HENRY YOUNG DARRACOTT SCOTT 1822–1883

Military Engineer and Chemist

Henry Scott's versatility had much in common with other engineers of the Victorian Age. He retired an honorary major general, having served as a military engineer frequently concerned with fortifications, but studied sufficient chemistry to be able to develop and patent several fast-setting cements. Like many soldiers of that period he was seconded for civilian service, during which time he co-ordinated the design and construction of the Royal Albert Hall in Kensington, the work for which he is now probably best remembered.

Henry Young Darracott was born to Edward and Elizabeth Scott as their third son in January 1822 in the Britton Side, now called Bretonside, area of Plymouth near Sutton Pool, and was baptised in the nearby church of Charles the Martyr. His father had quarrying and brewing interests but was financially sufficiently comfortable to regard himself as one of the gentry. The young Scott was educated privately and entered the Royal Military Academy, Woolwich, the forerunner of Sandhurst, as a cadet in 1838. He was commissioned as a second lieutenant in 1840, pursued further studies at the Royal Engineers Establishment in Chatham and held brief appointments at Woolwich and in Plymouth.

In 1844 he was promoted first lieutenant and posted to Gibraltar where he was engaged on the reconstruction of the fortress. The engineering and supervisory skills he then practiced, although directed to a military objective, were similar in kind to those of the great canal, bridge and tunnel builders whose work became known as 'civil engineering'.

It was in Gibraltar, as the fortifications were being dug, that Scott first observed the interaction of freshly exposed shale with the atmosphere and became interested in its potential as a raw material for cement making. This observation was to have a major impact on his subsequent career, converting him from a competent military engineer into an innovator in building technology and an entrepreneur.

In 1848 Scott was posted to Royal Military Academy Woolwich as Assistant Instructor in field-works, fortifications. He also commenced a chemistry course at Kings College London and began his experiments on a shale-based cement. Scott was made Senior Instructor during 1851, and in November of that year was promoted second captain, becoming a captain in 1855.

It was in this year also that he married Ellen Selena Bowes, the youngest daughter of a major general. They had a large family, the adequate support of which may have been an extra spur to his natural talent for invention. Until 1872, when pay scales were revised, an army officer could scarcely survive on his army pay, and most depended on 'private means' or family money for financial stability. Scott undoubtedly channeled his technological expertise into money-making activities, as he was entitled to do, in parallel with his military duties.

During 1854 and 1855, whilst at Woolwich, Scott invented and patented a novel cement with fast setting properties that made it particularly suitable for plaster and other decorative work. This was a direct result of his laboratory experiments with sulphuric acid and quicklime (don't even think of copying him!) in which he sought to reproduce the natural reaction in volcanic regions of sulphur oxides and moisture on calcium-containing minerals. By the 1870's Scott's Patent Cement was better known as 'selenitic cement', a reference to the mineral selenite or gypsum. Review articles about cements in the 1870's and 1880's frequently made reference to his patents.

Scott's work needs to be seen in the context of cement technology of the time. Using the word 'cement' for any paste or mechanically plastic material with good adhesion to a solid substrate and capable of subsequent hardening, three broad compositions were known – lime mortar, Portland cement and Plaster of Paris.

Lime mortar had been known since early medieval times. Here limestone was burnt to produce quicklime, the lumps of which were then slaked with water producing a fine powder. More water was added to this slaked lime which was beaten into a thick slurry before incorporating the sand it was intended to bind. The resulting mortar was versatile, but took a long time to set firm, and even then its final hardness and strength were low and its water resistance poor. If the original limestone contained a natural admixture of clay, it was observed that the mortar's properties improved, but the lumps were less likely to form a powder on slaking.

A further development had been Portland cement, patented in 1824. It was first produced in quantity in 1845 by calcining a slurry of chalk and clay in upright kilns as a batch process. Continuous process rotary kilns were not used until 1880. This cement had much improved properties especially of strength, water resistance and reduced time for hardening. However, the extensive ball-milling necessary to make it fine enough for good adhesion raised its price significantly. Additions of gypsum, ball-milled along with the fired cement clinker could be used to control the hardening time of the final product. Alternatively when gypsum is heated to 128 degrees Celcius it loses most of its water of crystallization, becoming Plaster of Paris once the calcined product has been finely ground. This was the material that Scott introduced, at 10 – 15% by mass, into a lightly clay-bearing quicklime before slaking. The resulting cement, when beaten into the conventional slurry and mixed with sand, set quickly, had very good adhesion and was particularly hard. Furthermore it could take up more sand than the common lime mortar, reducing the cost of its use, even after pricing in Scott's patent royalties.

These patents, recognizing the novelty of his contribution, covered the composition of the new cement, the process of making its precursors, compounding the raw cement and the method of producing the plastic mixture ready for application. The second patent proved to be commercially viable and a Kent cement maker began production. The new product was widely used in public construction projects, latterly for many of the London School Board's schools and the Albert Hall.

