing, and as soon as ever they discover or think that they have made an imprudent contract, begin immediately to have recourse to every expedient to get rid of it . . . » Moreover «I have always found that the work was much better done and that everything went on with more expedition and the Engineer's orders all were punctually attended to when the contractor had a fair and liberal compensation from his contract» (Rastrick 1833, 30)

Henry Robinson Palmer, founder of the ICE, was of a similar mind (Palmer 1833). Engineers discussed this approach in their evidence to the Select Committee on the Southampton Railway (Southampton 1833). While Rastrick's theory may have been sound there were practical problems in finding contractors with the financial resources to take on such lots. A number of contractors with many years of experience in civil engineering, but only a handful had taken on contracts of more than £100,000 in value before this time, which may have cautioned a circumspect approach. Perhaps there was a feeling that the domination of public works contracting by McIntosh and Banks in the 1820s may have worked against the client's interests (BDCE). In practice contracts were let in batches to suit project control, the office workload dictated the timetable, with lot size determined by convenience and the engineering challenges anticipated. Most were for 4–6 mile lengths, excluding special structures. For the Tring contract major contractors were invited to tender,[79] anticipating the heavy work involved, but elsewhere there was a free-for-all.

Stephenson and the Board were aware of the risks attached to accepting the lowest tenders from inexperience or under capitalised contractors, and contractors were expected to provide 10% sureties, and operate with a retention (Townsend). Tables 5 & 6 provide details of the contracts, date, contractors, estimates, tenders and out-turn. Table 7 gives an indication of the contractors previous experience. The line was broken down into smaller lots than Rastrick and Palmer had advised and Stephenson seems to have determined on a value of 30–50,000 pounds (London, 12.11.1834). However as a few contractors took several lots, Rastrick's suggestion could have been met in practice, and arguably Stephenson did not take full advantage of the contracting experience available.

The most striking things about the tables are the number of contractors who «failed». Eight contracts of 30 were completed by the Company, and in 4 other cases contracts were either re-let or completed by another contractor on the line. Interestingly few of these enterprises continued contracting into the 1840s. Perhaps some contractors were too old to meet the physical challenges involved, while their younger assistants, often their children, lacked the necessary experience.

Expenditure and Cost Control

The eventual cost of the London and Birmingham Railway on opening at c.£5.5 million was twice that of the Parliamentary estimates. In some quarters Stephenson was heavily criticised for extravagance and the inaccuracy of his estimates, but generally the view of his contemporaries was one of respect for his achievement, a view no doubt shaped by the financial success of the railway.

Table 8 displays how estimates changed from 1831 as construction proceeded, revised estimates made in the light of escalating expenditure, and final costs when the line was opened.

The costs of John Rennie's proposals were never published, but estimated for civil engineering work at £1.25 million. The detailed estimates for parliament were prepared by Stephenson and Gooch, presumably based on the Liverpool and Manchester experience. In almost every category estimates were grossly exceeded, and in this context those within Stephenson's direct control, particularly the civil engineering work, are not disproportionately costly (Table 8). Bearing in mind that the tenders came in within Stephenson's estimates (table 6), and most other leading engineers broadly concurred with Stephenson's figures, contemporary explanations for the cost overruns must be taken seriously.

As detailed at the end of 1836 these were the engineering problems posed by the difficult ground conditions on the Primrose Hill, Kilsby and Blisworth contracts, the increase in the volume of earthworks caused by modifications to the design slopes, all within Stephenson's sphere, unexpectedly high land prices, the additional costs of stations, and rising iron prices. The price of land and iron (Table 8 and fig 1) while attributable in part to the demand from the railway, were beyond its control. The increased costs of the stations were attributed to the improving prospects for railway traffic, in part due to the establishment of further connecting lines, and the success of the railway on opening; this also led to the purchase of more locomotives and rolling stock. It is of some interest that in some earlier estimates Stephenson had perhaps made more realistic estimates regarding the stations.

