Genius or Great Systems Engineer?

Isambard Kingdom Brunel

Dr. Felix Schmid
Civil Engineering, University of Birmingham

Overview of Talk

- Era of Marc Brunel and Isambard Kingdom Brunel;
- Background to the Brunel family;
- Trials and tribulations of Marc Isambard Brunel;
- The Thames Tunnel;
- Clifton suspension bridge for Bristol;
- The Great Western Railway and Saltash Bridge;
- A hospital for the Crimea;
- The Great Western Steamship Company
- The Great Britain;
- The Great Eastern and calamity.
Where did it start?

- 18th century created ‘the engineer’ in both France and Britain;
- France developed the famous ‘ingenieur’, designer of roads and war machines, with an academic education;
- Britain’s industrial revolution resulted ‘the engineer’ as the person who learnt his trade and then moved up the hierarchy;
- BUT: Great engineers were essential for both nations.

Transport Revolution in Britain ca. 1770

- Roads improved by turn-pike companies:
  - Capital investment into infrastructure as viable opportunity;
  - Salt-route from Cheshire to Sheffield: first Mam Tor road.
- Journey time and cost reductions thanks to better roads:
  - Huge journey time reductions between cities (50% 1770-1830);
  - General journey time reduction of 80% between 1750 and 1830;
  - 1750s London to Edinburgh in summer: 10 days by horse;
  - Stage-coach London to Edinburgh in 1836: 45 hours;
  - Between 1790 and 1830: 8-fold increase in departures and 15-fold increase in people carried (outside-class, see Thomas Hardy).
- Early concentration of operators:
  - 275 out of 342 London departures by 3 companies;
  - Robust time-tabled system with connections.
- Even poor people use the stage-coach in Britain from 1800.
The Father: Marc Isambard Brunel

- 25 April 1769: Marc Isambard (or Isambart) born to a prosperous farming family in Normandy, at Hacqueville;
- The 11 year old declares that he wants to become an engineer and is sent to the seminary in Rouen;
- Luckily, the head of the seminary recognises his skills and arranges for Marc to have tuition by Monge (famous mathematician) and others to become a navy officer cadet;
- At the time, engineering science education in France is the best in Europe (and thus the world…);
- Joins navy in 1786 and is paid off in 1792. His royalist views make life hazardous since the French revolution is in full swing;
- 4 December 1792: Sophie (Sophia) Kingdom, 16th child of William Kingdom, born in 1776, arrives in Le Havre to complete her education. Elder brother had sent the orphan…
Boy meets Girl in Revolutionary France

- Sophie is 16 years old and stays with the Carpentier family in Rouen to learn French and to teach English;
- 17 January 1793: Marc meets Sophie and they fall in love – much to the displeasure of Mme Carpentier – but truly ‘forever’;
- 21 January 1793, Louis XVI is executed on the Guillotine;
- Marc Brunel has to leave France, being a known royalist, and on 7 July 1793 embarks in Le Havre for America;
- Marc lands near New York and gets involved in many projects, including a major canal design;
- Sophie is incarcerated in a convent as a suspicious alien – the guillotine is used daily to maintain a stable prison occupation;
- Marc is said to have been City Engineer in Chief of New York but no records confirm this.

A Spell abroad and Romance Blossoms

- Marc works in the New York area for 6 years and is said to have designed the first opera house;
- At a party (presumably at cigar time) Marc learns about Royal Navy’s requirement for 100,000 ship’s pulley blocks per year – all currently made by hand and of poor quality;
- 7 February 1799 resigns post in USA and travels to Britain with a recommendation to the Navy minister;
- Marries Sophie in November 1799 and sets up home with her;
- Starts his inventing and designing career with a proposal to Bentham for machine manufactured pulley blocks;
- Henry Maudslay produces prototype and production machines to Marc’s designs;
- 1801 moves to Portsea and builds a factory in Portsmouth;
- Designs army boot making machinery and builds a saw-mill where there is a broad-gauge ‘railway’ to transport logs…
The Consequences of Romancing