In 1855 Scott, by then a captain and still at Chatham, took charge of the chemistry laboratory and the surveying course there. He continued to experiment with his selenitic cement and laid the groundwork for the Royal Engineers' improved understanding of cement and concrete in military applications.

During his lifetime he was granted some fifty-nine patents relating to lime, cement and new kilns of which he was the inventor. Not all his patents were exploited successfully; a patent dated 1868 covered a process for treating raw sewage and producing a cement from the sludge, but the company set up for this purpose failed. By contrast, his Patent Selenitic Cement company was formed in 1871 and traded until the expiry of the patent after his death.

1856 saw the end of the poorly handled Crimean War against Russia. The inevitable public outcry at the conduct of the war led to criticisms in Parliament that had to be answered. In this Scott assisted the Royal Engineer Establishment's director in reforming the surveying and architectural courses offered there. He also pioneered a fresh approach to landscape field sketching, which was a necessary military skill in the days when a whole battlefield might be seen from a single vantage point and before the days of quick and convenient photography. His system was adopted at Woolwich and at Chatham, becoming a feature of the training of army officers generally.

In May 1863 Scott was promoted brevet-major, giving him the authority and privileges of the rank without the extra pay, and in early December to lieutenant colonel. He was then seconded to the civil service to work with the 'Commissioners of the Exhibition of 1851', the body which was responsible for carrying forward the ideals of science, technology and commerce that had been engendered by the Great Exhibition, and later to the Council on Education, Kensington Museum. He served as Secretary from 1873 until 1882.

This pattern of 'secondment to the civils' was common in the army of this period. Preparing for war, the army frequently had more trained manpower available in peacetime than could conscientiously be employed. Furthermore, despite many weaknesses, army training produced officers who also had the technical, managerial and administrative skills plus an ability to think on their feet, so much in demand for the numerous public works that accompanied the country's industrialization at this time.

On the death in 1866 of a fellow Royal Engineer officer who was serving as the architect to the Department of Science and Art, Scott was made his successor as Director of Works. A year later he began work on the Albert Hall as the co-ordinating manager underpinning its design and construction. Although his architectural knowledge was only basic, his skill was to draw together the disparate contributions of design draughtsmen, architects, decorative artists, engineers, manufacturers and suppliers. Here his social skills and ready ability to give 'credit where credit was due' served him and the project he was supervising, very well.

The Albert Hall's characteristic roof profile derived from a state-of-the-art elliptical beam design, enabling the oval ground plan of the hall to be spanned without the arena and seating galleries being obstructed by roof supports. In this, Scott was co-ordinating the efforts of leading structural designers, engineering companies and consulting engineers, one of whom was John Fowler, later to collaborate in the design and construction of the Forth railway bridge.

The roof was completed in 1871. Despite the assembly of such expertise, wide span roof design was still an inexact procedure. The story is told that Scott removed the final scaffolding support himself in an empty building, in case there was any substance in the gloomy predictions of some commentators that the structure would fall in, a story that echoes the experience of Brunel thirty years earlier. Brunel then had teased the detractors of his brick railway bridge at Maidenhead by having the timber formwork supporting the elliptical arch secretly drawn back a few inches, but otherwise leaving it in place so that they assumed he doubted his calculations. The formwork blew down in a storm about a year later but, 165 years on, the bridge continues to carry West Country rail traffic, just as the Albert Hall's roof remains in place.

Scott was promoted brevet-colonel in 1871 and retired from the army having been made an honorary major general and civil companion of the Order of the Bath, CB. He became an associate of the Institution of Civil Engineers, later publishing with Gilbert Redgrave, a designer draughtsman from Albert Hall days, a paper on the manufacture and testing of Portland cement. Scott became a Fellow of the Royal Society in 1875.

General Scott's last months were sad. A government decision early in 1882 transferred responsibility for other public buildings in the South Kensington complex away from Scott, and he was dismissed from the Secretaryship of the Board without financial compensation. With his wife and eight of his fifteen children still dependent on him, the stress brought on by his abrupt dismissal seriously damaged his health and he died aged 61 years in April 1883. He was buried in Highgate Cemetery, London.

During his life he had influenced the practice of military engineering, shown himself to be a serious inventor and entrepreneur, and was a leading contributor to construction and development in the area of South Kensington, London.

R D Battey

GEORGE JACKSON CHURCHWARD

1857–1933

Engineer and Inventor

George Churchward's father owned and farmed land in the South Devon countryside. George as a youth was of sturdy build with ruddy complexion, fond of the outdoors, especially when fishing and shooting, and would have been expected to follow his father's footsteps in making a living from the land. However, his career was to follow a quite different path.

George was born in 1857 at Rowe's Farm, Stoke Gabriel, the second son of George Churchward and his wife Adelina, who raised two other sons and two daughters there. The Churchwards were a prominent family in and around Stoke Gabriel, to this day a delightful village close to the River Dart. George's uncle, Frederick Churchward, was the last squire of that community, and was sufficiently affluent to be able to support the education of the next generation of Churchwards.