Expenditure is displayed graphically in figure 2 With regard to progress on works, the initial idea was to let the London and Birmingham section contracts first, to bring in income, and then those anticipated taking longest. Each contract specified quantities of earth to be shifted by specific target dates. Almost immediately problems with this approach were exposed due to the frailty of the contractors; this put

Table 5. Contracts

Contract	Length in Miles	Contractor	Date	Price (£)
Euston Extension	1	W. and L. Cubitt	Dec 1835	76,860
1B Primrose Hill	$5\frac{3}{4}$	T. Jackson*	May 1834	119,987
2B Harrow	$9\frac{1}{2}$	Nowell and Sons	May 1834	110,227
3B Watford	5	James Copeland	May 1834	117,000
4B King's Langley	$2\frac{1}{4}$	W. and L. Cubitt	September 1835	38,900
5B Berkhamsted	$4\frac{1}{2}$	W. and L. Cubitt	September 1835	54,660
6B Aldbury	$2\frac{1}{2}$	Richard Parr	September 1835	14,500
1C Tring	6	Thomas Townshend*	September 1834	104,496
5C Leighton Buzzard	3	James Nowell	September 1835	38,000
6C Stoke Hammond	4	E. W. Morris	September 1835	39,303
7C Bletchley	$3\frac{3}{8}$	John Burge	September 1835	54,500
2C Wolverton	5	William Soars*	October 1834	67,732
4C Wolverton Viaduct	$\frac{1}{8}$	James Nowell	February 1835	25,226
3C Castlethorpe	$4\frac{1}{2}$	Craven and Sons	October 1834	49,735
1F Blisworth	5	William Hughes*	February 1835	112,950
2F Bugbrooke	5	John Chapman	February 1835	53,400
3F Stowe Hill	$1\frac{1}{4}$	John Chapman	February 1835	23,050
4F Weedon	$1\frac{1}{8}$	Edward Beddington	May 1835	23,090
5F Brockhall	$3\frac{1}{8}$	J. and G. Thornton	May 1835	34,157
6F Long Buckby	$3\frac{5}{8}$	J. and G. Thornton	May 1835	42,582
7F Kilsby Tunnel	$1\frac{3}{8}$	Nowell and Sons*	May 1835	98,988
7G Rugby	$5\frac{1}{8}$	Samuel Hemming*	February 1835	59,283
6G Long Lawford	$3\frac{1}{4}$	W. and J. Simmonds	February 1835	20,330
5G Brandon	$4\frac{1}{4}$	Samuel Hemming*	February 1835	40,000
5G Avon Viaduct	$1\frac{1}{6}$	Samuel Hemming	November 1835	7,970
4G Coventry	$7\frac{3}{4}$	H. Greenshields*	November 1834	101,700
3G Berkswell	$4\frac{1}{2}$	Daniel Pritchard	November 1834	53,248
2G Yardley	$7\frac{1}{2}$	Joseph Thornton	August 1834	68,032
1G Saltiey	$1\frac{7}{8}$	James Diggle	August 1834	32,878
1G Rea Viaduct	$\frac{1}{8}$	James Nowell	August 1834	13,644
* work later taken over by Company				1,698,681

Table 6. Contract estimates and final expenditure

Contract	Parliamentary est 1832	Engineers' est 1834	Contract price	Revised contract price	Dec 37 expend	Final expend	% overrun on estimates
1b	93998	120668	119987			280014	232
2b	88436	104089	110277			144574	139
3b	105738	102944	117000			138219	134
4b	33775	41114	38900			57386	139.5
5b	41562	58648	54660			65002	111
6b	15795	16694	14500	16694		25134	150.5
1c	86006	*98298*	**104496**			144657	147
5c	32422	**33502**	**38000**			43162	129
6c	42048	**43869**	**39303**			42345	96.5
7c	40468	**48398**	**54500**			61071	126.
2c	73920	*75081*	**67732**			107765	143.5
4c	31150	*27163*	*28132*	25226		28964	106.6
3c	43271	*45224*	*48414*	49735		71873	159
1f	113400	*110097*	**112950**			184301	167
2f	45455	*56414*	**53400**			65013	115
3f	19887	*24596*	**23050**		25571	31536	128.
4f	80104	*28217*	**23090**	26150	25860	31442	111
5f		*40000*	**34157**			50583	126
6f	39297	*46293*	**42582**			48256	104
7f	84815	*102174*	**98988**			291030	285
7g	55971	*72684*	**59283**			93384	128.
6g	23119	*26882*	**20330**		22740	25893	96
5g	38775	*43648*	**40000**		42272	55090	126
avon	6519	*8031*	**7979**		8421	8621	107
4g	103335	*108898*	**101700**		127488	150496	138
3g	63264	*50252*	**53248**		56281	62738	125
2g	70512	*66842*	**68032**		68127	78131	117
1g	32883	*35057*	**32878**		34862	38707	110
rea	9489	*13380*	**13644**		14928	15505	116
Euston	83810	*83810*	**76860**			91528	109
Total	1599224	1732967	1698072	1698681		2532420	146