- Sophie and Marc have three children and move to London:
  - Sophia, 1802-1878
  - Emma, 1804-1875
  - Isambard Kingdom, 9 April 1806.
- Marc: Engineers must be able to draw quickly and accurately;
- At 6 years of age IKB has mastered Euclid and can draw accurately;
- In 1820, Marc sends 16 year old Isambard to College of Caen, France, because maths and sciences taught better in France;
- Lycée Henri Quatre in Paris;
- 1st apprenticeship with Louis Breguet in Paris.
IKB’s Return to England

- Isambard Kingdom Brunel returns to England for a second apprenticeship, this time with Henry Maudslay of Maudslay, Son and Field;
- The family lives happily in the countryside, at Chelsea;
- Isambard learns about accuracy and high standards from both Breguet and Maudslay;
- Returns to England in 1823 and soon becomes involved with Marc’s Thames Tunnel project:
  - Isambard lays the second brick of the tunnel, after his dad.
- Isambard starts writing diaries: “I am always building castles in the air, what time I waste”.

The Brunels’ Thames Tunnel

Studies & Apprenticeships
Thames Tunnel

I K Brunel
Why Build a Thames Tunnel?

Marc Brunel’s Thames Tunnel Design
The Thames Tunnel – 1st Phase

- In 1807, Trevithick appointed Engineer to the Thames Archway Company to build a tunnel from Rotherhithe to Limehouse:
  - Attempt to build the tunnel by the ‘drift method’ fails in 1808, even though it is only 3 ft wide by 5 ft high. Tunnel collapses in poor ground.
- In 1818, Marc Brunel and Thomas Cochrane completed design of iron tunnelling shield to work in soft soils (London “clay”…):
  - 35 ft wide (to build two ‘bores’), 20 ft 6” high, 1300 ft long;
  - Launched from a shaft, built using a 50 ft diameter iron ring and brickwork, reaching 42 ft into the ground when finished.
- 1825 start of work, with William Armstrong as site engineer:
  - Marc refuses to use piece work because it leads to haste and risk;
  - Fever amongst workers. Marc Brunel and Armstrong succumb to illness in April 1826 and Isambard (aged 20) is put in charge.
- April 1827: 540 ft completed but lots of problems – diving bell.

Marc Brunel’s Vision

Père et fils…
Brunel and Cochrane’s Tunneling Shield 1818

The Thames Tunnel – 2nd Phase

- 18 May 1827: First irruption of Thames into the work site;
- Marc is not well enough to act;
- Isambard inspects damage in the diving bell the next day;
- A hole has developed in the bottom of the Thames;
- Gravel and sandbags are used to fill the hole;
- Work only resumes in November after mud has been cleared from tunnel;
- Party in tunnel to celebrate re-start;
- 14 January 1828: Second irruption of Thames into tunnel, Isambard nearly killed and several workers drowned. IKB very ill for months.
The Thames Tunnel: Completion

- Government agrees a loan of £246,000. Gives £30,000 in December 1834;
- New start on 18 March 1835 with drainage work and removal of old shield (80 t):
  - “The stringent conditions imposed by the treasury resulted in much unnecessary time, money and anxiety being expended (Bagust, 2006)”.
- Revelation of size of second irruption;
- Installation of new shield (140 t);
- Start of tunnelling work on 1 March 1836:
  - Much illness in the tunnel, with workers hospitalised;
  - Gas and fluids penetrating into the workings;
  - Regular small explosions of gas but shield works;
  - Frequent small and large irruptions – dealt with easily!
- Start on Wapping shaft on 9 October 1840 reveals polluted ground but shaft is sunk successfully:
  - Again lots of problems with water as the tunnel is about to enter shaft.
- Tunnel opens on 25 March 1843 – Marc Brunel takes part, despite suffering a stroke on 7 November 1843. HRH Victoria and Albert visit in July 1843;
- 1869: Foot tunnels converted for use by East London Railway.