When George was old enough, he attended Totnes Grammar School, some five miles from his home, during which time his uncle arranged private tuition for him during school holidays, together with his own son Charles and another nephew, Paul. Whilst at the Grammar School, it was recognised that George had an unusual ability with mathematics and an enthusiastic interest in all kinds of machinery. As his scholastic talents were developing, it seems likely that his mechanical interest was fostered by regular sights of locomotives travelling the South Devon Railway, which had served Plymouth and Exeter via Totnes since its inauguration in 1849.

In 1873, at the age of 16, George became articled to John Wright, the Locomotive, Carriage and Wagon Superintendent of the South Devon Railway, whose locomotive works were situated at nearby Newton Abbot. In 1875, he and fellow apprentice Richard Granville showed their mechanical ingenuity by designing and building one of the earliest motor cars. It was a three-wheeler with a large single wheel at the front, steered by a tiller, and driven by a steam engine they had designed. As recently as 2000, it took part in the annual London to Brighton run, when it was the oldest vehicle in the outing.

In 1876, the Great Western Railway, which had become the largest railway system in the country, took over the South Devon Railway. This gave Churchward the opportunity of improving his prospects by going to Swindon to complete his four-year pupillage under James Armstrong, the Locomotive Superintendent of the Great Western, where he gained invaluable experience in all aspects of railway development and management.

On completion of his training, Churchward spent three years on various drawing office tasks before being assigned in 1880 to work with his boss's son, Joe Armstrong, in the design of a new form of braking system. The power and speed of locomotives had increased dramatically and there was concern that the capacity of braking systems had not kept pace. Within two years, the first vacuum brake system was in production and this proved to be a huge success. Churchward's creative flair was duly recognised and his career advancement was undoubtedly boosted. In 1882, at the age of 25, he spent a brief period as an inspector of materials before being appointed Manager of the Carriage Works at Swindon in 1885.

During the following years Churchward was heavily involved in the development of carriage and wagon improvements to meet the constantly growing demands for transportation by rail. One vitally important task was to devise ways and means of coping with the difference in track width adopted by rival railway companies. Brunel had built the Great Western system to a gauge of 7 feet (2.1 metres), believing this would be safer at the higher train speeds he envisaged, but most companies had invested in George Stephenson's gauge of 4 feet 8.5 inches (1.4 metres). This difference created expensive delays for Great Western at change-over locations. After much deliberation, Great Western eventually had little alternative but to adopt the narrow gauge, but until this was achieved in 1892 it had to operate with rolling stock capable of running on both gauges. Churchward devised a means of converting carriages to suit both gauges for which the change-over took no more than 30 minutes. It was done by supporting the carriage frame on trestles whilst both four-wheeled bogies were withdrawn by hydraulic means and replaced by similar bogies of the alternative gauge. This was one of many of his pioneering achievements, which included the introduction in 1892 of Britain's first corridor train, duly equipped with the luxury of steam-heating throughout.

By 1895 Churchward had clearly demonstrated his exceptional ability and was made Assistant Manager of the locomotive works at Swindon. He greatly relished this move as he had developed a huge passion for steam locomotives during his pupillage. From 1899, due to the failing health of William Dean, the Locomotive, Carriage and Wagon Superintendent, Churchward was effectively in charge of these departments before officially succeeding Dean in 1902, at the age of forty-five. He then became the driving force behind the expansion and modernisation of the Swindon works, which by the time of his retirement in 1921 had held the accolade of being Britain's most modern locomotive works for at least a decade. This was in spite of the first World War, which had a great impact on the Swindon works, when it became heavily involved in the manufacture of munitions. Churchward also directed this diversionary operation, which was recognised by his appointment to CBE in 1918. At the same time, he was an active member of the Institution of Mechanical Engineers and the Institution of Civil Engineers, and in 1917 was elected President of the Association of Railway Locomotive Engineers.

The enhancement of the Swindon works was a direct consequence of Churchward's outstanding ability as a designer and builder of locomotives. The maximisation of engine power allied to economy of running was of paramount importance during a period when there was competition, not only between British railway companies, but from abroad also, especially France and USA. Churchward had the knack of spotting weaknesses and opportunities for improving performance in all aspects of his machines. His technical genius, meticulous approach to research and design, and constant pursuit of engineering excellence ensured the pre-eminence of his locomotives.

The output of locomotives, carriages and wagons from the Swindon works during Churchward's reign was truly phenomenal. More than 3,000 locomotives were manufactured under his direction, together with the rolling stock they were built to haul. Many notable feats were performed by his engines. In 1904 the famous 'City of Truro' was the first to haul a train at a speed of 100 miles per hour. The GWR heavy-freight engines, known as the 2800 class, were outstanding. In 1906 No. 2808 set the haul-breaking record with a train in excess of 2,000 tons, and when No. 2807 was withdrawn from service in 1963, it had clocked 1,472,687 miles during a working lifetime of 57 years. It is quite remarkable that Churchward's locomotive designs, subject only to minor modifications, endured for 25 years after his retirement.