Table 7. Contractors Experience, etc.

Name	Years Experience	Principal Works
Edward Beddington	no information	
John Burge	c.5 years	St. Katharine's Docks
John Chapman	no information	
James Copeland	c.10 years	Liverpool and Manchester Railway, Leicester and Swannington Railway
Hiram Craven	25 years	Union Canal, Hull Junction Dock
W. and L. Cubitt	15 years	Fishmongers Hall
James Diggle	?5 years	?Warrington and Newton Railway
Hugh Greenshields	c.10 years	Sankey Viaduct, Liverpool and Manchester Railway
Thomas Harding	?only as labourer	Leicester and Swannington Railway
Samuel Hemming	15 years	Bombay Engineers 1819
William Hughes	30 years	Caledonian Canal
Thomas Jackson	10 years	Assistant to Grundy, London Building Contractor
William Mackenzie	25 years	Birmingham Canal
E. W. Morris	15 years	Holyhead Road, B&LJ Canal
James Nowell	20 years, mason	Various churches
Joseph Nowell	20 years, mason	Macclesfield Canal, St. Helens Railway
R. Parr	mason	Newcastle and Carlisle Railway
Daniel Pritchard	20 years	Harecastle Tunnel, Trent and Mersey Canal
W. and J. Simmonds	no information	
William Soars	c.15 years	Macclesfield Canal
George and James Thornton	10 years	Liverpool and Manchester Railway
Joseph Thornton	5 years	Liverpool and Manchester Railway
Thomas Townsend	40 years	Birmingham Canal

the construction timetable under pressure. The timetable was also upset by delays in preparing the drawings and specifications. The early prospects of revenue were diminished.

As early as September 1835 Stephenson was under pressure to improve progress, and he made suggestions for speeding up work at Primrose Hill (London, 22 9 1835) At the end of December he provide estimates for expenditure in the following year (London, 29 12 1835) Following his report on progress on the Southern section at the end of January a special committee was set up to inspect the works, and report on the state of progress (London, 27 1 1836). There was concern about running out of finance, and contract targets not being hit, with the first contracts due for completion that June. It was clear that under existing conditions there was no prospect of opening the line on time A further inspection was crushing in its condemnation of the contractors Copeland and Harding:

Table 8.

	Feb 1831 Est	Parl Ests 1833	Contract tenders 1835	1836 ests	June 1840	1840 as % of 1833
works	1671574	1558852	1698681	2528890	3927647	252
land	423100	250000	250000	506500	706152	169
parliament	50000	73000	**72869**	84869	**72869**	99.8
permanent way	547968	315900	315900	693822		0
rolling stock	168000	61000	61000	253715	336097	196
other costs		99191	99191	224277	295609	298
contingencies	150000	294648	294648			0
buildings	71000	19600	19600	154421	360000	507
Total	3081642	2672191	2811889	4446594	5698374	213

> . . . the system now acted upon by the contractors is unskilled and altogether inefficient for the proposed object . . . Mr Copeland has been absent for the railway above 6 weeks and does not appear to have the power to act when present. Mr Harding is little better than a labourer and has no authority.(London 1836, 205–209, 212–216)

Stephenson came under increasing pressure to perform. By the end of 1836 the Board realised that the financial estimates would have to be revised, in the light of slow progress, and also escalating costs. The crisis of confidence in Stephenson's ability had reached its peak over the construction difficulties caused by quicksand in the Kilsby tunnel. As Stephenson determined his course of action a Company Secretary Captain Moorsom arrived, and was fortunately impressed enough to persuade his colleagues it was not necessary to call on another engineer (Jeaffreson, 203–204). This said, directors' visits continued and in April 1837 it was decided to assign individual directors to monitor each unfinished contract (London, 12 4 1837). This could be said to be undermining the engineer's authority, although in the end it may have enhanced it as his engineering judgement, exposed to the utmost scrutiny, was vindicated.