Systems Engineering…

“Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements and then proceeding with design synthesis and system validation while considering the complete problem. Systems engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.”
Marc and Sophie send Isambard to Clifton in Bristol to convalesce from his accident and subsequent illness – but IKB can not rest like normal people. There are always projects on which to work…
Thomas Telford and Brunel

- 19 November 1829, Brunel submits four designs for a suspension bridge across the Avon gorge at Clifton in a competition with 22 entries:
  - Lengths between 720 and 1000 ft;
  - One involving short tunnels at either end.
- Telford, the judge, rejects all 22 as unpractical or simply poor;
- Telford puts forward his own design which is heavily criticised by IKB!
- Second competition held in 1831 includes a design by Telford;
- Marc Brunel does much design work on Isambard’s bridge.

Brunel’s Clifton Suspension Bridge

Telford’s design with two huge towers to shorten suspension section rejected on grounds of cost and Brunel is asked to work on his designs:
Clifton Bridge Construction

- After some machinations, the third placed design by Brunel is chosen as the best;
- I K Brunel is appointed Engineer to the Clifton Bridge for a fee of 2000 guineas;
- Work starts on 21 June 1831 but is quickly suspended;
- In between, Brunel designs the Hungerford pedestrian suspension bridge in London (completed in 1845, demolished in 1860 to make way for railway bridge);
- New start on 27 August 1836 but the two towers are only completed in February 1843. Brunel is instructed in 1851 to sell all stored materials;
- Bridge opens on 8 December 1864 to the revised Hawkshaw & Barlow design, using components from Hungerford Bridge.
Systems Engineering?


Clifton Suspension Bridge

Y  Y  Y  Y  N  N  Y  Y  Y  Y

The Great Western Railway

1800  1805  1810  1815  1820  1825  1830  1835  1840  1845  1850  1855  1860  1865  1870

1806-04-09  1820-3  1818  1829  1843  1833  1862  1867

I K Brunel
Studied & Apprenticeships
Thames Tunnel
Clifton Bridge
Great Western R.
Engineer to the Great Western Railway

- 1831: Brunel travels on Manchester to Liverpool Railway (built by George and Robert Stephenson):
  - “I record this specimen of the shaking on the Manchester Railway. The time is not far off when we shall be able to take our coffee and write while going noiselessly and smoothly at 45 miles per hour – let me try.”
- Brunel feels prompted to look for railway engineers’ posts everywhere but is initially unsuccessful;
- 6. March 1833: The directors of the Bristol Railway appoint him as their chief engineer, despite his young age, with just one vote more than necessary;
- Brunel sets about finding the BEST route for GWR and reports on his survey at end of May, as promised.

Brunel knows: Railways Shrink Space

- Areas accessible within one hour’s journey time grow hugely:
  - Black: 5 km/h;
  - Yellow: 50 km/h;
  - Green: ca 100 km/h;
  - Red: ca 200 km/h;
  - Orange: ca 300 km/h.
- It was THE business of the future for him.
Wagon-Ways to Railways

- 100s of miles of wagonways and plate-ways in Britain by 1800:
  - Individual lines are 10s of miles long – cheaper to build and operate than canals – and faster to operate;
  - Modelled on turnpike roads with open access for operators;
  - ‘Traction’ by animals and people.

- Iron rails and stationary steam engines lead to ‘proper’ railways and development of so-called ‘loco-motive’ engines:
  - Trevithick builds first ‘real’ locomotive in 1804 – the result of a bet which ran something like: ‘It will never travel 9 miles!’
  - Stockton to Darlington (world’s 1st public railway with tolls) opens in 1825 with a gauge of 4’8” as at Killingworth Colliery (designed by George Stephenson).