A significant feature of GWR was Churchward's introduction, between 1903 and 1911, of a series of nine different locomotive types of advanced design, to meet the whole range of the company's needs, from main-line passenger express to shunting in the local goods yards. He also introduced a high level of standardisation of components for use throughout his range of locomotives, which simplified production and maintenance during this period of robust expansion of rail transportation.

It was customary in those days for the leaders of industry and commerce to become involved in local government affairs. Accordingly, Churchward joined the Swindon New Town Local Board and was later elected a member of the Swindon Urban District Council when it was established in 1894, becoming the chairman 3 years later. In 1900, Swindon was granted a Charter of

Incorporation by Queen Victoria, and Churchward became the first mayor of the new Municipal Borough. He maintained his interest in the town's affairs for many years, and became the first honorary freeman of the borough in 1921 in recognition of his extensive services to the community.

Throughout his adult life, Churchward displayed many invaluable leadership qualities. Undoubtedly, he had great depth of vision and applied his mind to problems in a logical, calculating manner. He maintained a respectful relationship with technical staff and factory workers alike. He spoke to them in a language they easily understood, and inspired them by his enthusiasm to contribute their best efforts, for the betterment of their industry and their community. In an era when bowler hats were a mark of authority, and those wearing them were to be feared, he regularly wore a trilby hat, which displayed his approachability. En route from his home 'Newburn', on the fringe of the works complex, to his office desk he would talk with foremen and chargehands, to gain their views on the jobs in hand. There are reports of his picturesque language, and his delight in mild practical jokes, but despite this familiarity, he did not tolerate unpunctuality, and expected high standards from those in his employ. No doubt these admirable characteristics played a big part in the making of the hugely successful locomotive industry of Swindon.

The circumstances of Churchward's retirement at the end of 1921 are interesting. He was in charge of Great Western engineering for over twenty years, his post being re-designated Chief Mechanical Engineer in 1916, but the impetus he imparted to the company seemed to founder a little following the first World War. A considerable proportion of the nation's workforce experienced the fighting at first hand in which the bloody trauma of trench warfare dominated. No doubt the attitudes of survivors to the conditions of their later employment were affected. Not surprisingly, the post-war government made large concessions to the trade unions, but Churchward was not always prepared to accept trade union demands in his works. His despair reached the point in 1921 when he declared 'I can see that it is time 'The Old Man' retired', and so he did, at the age of sixty-four. It seems there was no ill-feeling, as the workforce contributed over £500 to a retirement gift, which was a substantial amount in 1921. Churchward put this sum into a trust fund, the interest from which was destined to fund book prizes for successful students.

After retirement, Churchward continued to live at 'Newburn'. He had never married, and little is recorded about his private life. However, it appears that he had retained his Devon-inspired love of the countryside and his favourite pursuits of fishing and shooting throughout his working life. And he maintained a happy relationship with his two sisters, Mary and Adelina, who were still active in the Stoke Gabriel community. However, it seems that he was unable to totally divorce himself from railway matters, and one wintry day in December 1933, he set out on one of his favourite walks from 'Newburn', part of which took him along the adjacent main line track. The weather was miserable, and his gardener suggested it was unwise to do the walk in the prevailing low-lying fog. But Churchward insisted that he wanted to inspect a section of the track, the condition of which concerned him. So he went ahead, but tragically did not complete the walk. Hampered by poor visibility and the deafness of advancing years, he was struck and killed by an engine derived from one of his own designs.

Churchward was buried at Christ Church, Swindon, but he is not forgotten in Stoke Gabriel. The headstone at the grave of his two sisters in the churchyard of St. Mary and St. Gabriel includes a simple commemoration to George Jackson Churchward CBE. Nearby at Rowe's Farm (Grid Reference 847578), there is a small tablet on the wall of the building to commemorate the 140th anniversary of his birth, unveiled by the Chairman of the Railway Division of the Institution of Mechanical Engineers in 1997. Modest reminders of a son of rural Devon, whose fame in the fast-moving world of engineering had spread nationwide and beyond.

J P Westwell

THOMAS MUDGE 1715–1794

Clock and Watch Maker

The measurement of time is a problem that has exercised man's mind since the early days of civilisation and as the years went by the need for a reliable timekeeping instrument increased. The first method for measuring time was probably the sundial but this only functions in daylight hours and when the sun is shining. Various other systems were tried with limited success but the advent of the industrial age gave rise to the birth of a body of watch and clock makers whose unique skills enabled them to create very reliable timepieces.

One such person was Thomas Mudge who invented the lever escape mechanism. Mudge was one of the most brilliant watch-makers the world has known and it was this invention that allowed the movement of timepieces to be controlled and regulated so that they kept very accurate time.

Mudge was born into a remarkably talented family in the city of Exeter and it is worth recalling a little of the history of his family, which distinguished itself in so many ways.