One can see the fates conspiring against Stephenson. Having promised a, delayed, opening at the end of 1836, the weather conditions caused him to withdraw all forecasts in December (Engineers, 12 1836). In the end the effort involved was enormous, with regular night work endorsed by the directors in the pursuit of an opening of the railway. The additional costs were met by additional borrowing and calls on shares permitted by supplementary acts of Parliament.

From extant records it is known that George Aitchison was responsible for monitoring project costs in the London office, Stephenson produced a regular account of work done and to be done, and latterly printed reports were provided for the Birmingham Committe. Project control could not have been tighter.

The civil engineering industry has an unenviable public reputation for cost overruns on major projects. The Channel Tunnel construction costs escalated

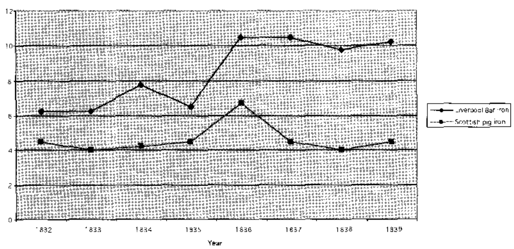

Figure 1
Movements in Price of iron

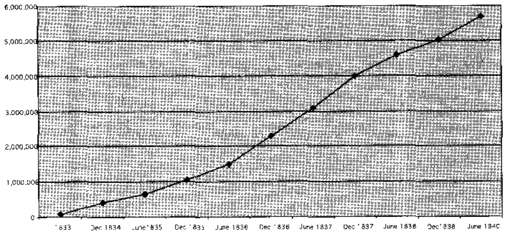

Figure 2
Expedinture en London and Birmingham Railway

from an estimated £3.8 billion to £5.8 billion in real terms; in contrast the civil engineering work on the Millennium Dome was delivered ahead of time and below budget. Cost overruns more typically occur on prototype projects such as the Thames Tunnel (estimates £200,000; final costs c.454000), particularly where ground problems are experienced. The scale of the London and Birmingham, particularly the Kilsby Tunnel, exposed its shareholders and engineers to such a risk. Despite the thoroughness of Stephenson's approach he can be criticised. Although not evident from most other engineers' parliamentary evidence the costs of gentler slopes could have been anticipated. John Rennie snr's experience at the Mint, and problems at Highgate archway had revealed difficulties in working with London Clay. Another alignment could have been selected away from Kilsby, as demonstrated by Sir John Rennie's route, which was very similar to parts of the later GWR route to Birmingham, though longer than Stephenson's. Stephenson and Gooch had actually surveyed an alternative. However generally Stephenson's work and project control was exemplary and it was the complexity of the project that determined the resources required.

Relationship with contractors

Stephenson generally did well both for the contractors and the Railway Company. He was prepared to negotiate on prices, but less compromising on lack of progress. As work progressed Stephenson increasingly recommended the Company took over contracts. This was anticipated in a letter to Moorsom, on 30 November 1835, which encapsulates his attitude to the contractors-:

> «with contractors who understand the work and with adequate capital you will not have to do any more than urge them on and serve notices. With others the Company may need to enter the works and provide materials, as you have already had to in two cases». (Engineers, 30 11 1835).

One can have sympathy with him; at much the same time Forster was reporting:

> «There seems a sort of fatality among our contractors. Nowell has been seriously ill and is still weak. Chapman is very ill of inflammation in the region of the heart, and poor Hughes is lying in an almost helpless state at Northampton, of a paralysis of the limbs». (Engineers, 30 12 1835)

Having persevered with William Soars in the face of all kinds of financial and engineering difficulties he finally requested the London Committee «would authorise him to serve Mr Soars with notice of the termination of the contract, as the only resource which the Company had left . . . » (Directors, 17 5 1837)

Generally he was fair to the contractors and paid them in full for their work. Although they were only paid monthly, rather than fortnightly which was more common e.g on the GWR, he was aware of the financial problems this could cause. He recommended the Board advance money for them to obtain wagons and to purchase locomotives to make them available for the contractors to move material more effectively.[1] The whole system relied upon trust and vigilance. Once work had begun in earnest it was impossible for Stephenson to personally supervise all the works. He had to trust his sub-assistants, and concentrate his efforts where there were problems, most notably at Kilsby. This approach seems to have worked well.