Construction and Part Opening of GWR

- Royal assent for the Act authorising the building of the GWR given 31 August 1835, the first submission having been made to Parliament in November 1833;
- Detailed survey could now be undertaken by Brunel and his team of surveyors;
- Brunel argued for the use of broad gauge (7 ft) in September 1835 and designed his own track – which ended up being too ‘stiff’ due to piles being driven into the ground;
- Paddington to Maidenhead section opens 4 June 1838;
  - But George Henry Gibbs writes: “With all his talent he [IKB] has shown himself deficient in his own mind so as to enable him to proceed rapidly, economically and surely. There have been too many mistakes; too much of doing and undoing.”
- Happily, the appointment of Gooch and new locomotives from Stephenson’s works eliminate main problems and profits flow.
F. Schmid

Brunel’s Wharncliffe Viaduct

Wharncliffe Viaduct in 2005
The Great Railway Gauge Debate

• Brunel chose broad gauge (7 ft) for the Great Western Railway (GWR) for good reasons;
  – Standard gauge was not really a standard at all;
  – Broad gauge expected to allow greater speed and comfort.

• Two early railways were built to 5 ft gauge:
  – Eastern Counties Railway (ECR), opened 20.6.1839 and eventually 51 miles long.
  – Northern & Eastern Railway (N&ER), opened 15.09.1840, about 40 miles;
  – The two lines were merged into the Great Eastern Railway in 1862 and 1902 respectively.

• Both were converted to ‘standard’ gauge in September and October 1844;

• The Great Western to Penzance was only converted in 1892 although ‘coal wagon gauge’ had reached Paddington in 1863.

Battle of the Gauges – 7 ft is wide!

‘Sleeper’ on the 7 ft gauge track: Prof. Heinz Wolff of Brunel University
Brunel’s Track System

W.H. Robinson, Railway Ribaldry, GWR, 1935

Not including trams and metros!

Gauges and Track Length (2004)

<table>
<thead>
<tr>
<th>Gauge (Range)</th>
<th>Route Length</th>
<th>Gauge (Range)</th>
<th>Route Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Various Narrow</td>
<td>3936 km</td>
<td>1067 mm</td>
<td>96,717 km</td>
</tr>
<tr>
<td>600 mm</td>
<td>4188 km</td>
<td>1372 mm</td>
<td>77 km</td>
</tr>
<tr>
<td>750-760 mm</td>
<td>7075 km</td>
<td><strong>1432-1440 mm</strong></td>
<td><strong>701,955 km</strong></td>
</tr>
<tr>
<td>800 mm</td>
<td>10 km</td>
<td>1520-1524 mm</td>
<td>162,761 km</td>
</tr>
<tr>
<td>914 mm</td>
<td>7061 km</td>
<td>1600 mm</td>
<td>12,748 km</td>
</tr>
<tr>
<td>950 mm</td>
<td>1501 km</td>
<td>1668 mm</td>
<td>14,405 km</td>
</tr>
<tr>
<td>1000 mm</td>
<td>92,171 km</td>
<td>1676 mm</td>
<td>79,288 km</td>
</tr>
<tr>
<td>1050-1055 mm</td>
<td>5480 km</td>
<td>Dual Gauge</td>
<td>1895 km</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1,191,268 km</strong></td>
<td><strong>Electrified</strong></td>
<td><strong>254,733 km</strong></td>
</tr>
</tbody>
</table>

Not including trams and metros!
INCOSE at Network Rail - Talk
by F Schmid for I K Brunel 201
6 June 2007

IKB - Engineering Genius or ‘just’ a Great Systems Engineer

Slide No: 41

F. Schmid
Systems Engineering?

Great Western Railway

Complex? Interdisciplinary?
Stakeholders? Functional?
On Time? To Budget?
High Quality? Sustainable?
Safe? Innovative?
Good Looking?

Y Y Y Y Y Y ½ Y Y Y ?

Slide No: 42

F. Schmid
Paddle Steamer Great Western

1806-04-09 1820-3 1829 1833 1835-8
1859-09-15

1806-04-09 1820-3 1829 1833 1835-8
1859-09-15

Studies & Apprenticeships
Thames Tunnel
Clifton Bridge
Great Western R
PS Great Western

I K Brunel

Slide No: 42

UNIVERSITY OF BIRMINGHAM

Page 21
The Paddle Steamer Great Western

- Timber hulled paddle steamer built in Bristol;
- Construction started by the Great Western Steamship Company in late 1835 to ‘extend the GWR to New York’;
- Launched in Bristol on 18 July 1837 and taken to London for fit-out;
- Maiden voyage marred by fire in engine room while still in the Thames estuary: IKB nearly dies;
- Leaves London on 31 March and Bristol on 8 April 1838 to reach New York on 23 April, a few hours behind the Sirius, a small Irish packet boat which had been pressed into service to compete;
- Sirius had burnt anything burnable on board while the Great Western arrived, after a much shorter crossing, with 200 t of coal, proving Brunel right and Dionysius Lardner wrong!