His father, the Reverend Zachariah Mudge was born of relatively humble parents in 1694 and studied at Exeter Grammar School until he was thirteen or fourteen years of age. His original wish was to become a member of the non-conformist church but instead he became a master at a local school run by a Dr John Reynolds and later at Bideford Grammar School. Zachariah's three eldest children, one of whom was Thomas, were born in Exeter. Thomas had three younger brothers, the first who was three years his junior, became the Reverend Richard Mudge, a composer who is said to have impressed even Handel himself when playing the harpsichord. Another brother, six years younger went on to become a physician and won a prestigious gold medal for his work on reflecting telescopes. Altogether there were six children of the marriage.

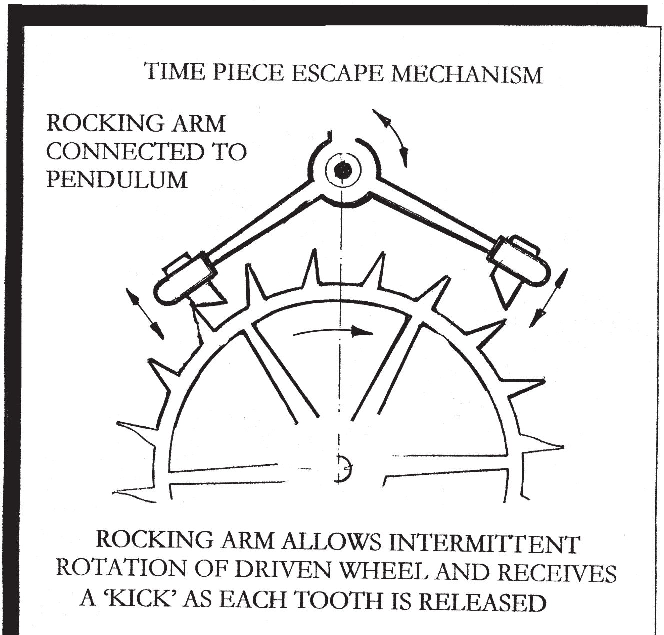
It was at about the age of fourteen years that the young Thomas, having shown an aptitude for things mechanical, (he would take clocks apart and reassemble them with ease) was apprenticed to George Graham of London, one of the most eminent watchmakers in the country. Records of the time indicate that the premium his father paid for this apprenticeship was £30 and the Worshipful Clockmakers Company register of apprentices shows that it was for a minimum of seven years from May 1730.

It was not unusual in those days for this premium to be handed to the business owner's wife to help pay for the apprentice's food and lodgings at the workplace. Mudge displayed great ability and enthusiasm and after completing a highly successful apprenticeship, he was made a freeman of the Worshipful Company of Clockmakers of London on the 15th January 1738. During his service an apprentice was subject to a legal contract that could only be ended early by mutual agreement, hence the terms 'to become a freeman' at the end of a successful apprenticeship. Mudge continued to work for Graham for a further thirteen years before eventually taking over separate business premises nearby at 151 Fleet St. Graham is recorded as having died in 1751, without doubt, a very great loss to the profession.

Until about the late 19th century clocks and watches were, in the main, made to order and were far beyond the means of the average person. To meet the requirements of the man in the street, clocks were provided on church towers and public buildings to ensure he attended church services and his place of work on time many chiming every quarter of an hour.

In about 1752 after becoming established in his own right, Mudge was approached by another highly acclaimed London watchmaker, John Ellicott, and asked to make an equation watch for King Ferdinand VI of Spain. An equation watch is one which corrects for the non-regularity of the earth's motion by adding or subtracting seconds from solar time inorder to obtain a 'mean time'. Ellicott had turned down the request but considered Mudge to be one of the few craftsmen able to carry out the work. Making such a watch would prove to be a most complicated operation, calling for a mechanism that would show the sun time as well as normal time. Clocks of this type, even now, are very rare.

However, on learning that Mudge had been tasked with the undertaking by Ellicott, the King approached Mudge directly and gave him the instructions. In due course Mudge constructed the watch showing both true and sun times, as well as striking the hours and the quarters. He even went on to mount the watch in the top of a walking cane. The King was highly pleased with the result and told Mudge that he was prepared to give more than the 480 guineas (£504) that Thomas had charged him. This was,



of course, a very considerable sum of money at the time, equivalent to many thousands of pounds today.

Mudges' fame was spreading and in 1755 he took William Dutton, another past apprentice of the late George Graham, into his business. This enabled Mudge to spend more of his time improving and enhancing clock and watch mechanisms. His finest achievement during this period, was without doubt, the development of the lever escapement which is still used to this day to control and regulate the movement of many watches.

The escapement, or escape movement mechanism, is that part of a watch or clock, which converts the 'raw' power of the driving force e.g. main spring, weight, or electric motor into regular uniform impulses. This was achieved by the use of a small bar, carrying a tongue at each end, which is rocked alternatively into the teeth of a wheel. He was also one of the first makers responsible for using jewels as pin movement bearings which are still used to this day.

For the next five years or so all clocks and watches made were signed with the name Thomas Mudge but later when William Dutton became a partner in the business, this was changed to Mudge & Dutton and remained that way, even after Thomas left the Fleet St. business.