Site Investigation

The quantities of earthwork made it necessary to use exceptional care in deciding on the slopes to be adopted in cuttings. A thorough site investigation was therefore carried out as a preliminary to parliament with about 45 borings, mostly from 10 to 20m deep; well records were examined and observations made in quarries and road or canal cuttings close to the line. Further investigations followed the passage of the Act, leading to a modification of design slopes, reducing their steepness, and causing a consequent increase in costs.

Design of the works

With regard to the design of the bridges and station structures Stephenson himself was heavily involved in the detail of the drawings and specification. He discussed his ideas with his assistants, thus on finds him discussing the details of skew bridges with Buck in February 1834 . . . (Stephenson 1834). His discussions were not confined to senior colleagues as he readily accepted Charles Fox's contributions to the design of the iron roof structures and bowstring bridges. Moreover, despite the attention paid to the specifications, one finds him prepared to modify the designs, and recommending increasing the costs where necessary, as with the early decision to substitute roman cement for lime mortar in the bridges (Engineers, 28 5 1835), influenced no doubt by problems at Primrose Hill tunnel.

The station buildings, excluding the platforms and train shed roofs were, as normal for railways of the time, designed by the architects, Hardwick, Aitchison and latterly Francis Thompson. The detail of the station layouts were organised by Bagster. Stephenson concentrated on the operating side, providing general plans and instructions on what he expected, and offering general guidance, insistent that the stations could accommodate all anticipated traffic.

Construction

The first three contracts were let in May 1834; another eight had followed by November, and by February 1835 work was proceeding on more than half of the total length of the line. Work began in June 1834 and a year later work was in progress on twenty contracts with 4,000 men employed. All contracts had been let by November 1835 and the next month work started on the extension from Camden Town to Euston. During the following two years, with work proceeding on the whole length (now 112 miles), as many as 12,000 men were employed.

From specifications, working drawings and some of Stephenson's evidence on later railway Bills, it is possible to find the slopes at which practically every cutting and embankment were actually made. Examples are given for a dozen different strata in Table 9. This can be regarded as the most comprehensive, and most advanced, set of data for the period; several changes had been introduced since 1832:

Clearly Stephenson gave a good deal of thought to his clay slopes, prompted by Rastrick's advice and almost certainly influenced by Parnell's *Treatise on Roads* published in 1833,[2] as well no doubt by his own further enquiries. The effect of these changes was to increase the projected total volume of excavation to rather more than 12.5 million cubic yards, with perhaps about 11.5 million in the embankments with consequent increase in costs. While many modifications had been introduced before the contracts were let, one also comes across examples, as at 4G , when this was done shortly afterwards, perhaps in response to better knowledge of the ground. (Engineers, 4 March 1835). Practical problems in construction dictated further changes, as at Wolverton embankment. Ultimately perhaps 14 million cubic yards of material were excavated, an obvious source of the cost escalation.

Construction of embankments was generally carried out at full height, i.e. by tipping material at the end of an embankment until the final height was reached, rather than tipping at several levels simultaneously. The latter method had some attractions as it offered the possibility of working in more than one place simultaneously and less likelihood of subsidence, but in practice it proved difficult to manage such operations. A typical rate of progress on the Watford embankment was c. 190.000 cubic yards placed a year, and for Willesden embankment c. 160,000 cubic yards a year. More material could be removed if it was being excavated to spoil, and at Tring the average rate was 400,000 cubic yards of excavation a year.

By a concentrated effort probably without parallel hitherto in the history of civil engineering, and not surpassed for a long time afterwards, the line was opened from Euston to Tring (32 miles) in October 1837, from Birmingham to Rugby (29 miles) in April

1838, and throughout in September 1838. Overall about 3.1 million cubic yards of material were excavated a year, muck shifting on a scale not repeated elsewhere in the UK until the Great Central Railway some 60 years later (Skempton 1996b).