Dimensions of PS Great Western

- Length 236 ft
- Breadth 35 ft 4 in
- Draught 16 ft 8 in
- Register Tonnage 1320 t
- Displacement 2300 t
- Machinery: 2 off 450 hp side-lever direct acting steam engines
- 2 paddle wheels in diameter: 28 ft 9 in
- Speed 12 knts
- William Patterson, Bristol
- Scrapped in 1857 Greenwich
Dr. (!) Dionysis Lardner was convinced it would never get there

Systems Engineering?

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>?</td>
<td>?</td>
<td></td>
<td>?</td>
<td>?</td>
</tr>
</tbody>
</table>

Paddle Steamship Great Western

Slide No: 46
Construction of Box Tunnel near Bath

- 1806-04-09
- 1820-1
- 1818
- 1829
- 1833
- 1835-8
- 1836-41
- 1843
- 1859-09-15

Studies & Apprenticeships:
- Thames Tunnel
- Clifton Bridge
- Great Western R
- PS Great Western

Box Tunnel, 1836-1841

Started from both ends and from 8 intermediate vertical shafts!
**Systems Engineering?**

- Complex?
- Interdisciplinary?
- Stakeholders?
- Functional?
- On Time?
- To Budget?
- High Quality?
- Sustainable?
- Safe?
- Innovative?
- Good Looking?

| Box Tunnel (GWR) | Y | Y | N | Y | Y | Y | Y | Y | Y |

**Romance for Isambard Kingdom Brunel**

- 1806-09: 1820-3
- 1818: Studies & Apprenticeships
- 1829: Thames Tunnel
- 1835-8: Clifton Bridge
- 1836-41: Great Western R
- 1836-07-05: PS Great Western
- 1836-09: Box Tunnel
- 1836-09: Marriage to Mary Horsley
- 1859-09-15: I K Brunel

---

**UNIVERSITY OF BIRMINGHAM**

---

**Page 25**
Marriage to Mary Horsley

- Mary Horsley was one of three sisters of John C. Horsley, artist;
- Isambard wins her heart against stiff competition: F. Mendelssohn;
- Mary marries I K Brunel on 5 July 1836;
- Children Isambard, Florence Mary and Henry Marc.

Brunel’s Locomotives and Daniel Gooch

- 1820-3: Studies & Apprenticeships
- 1829-8: Great Western R
- 1833: Thames Tunnel
- 1835-8: Clifton Bridge
- 1836-41: Box Tunnel
- 1836-07-05: Marriage to Mary Horsley
- 1837 (21 years old): Gooch Loco Eng.
- 1859-09-15: Thames Tunnel
- 1867: PS Great Western
- 1862: Great Western R
Brunel’s Locomotives and North Star

Daniel Gooch and Firefly

Great Western Locomotives

Systems Engineering?

Complex?
Inter-disciplinary?
Stakeholders?
Functional?
On Time?
To Budget?
High Quality?
Sustainable?
Safe?
Innovative?
Good Looking?