His lever escapement mechanism was included in a watch he made in 1770 for Queen Charlotte, wife of King George III. At present this watch is believed to be in Windsor Castle and still capable of keeping good time. It is said that Queen Charlotte held Mudge in very high esteem and it was through her recommendation that Thomas' second son the Reverend John Mudge was given the living at Brampford Speke near Exeter.

At this time the Admiralty had become increasingly concerned about the shipping losses resulting from mariners being unable to fix their exact position when at sea. For navigation purposes a watch must be very accurate indeed for although latitude can be determined by taking sextant readings of the sun, establishing the longitude is a more difficult process. The government of the day set up a Board of Longitude that offered a monetary award to the person who could make an accurate timepiece that would meet the Board's very strict specification. The award was eventually given to John Harrison and the chronometers he made can presently be seen on display at the Royal Greenwich Observatory.

Naturally Mudge who was also a contender for the award at the time. was very disappointed at not succeeding and in 1771, at the age of fifty six years he decided to leave his London business, return to the West Country and set up a workshop in Plymouth to devote his semi-retirement attentions to the further development of marine chronometers. Plymouth was chosen for several reasons, firstly for its very obvious seafaring activities and secondly, because his brother Dr John Mudge lived in the city. His late father, the Reverend Zachariah still owned a house there in which, it is believed, Thomas lived.

In 1774 he completed his first marine timekeeper which was submitted for examination and after testing, the Board of Longitude awarded Thomas £500 to construct two more. All three were then tested on long voyages at sea and while they performed with great accuracy under most conditions, the Astronomer Royal at Greenwich Observatory decided that some of the temperature variations experienced at sea affected the watches and a further award could not be given.

Naturally Mudge was again disappointed and told the Board that the testing methods they had used were, in his view, inappropriate. The Astronomer Royal was forced to defend the decision and an official inquiry was subsequently held at which Mudge was represented by his first son Thomas junior who was a Lawyer at Lincoln's Inn. This eventually resulted in a committee of Parliament recognising the watchmaker's outstanding ability and workmanship and in 1793 awarded him a further £2,500.

Mudge died at the age of seventy nine and an entry in the obituary list of the 'Gentleman's Magazine' of 1794 reads '14 November, at an advanced age, at his son's house in Walworth, London, the ingenious Mr. Mudge, late watchmaker in Fleet St.' Records show that his funeral took place on 21 November at the church of St Dunstan in the West and that he was buried in its Fleet Street churchyard. A portrait of Thomas Mudge hangs in the portrait gallery of the Worshipful Company of Clockmakers in the Guildhall, London.

Clocks and watches are, of course, no longer the sole domain of the mechanical engineer. Electronics are employed to control time and accuracy and with some, incoming radio signals are received within the watch to check not only the time but also the time zone in which the timepiece is being used.

Today, most watches are driven by small batteries and being mass-produced are relatively cheap, consequently it is not easy to appreciate the problems that faced Mudge and his contemporaries in the 18th century. Machinery has replaced the manual skills they so painstakingly acquired but a study of the many books on horology reveal the magnitude of the task that faced these early pioneers. They also provide a fascinating record of the development of clocks and watches, the complex mechanisms of which we now take for granted. The role of the engineer in the design and layout of such complex pieces of equipment is still an essential one.

S J Heard and A G Banks

ISAAC WATTS 1797–1876

Naval Architect

The nineteenth century witnessed remarkable changes in the design of warships. These developed from the three-decker wooden walls of Nelson's fleet which were propelled by the wind, to become armoured steel battleships with propellers driven by steam engines and with heavy guns mounted in turrets. Watts was a very significant figure in these developments.

Watts was born in Plymouth and baptised on 31 July 1797. He was the only son of William and Elizabeth Watts, and had two younger sisters, Ester and Marie. He was apprenticed to a shipwright at the age of thirteen or fourteen and he must have been a bright pupil because he subsequently passed the competitive examination for the School of Naval Architecture at Portsmouth. This School had been set up in 1810 following widespread worries that British ships were inferior to those of some other nations, notably France, although there is some doubt whether these concerns were really justified. This initiative was probably the first time that a major employer had set up a formal education and training scheme aimed at producing candidates for senior posts, but it also provided a means for dispelling concerns regarding the low standard of education of dockyard officers.

The School was small, the original intention being to enter twelve students each year, but in most years the number was much fewer, and when the School closed in 1832 there had been a total of only thirty graduates. However, a number of these made distinguished careers including Watts who entered the School in

1814 at the age of seventeen. Here he embarked on a tough course lasting seven years including studies of mathematics, mechanics, hydrostatics, drawing, French and naval architecture. These theoretical studies occupied about half his working hours, the remainder being devoted to practical work in the workshops and in building ships. During the last year of the course some months were spent at sea with the Royal Navy. Students were paid sixty guineas (£63) per annum during their first year, rising in steps during their course to reach 140 guineas (£147) per annum, the latter sum being equivalent to about £10,000 now. Any student today would be very happy to receive a grant of this magnitude, and no doubt Watts felt quite wealthy at a time when the average wage of workers was very low.