CONCLUSIONS

The successful completion of the London and Birmingham Railway in June 1838 consolidated the reputation of Robert Stephenson among his contemporaries as the leading civil engineer of his generation. It revealed the frailty of even the most experienced contractors, and a full range of difficulties posed by earthworks and tunnelling. While one can criticise a route selection which involved Kilsby Tunnel, close to an alignment which had already caused problems for canal builders, and the initial recommendations regarding earthworks, one can only admire, like most of his contemporaries, the scale of the achievement. Many of the cost increases stemmed from changes to the original brief to accommodate more traffic. It is arguable Stephenson should have recommended gentler slopes for the cuttings and embankments, and thus anticipated additional costs. Certainly past experience could have been used to justify this approach, but many engineers supported his recommendations. Many of these specifications had been altered before construction began, suggesting a flexible approach to engineering decisions.

The impact of the London and Birmingham Railway on the engineering literature of the time can be likened to that of Smeaton whose published record had guided the previous generation of engineers. Drawings and specifications formed major proportions of Brees' *Railway Practice*, and Simms *Public Works of Great Britain*, available as a model to all the engineers active in civil engineering at the time, «time-saver» standards for the railway age (Brees 1847; Simms 1838). Dempsey's papers on railway engineering for the

Table 9. Examples of cutting slopes on the London and Birmingham Railway

Stratum	Cutting	Date of Contract	Maximum Depth		Slope
			m	ft	
London Clay	Primrose Hill	May 1834	12	42	3:1
London Clay	Kensal Green	May 1834	9	30	2:1
Reading Beds Clay	Watford Heath	May 1834	12	41	2:1
Oxford Clay	Denbigh Hall	October 1834	13	45	2:1
Upper Lias Clay	Bugbrooke	February 1835	14	47	2:1
Lower Lias 'shale'	Church Lawford	February 1835	9	30	$1\ ^{1}/_{2}:1$
Keuper Marl	Yardley	August 1834	14	45	$1\ ^{1}/_{2}:1$
Lower Chalk	Tring	September 1834	17	57	1:1
Upper Chalk	Watford	May 1834	18	63	$^{3}/_{4}:1$
Lower Greensand	Linslade	September 1835	18	60	$^{3}/_{4}:1$
Keuper Sandstone	Berkswell	November 1834	17	55	$^{3}/_{4}:1$
Great Oolite	Blisworth	February 1835	17	52	$^{1}/_{4}:1$
Limestone					
Carboniferous	Beechwood	November 1834	17	54	$^{1}/_{4}:1$
Sandstone					

Royal Engineers were based heavily on London and Birmingham practice, subsequently published as a monograph through three further editions (Dempsey 1855). Practical experience of the construction of cuttings and embankments was reflected in papers and discussions at the Institution of Civil Engineers and elsewhere, while the illustrations of Bourne, and the texts of Roscoe and Lecount provided vivid images of the construction of the line (Bourne 1839; Lecount 1839; Roscoe 1839). Neither Locke nor Brunel served as such as exemplars to the profession.

Though Stephenson and his engineers experienced considerable troubles of a geotechnical nature, these must be seen in context of a project of unprecedented magnitude with regard both to the scale and number of works involved. Some of the problems could not possibly have been foreseen; all were satisfactorily solved, and for mile after mile many of the huge cuttings and embankments and viaducts never gave any trouble at all. Indeed Thomas Gooch regarded the northern section for which he was responsible as straightforward work (Gooch).

Notes

1. This had been done on the Liverpool and Manchester Railway. By 1833 contractors were purchasing their own locomotives on other contracts.
2. H Parnell. A Treatise on roads. London: Longman, 1833. Thomas Telford had spent several days in 1833 on Parnell's book which reflects his practice, particularly on the Holyhead Road. Slopes recommended (pp.80–87) for cuttings, except in stone, never less than 2:1 to admit sun and wind to the road. He recommended slopes for cuttings and embankments in London/plastic clay 3:1, chalk or chalk marl 1:1, solid sandstone 1:4, but if sandstone strata was mixed with marl the safe slope could vary between 1–5:1 and 1:4 according to the inclination of the strata; for Oxford clay 3:1–2:1, solid limestone 1:4, limestone and clay 1.5:1–2:1; granite, slate, etc., 1:4. Parnell also emphasised the need for good drainage, sod cover, and laying embankments concavely rather than convexly, i.e., from the outside in.