Y Y Y N Y Y N Y Y N

Slide No: 53

Slide No: 54
Progress and Opening of whole GWR

- Construction of Maidenhead Bridge ("it will fall down, it will never work") allowed service to Twyford in July 1839, Reading in March 1840, Wooton Bassett December 1840, Chippenham 31 May 1841;
- Bristol to Bath (the difficult end) opened 31 August 1840 and completion of Box Tunnel (1¾ miles long, under construction since September 1836) in June 1841 closed last gap between London and Bristol;
- 30 June 1841: A special train leaves Paddington and reaches Bristol after a journey of 4 hours;
- Brunel could now focus on the design of the stations, in particular, the terminus in London, at Paddington.
**Screw Steamship Great Britain**

- **1800**
- **1805**
- **1810**
- **1815**
- **1820**
- **1825**
- **1830**
- **1835**
- **1840**
- **1845**
- **1850**
- **1855**
- **1860**
- **1865**
- **1870**

**1806-04-09**

- **1818**
- **1820-3**
- **1829**
- **1833**
- **1835-8**
- **1836-41**
- **1836-07-05**
- **1837 (21 years old)**
- **1839-43**
- **1859-09-15**

**I K Brunel**

- Studies & Apprenticeships
- Thames Tunnel
- Clifton Bridge
- Great Western R
- PS Great Western
- Box Tunnel
- Marriage to Mary Horsley
- Gooch Loco Eng.
- SS Great Britain

---

**Dimensions of Great Britain**

- **Length**: 322 ft
- **Breadth**: 50 ft 6 in
- **Draught**: 16 ft
- **Register Tonnage**: 3,270 t
- **Displacement**: 3,618 t
- **Machinery**: 1 off 1000 hp vee-cranked overhead acting steam engine
- **1 six bladed screw**: 15 ft 6 in in diameter
- **Speed**: 12 knots

---

**F. Schmid**

**I K Brunel 201 – INCOSE, London**

---

**UNIVERSITY OF BIRMINGHAM**

---

**Page 29**
SS Great Britain’s Survival

- First large ship to be equipped with screw propulsion (based on Bramah’s thinking and Marc Brunel’s experiments);
- Travelled to New York many times, despite having run aground on the Irish coast on her 5th voyage – and being left there for 6 months to Brunel’s disgust;
- Great Western and Great Britain sold to Gibbs, Bright and Company and converted to greater capacity with new engines between 1847 and 1852;
- Successful operation to Australia on many trips;
- Stripped of engines in 1882 and used as a cargo vessel;
- In difficulties around Cape Horn in 1886, loses masts and seeks shelter in Port Stanley and is sold as a coal and wool store;
- 1937 – beached in Sparrow Cove and holed to avoid refloating;
- 22 June 1970: SS Great Britain returns to England and on 5 July to Bristol where she lies restored in Great Western Dock.

Systems Engineering?

- Complex? Y
- Inter-disciplinary? N
- Stakeholders? Y
- Functional? Y
- On Time? Y
- To Budget? Y
- High Quality? Y
- Sustainable? Y
- Safe? Y
- Innovative? Y
- Good Looking? Y

Screw Steamship Great Britain: Y N Y Y Y Y N Y Y Y Y
GWR Extension from Exeter into Devon

1800 1805 1810 1815 1820 1825 1830 1835 1840 1845 1850 1855 1860 1865 1870

I K Brunel

Studies & Apprenticeships
Thames Tunnel
Clifton Bridge
Great Western R
PS Great Western
Box Tunnel
Marriage to Mary Horsley
Gooch Loco Eng.
SS Great Britain
Atmospheric Caper

South Devon Railway and Vacuum…

• First train from London to Bristol could travel onwards from Bristol to Bridgewater by the new Bristol & Exeter Railway (approved in 1835);
• Exeter, 194 miles from London, reached on 1st May 1844;
• South Devon Railway achieves royal assent in July 1844 for the stretch Exeter to Plymouth through Dawlish;
• Brunel plans a route to Plymouth but worries about steep gradients (up to 2.5% between Newton Abbott and Plymouth) necessary to limit cost…
• Suggests use of an adhesion-independent technology recently applied to a short railway in Ireland:
  – The ‘atmospheric railway’ from Kingstown to Dalkeith had been invented by Clegg, assisted by Jacob and Joseph Samuda of London.
• Idea approved by the directors!
Atmospheric Principle

- A pipe with a slot at the top is placed between rails;
- ‘Locomotive’ is connected to a piston in the pipe;
- 8 pumping stations create a vacuum ahead of the train and atmospheric pressure pushes the train along, at up to 68 mph (a 28 t train);
- Seals perish quickly and Brunel has to abandon the system after one year;
- Locomotive development is such that gradients are no longer a problem in 1848.