On completion of the course at the age of twenty-four he was employed in Portsmouth Dockyard. There were a number of Royal Dockyards in the UK at that time, the most important of which were Portsmouth, Chatham and Devonport. Together they comprised a major industrial organisation employing many thousands of men. The key trade was that of shipwright of which Watts was one, but many other skills were employed including joiners, riggers, rope makers, sail makers, block-makers, founders, oar-makers, mast makers and many others.

Promotion for Watts was slow, the way up being blocked by old stagers who tended not to recognise younger talent. It was not until 1833 when he was thirty-six years old that he became a 'Foreman of the Yard', a middle management post much superior to a foreman in a commercial yard. He remained in this position for the next thirteen years, during which time he married and had five children, two sons and three daughters.

Promotion finally came to Watts in 1846 at the age of forty nine years when he was appointed as Master Shipwright at Sheerness where he was effectively general manager of one of the smaller Royal Dockyards. The following year brought further promotion when he was appointed to work in Somerset House in London as First Assistant to the Surveyor. He now became responsible for the design of all new ships for the Royal Navy.

This was an exciting time marking the beginning of the introduction of steam power with screw propellers to supplement sails for the propulsion of warships. The Admiralty had been spurred on by the success of propeller trials carried out in 1839 in Archimedes, a ship designed to demonstrate screw propulsion. However, although the benefits of screw propulsion were accepted, iron hulls which were being introduced for merchant ships, notably I. K. Brunel's SS Great Britain, were not in favour for warships because tests had shown that shot from a naval gun passed through iron plates and also led to lethal flying splinters.

For ten years following his appointment to the Surveyor's office, Watts thus found himself designing new wooden steam battleships, adapting sailing ships under construction to steam, and converting existing sailing wooden battleships to steam by installing boilers, steam engines, coal bunkers and propeller shafts. All the machinery was installed low down in the hulls where it would be well protected from shots fired from an enemy vessel and this also kept the centre of gravity of the ship low, increasing stability.

In 1851, three years after his appointment to Somerset House, Watts went to France to visit naval establishments and to observe developments in ship design. This must have given him an opportunity to practice the French language which he had studied at the School of Naval Architecture thirty seven years earlier, and it was in France that he was impressed by the progress being made in the design and building taking place on the battleship Napoleon. She was designed as a vessel which relied on steam power with sail as auxiliary, which was the opposite of British practice at the time. On Watts' return to London, much increased effort was put into the building of Britain's first real steam battleship, Agamemnon, which was built at Woolwich Dockyard and launched in 1852 only five months after the French ship. Agamemnon, which had a complement of 860 men, had a massive wooden structure on the stern which enabled the detachable propeller to be hoisted out of the water when the vessel was propelled by sail alone.

This was a time when Britain and France were closely allied and from 1854 until 1856 they fought the Crimean War together against Russia. The war led to a major expansion in warship building, and Watts was responsible for the design of a large fleet of gunboats for this purpose. Agamemnon was the flagship of the British Black Sea Fleet and led the shelling of the Sevastopol forts in 1854.

After the end of the war, British relations with France became strained when it was realised that the French were challenging the dominance of Britain as the world's major sea power. Britain then embarked on a programme of designing even larger steam powered wooden frigates culminating in the Oriando which had an overall length of 111 metres. However, wooden ships of this size showed structural weaknesses and had to be reinforced with iron. It was apparent that the all-wood construction of ships was reaching its limits.

In 1857 the French planned to halt all construction of wooden ships of the line and planned a new fleet which was intended to be iron hulled. However, French industry was not at the time capable of producing iron structures on such a large scale, so the first three ships were planned to have wooden hulls armoured with solid wrought iron plates. The first of these ships, Gloire*,* was launched in November 1859, but news of her building had reached the Admiralty in London the previous year, and had been received with some alarm. It was decided that something must be done. Many in the Admiralty favoured cladding wooden hulls with iron plates, but Watts argued successfully for iron hulls, having concluded that a ship which would be long enough to carry the specified armament would only be satisfactory with an iron hull.

The ship that emerged, Warrior, was an iron-hulled, ironclad frigate intended to overtake and destroy any warship then afloat. She was a 'broadside' design having the guns located along the port and starboard sides behind openable gun-ports, and in this respect she resembled the 'wooden walls' of Nelson's fleet, but she was armoured and had steam power as well as sails. The armour plating consisted of a belt of interlocking wrought iron plates on each side of the ship bolted on to the iron hull. Each plate was 10 centimetres thick, 4.6 metres long by 0.9 metre deep with tongued and grooved edges to engage with the adjacent plates, and each weighed 4 tonnes. This side armour was backed by 18 inches (45 centimetres) of teak to form an impregnable citadel. A full scale section of the ship was built and fired on by heavy guns to confirm the effectiveness of this protection. No ship can be said to be the sole work of one person, and Watts was supported by a team including a fellow Constructor, Joseph Large, and a Chief Engineer, Thomas Lloyd, both of whom were graduates of the School of Naval Architecture. It was nevertheless the drive and determination of Watts that led to the success of the project.