Reference list

BDCE. 2002. *A Biographical Dictionary of Civil Engineers in Great Britain and Ireland, vol.1: 1500–1830*. London: TTL, 2002.

Birmingham. 1833–1839. Minutes of Birmingham Committee, London and Birmingham Railway, PRO RAIL 384/65–67.

Bourne, J. C. 1839. Drawings of the London and Birmingham railway with an historical account by J. Britton. London: J C Bourne, 1839.

Brees, S. C. 1847 *Railway practice*. London: J. Williams.

Brunton, J. 1930. *John Brunton's Book*. Cambridge: University Press, 1930.

CEAJ (1837) Civil engineer and architect's journal vol. 1, 23 December 1837.

Chrimes, M. M. 2003a. Civil engineering 1500–1830: the biographical dimension. *Civil engineering*: ICE Proceedings, in press.

Chrimes, M. M. 2003b. Chapters , in M Bailey (ed) *Robert Stephenson*. Ashgate: Aldershot. To be published October 2003.

Conder, F. R. 1983. *The men who built railways*. London: TTL, 1983.

Directors (1831–1839) Minutes of the London and Birmingham Railway, PRO RAIL 384/1–5.

Dempsey, G. D. 1855. The Practical railway engineer. 4th edition, revised.London: J. Weale. 4 ed.

Engineer Reports (1833–1838) London and Birmingham Railway, PRO RAIL 384/101–103.

Gooch, T. L. Diaries and autobiography, mss, ICE Archives.

Jeaffreson, J. C. 1864. *The Life of Robert Stephenson*. London: Longman, 1864.

Lecount, P. 1839. *The History of the railway connecting London and Birmingham*. London: Simpkin and Marshall, 1839.

London (1833–1839) London Committee Minutes, London and Birmingham Railway, PRO RAIL 384/30–33.

Palmer, H. R. 1833. Report of Henry Robinson Palmer to the London and Birmingham Railway Company, 13 May 1833, Engineers reports, London and Birmingham Railway PRO RAIL 384/101.

Rastrick, J. U. 1833. Report to the London and Birmingham Railway Company, PRO RAIL 384/101, 13 May 1833.

Rawlinson, R. 1846. Evidence to Select Committee . . . Condition of the labourers employed in the construction of railways. London: HMSO, 1846.

Roscoe, T. 1839. The London and Birmingham railway; with the home and country scenes on each side of the line. London: C Tilt.

Simms, F. W. 1838. *Public works of Great Britain*. London: J. Weale, 1838.

Skempton, A. W. 1987. *British civil engineering literature 1640–1840*. London: Mansell, 1987.

Skempton, A. W. 1991. *John Smeaton*. London: TTL, 1991.

Skempton, A. W. 1996a. *Civil engineers and engineering in Britain 1600–1830*. Aldershot: Variorum, 1996.

Skempton, A. W. 1996b. Embankments and cuttings in early railways. *Construction history*, vol.11, pp. 33–50.

Smeaton, J. 1814. Reports of the late John Smeaton, F.R.S. made on various occasions in the course of his employment as a civil engineer. 4 vols. London: Longman.

Smiles, S. 1861. Lives of the engineers. London : Murray. Vol. 2.

Southampton, 1834. Minutes of evidence taken before the Lords Committee to whom the . . . «Act for making a Railway from London to Southampton» was committed. London: House of Lord.

Stephenson, R. 1834. Diary, mss. London: Science Museum.

Stephenson, R. 1838, Letter to I.K. Brunel, 23 September 1838, Bristol University, DM 1306/20.

Townshend, T. 1810–1846. Collection of papers, mss, ICE Archives.

Tucker, J. S. 1835, Specifications, mss, ICE Archives.

Watson, J. G. 1979. The Civils. London: TTL.