Slide No: 63

Not such a good idea to overcome hills
The Atmospheric Caper

Systems Engineering?

- Y
- Y
- Y
- N
- N
- N
- N
- N
- N

---

**GWR: Heading for Cornwall**

- Hayle to Portreath Railway was opened in 1837 from Hayle to Redruth, with steam traction and standard gauge;
- West Cornwall Railway, authorised in 1846, took over and extended the line to Truro and Penzance, with the first train running in 1852;
- Great Western acquired WCR and, ultimately; converted it to broad gauge in 1867 – through trains can now run from London to Penzance;
- First though: The river Tamar has to be bridged – in line with the requirements of the Admiralty: Only one central pillar allowed and clear passage under bridge 100 ft above high water;
- Brunel decides on two spans with landside viaducts to the abutments. 455 ft long and 56 ft deep, made from wrought iron with a mass of 1060 t each.
Royal Albert Bridge, Saltash

- 1820-3 PS Great Western
- 1835-8 SS Great Britain
- 1836-41 Box Tunnel
- 1836-07-05 Marriage to Mary Horsley
- 1837 (21 years old) Gooch Loco Eng.
- 1846-8 SS Great Britain
- 1847 Atmospheric Caper
- 1859 Saltash Bridge

Saltash Bridge – Construction Method

- Central pillar built by sinking two iron tubes through the silt on the bottom of the Tamar;
- Space between inner and outer tubes divided into pressurised compartments;
- Workers have to pass through air-locks;
- Bedrock proves to be faulty and an inner ‘diving’ bell has to be used to seal the rock;
- Bridge sections are floated in, raised onto the initial abutments which are then built up (hydraulic lifts).

W.H. Robinson, Railway Ribaldry, GWR, 1935
The Finished Bridge
IKB - Engineering Genius or ‘just’ a Great Systems Engineer

INCOSE at Network Rail - Talk by F Schmid for I K Brunel 201
6 June 2007

Slide No: 71

A Systems Engineer?


Saltash Bridge (GWR) Y Y A Y Y Y Y Y Y

Slide No: 72

Paddle Screw Steamer Great Eastern

I K Brunel
Studies & Apprenticeships
- Thames Tunnel
- Clifton Bridge
- Great Western R
- PS Great Western
- Box Tunnel
- Marriage to Mary Horsley
- Gooch Loco Eng.
- SS Great Britain
- Atmospheric Caper
- Saltash Bridge
- PSS Great Eastern

F. Schmid

I K Brunel 201 – INCOSE, London

Slide No: 72
PS Great Western

SS Great Britain

PSS Great Eastern

- Brunel’s last and hugely ambitious project;
- All previous ships had been too small to travel to Australia without taking coal in South Africa and bunkering in Australia;
- Built at John Scott Russell’s shipyard at Millwall on the Thames, mostly under Brunel’s direct supervision;
- Great problems with launching the ship – sideways!
### Dimensions of Great Eastern

- **Length**: 692 ft
- **Breadth**: 82.7 ft
- **Over paddle boxes**: 118 ft
- **Draught**: 30 ft
- **Register Tonnage**: 18,915 t
- **Displacement**: 27,419 t
- **Machinery**: 2 engines of 1000 and 1600 hp.
- **2 paddle wheels**: 56 ft dia.
- **1 screw**: 24 ft dia
- **Speed**: 13.5 kts
- **J. Scott Russell, Millwall**
- **Scrapped 1889 at New Ferry**
A Systems Engineer?

- Complex?
- Inter-disciplinary?
- Stakeholders?
- Functional?
- On Time?
- To Budget?
- High Quality?
- Sustainable?
- Safe?
- Innovative?
- Good Looking?

Paddle Screw Steamship Great Eastern  Y Y Y N N ½ N Y Y ?
Renkioi Hospital for the Crimea

A Systems Engineer?


Renkioi Hospital

N Y W Y Y Y Y Y Y Y N
Balmoral Bridge – Victoria is displeased

1818-20
1820-1
1829
1833
1835-41
1836-43
1836-07-05
1837 (21 years old)
1839-43
1847
1859
1854-59
1855
1854/7

I K Brunel

Studies & Apprenticeships
 Thames Tunnel
 Clifton Bridge
 Great Western R
 PS Great Western
 Box Tunnel
 Marriage to Mary Horsley
 Gooch Loco Eng.
 SS Great Britain
 Saltash Bridge
 PSS Great Eastern
 Renkioi Hospital
 Balmoral Bridge

F. Schmid

Balmoral Bridge (Aberdeenshire)
A Systems Engineer?

Interdisciplinary?
Stakeholders?
Functional?
On Time?
To Budget?
High Quality?
Sustainable?
Safe?
Innovative?
Good Looking?

Vicky’s Balmoral Bridge

N N Y Y Y Y Y N ?

The Last Days of IKB

- Brunel standing next to one of the 5 funnels of the Great Eastern;
- A very ill man but still in control;
- 11 April 1859 receives news of explosion on Great Eastern (human error related to funnel cooling);
- Ship easily repaired but Brunel suffers stroke on 9 September 1859 and dies on 15th September, aged 53.
Other Projects too Numerous to Recount

- Railway from Genova to Alessandria;
- Railway from Florence to Pistoia, in co-operation with Babbage;
- Docks in Cleveland, in South Wales and Bristol.

But there were critical voices too:

- ‘… I had liked the son [Isambard] but at our very first meeting I could not help feeling that his father far excelled him in originality, unworldliness, genius and taste.’ Charles Macfarlane, 1829 when IKB was 23 years old;
- Marc Bunel could not handle money and was happy if he and his family had enough to live on;
- Isambard managed his finances accurately but was not aiming to be super rich;
- He wanted to do a good job and be rewarded for it.
Success and Fame

- Brunel always insisted on investing in his projects to demonstrate his faith in what he proposed;
- Brunel had a good middle-class household for most of his life and spent money easily;
- Brunel did not die an exceptionally rich man – he left some £ 90,000 to his heirs, that is, an annuity of about £ 2500, enough to live comfortably;
- Daniel Gooch said of him:
  – “Great things are not done under those who count the cost!”

The Final Reckoning:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Thames Tunnel</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Clifton Suspension Bridge</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Great Western Railway</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>Paddle Steamship Great Western</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Box Tunnel (GWR)</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>Great Western Locomotives</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>Screw Steamship Great Western</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Saltash Bridge</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>Paddle Steamship Great Eastern</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>Renko Hospital</td>
<td>N</td>
<td>Y</td>
<td>W</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>Victoria’s Balmoral Bridge</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td></td>
<td>9</td>
</tr>
</tbody>
</table>

Total Number of ‘Yes’ = 88

I guess, he WAS a great systems engineer.
Let me satisfy the ‘Butists’!

But, it saved the railway’s bacon!

The Atmospheric Caper

Y N N N N Y Y N

Concluding Remarks

• Isambard Kingdom Brunel was a remarkable man who courted controversy throughout his life;
• There are few, if any, people active in the 19th century to have left as great a legacy as Brunel;
• The Great Eastern, the Clifton suspension bridge and other works were daring even by today’s standards;
• Brunel always applied the latest technologies and was generally aware of their constraints and limitations;
• Brunel directed the work of others effectively but was not always liked by his contractors;
• Most of his systems worked but he could admit his mistakes when they did not perform as intended.
Thanks for Contributions

- Institution of Civil Engineers, Annette Rühlmann;
- Harold Bagust – for his wonderful book on Marc;
- National Portrait Gallery – for the Horsley pictures;
- Birmingham University – for the time;
- Bristol University Library – for the signature;
- Brunel University Library – for Brunel and the funnel;
- Virgin Trains – for the journeys;
- Jacqui Whitehouse, University of Birmingham;
- Prof. Heinz Wolff, Brunel University;
- LTC Rolt’s Biography of Brunel.