The contract to build the ship was placed with the Thames Iron Works at Blackwall, and she was launched in December 1860, only 19 months after construction had started, and only a year after the French ship Gloire. However, Warrior was bigger, faster, stronger and more formidable than the French ship and its superiority was recognised worldwide. A sister ship, Black Prince, was laid down at Govan the following year, and this underlined the British superiority.

However, new concepts were in the wind in the form of turret ships, and Watts was in the forefront of these developments which would soon make ships like Warrior obsolete. The idea was that heavy guns should be mounted on armoured turntables where they could achieve a better rate of fire than broadside mounted guns, and were better protected from enemy fire. Watts designed an iron-hulled armoured turret ship, Prince Albert, and the wooden hulled Royal Sovereign, which were the first major British warships without sails.

However, Watts was reaching the end of his career. A re-organisation in 1860 had given him the title of Chief Constructor with a salary of £900 per annum which was a very substantial income at the time, and he was honoured for his services with a CB. He retired in 1863 having seen the Royal Navy through two technical revolutions, screw propellers and armour.

Watts' best known achievement, Warrior, lived on, thanks to her rust-resistant iron hull. She had a short active career in which she visited British and European ports, but she never fired a shot in anger, and after only about ten years she fell into obscurity. She was refitted in 1871 and became part of the reserve fleet, but by this time the 12 inch (30 centimetres), 35 tonne gun was in service which could pierce 14 inches (36 centimetres) of iron at 1000 yards (914 metres), and this spelt the end of Warriors active life. After spending time in a number of non-seagoing roles she eventually became a mast-less hulk used as a jetty at Pembroke Dock Oil Fuel Depot. There she remained until 1979 when she was rescued by a Trust and restored at Hartlepool before being towed to Portsmouth where she is open today to the public as a lasting tribute to Watts' talents.

Watts died at Broadstairs in Kent on 11 August 1876 at the age of seventy nine years and although his achievements are clear, the man himself remains a shadowy figure. He never published any account of his work, and no portrait of him is known to exist, so his character remains obscure. He was, however, known to be an autocrat in his professional life but whether this characteristic was also reflected in his private life will probably never be publicly known.

J E Conolly

JAMES MEADOWS RENDEL 1789–1856

Civil Engineer

Son of James Rendel, country surveyor and farmer of Okehampton and grandson of an architect John Meadows FRS, James was born at Thornbury Farm, Whiddon Down near Okehampton in 1789. He passed his youth in the neighbourhood of Teignmouth receiving his education at a country school and was initiated into the practical operations of a millwright by his uncle who resided there. From his father, who had charge of a district of roads, he obtained a degree of familiarity with the rudiments of civil engineering. Then, when he was about eighteen years old he went to London and obtained an appointment with Thomas Telford, who employed him on surveys and experiments for the proposed suspension bridge across the River Mersey at Runcorn.

Five years later he settled in Plymouth and commenced practice of his own being chiefly employed in the construction of roads in North Devon. In September of that year, having commenced on a proposal for a suspension bridge for crossing the Tamar at Saltash, he came under the notice of Lord Morley, who as Lord Boringdon had employed another civil engineer, James Green, some fifteen years earlier. He presented a plan in 1823 for a new road from the White Hart Inn in Okehampton to the Hatherleigh Road and to Five Oaks on the Launceston Road

In 1823 Lord Morley entrusted to Rendel the design of a suspension bridge to cross the River Plym at Laira. When the necessary Act of Parliament was obtained for a bridge, Samuel

Brown who had built the first suspension bridge of iron chain over the River Tweed complained that Rendel had 'made an exact transcription of his plan for the Tamar' and the idea of a suspension bridge was dropped. Roger Hopkins, a civil engineer from Plymouth, proposed a wooden bridge but at the last moment Rendel won the day by presenting an alternative elegant cast iron structure designed for five spans with the ironwork provided by William Hazeldine. He completed his bridge in 1827 and it lasted until 1962. For this fine bridge Rendel gained a Telford medal, having previously been elected a corresponding member of the Institution of Civil Engineers in 1824.

Rendel's experience of suspension bridge design with Telford was not wasted. He appreciated the importance of longitudinal stiffening girders to provide aerodynamic stability, advising on this for the Montrose, Scotland, and Menai bridges. He rebuilt the former in the 1830's and later designed suspension bridges in St James's park, London, and Inverness. It is unclear when he first developed the idea of a deep longitudinal truss as his drawings for the Laira proposal do not exist; the illustrations for his design for Clifton Gorge suggest that this idea may have been in place by 1830.

Soon after the completion of Laira bridge, Rendel constructed some roads for Lord Morley, the Cann Quarry, Plymouth, tramway and a sluice of unusual construction at the northern end of James Green's Chelson Meadow embankment along which Lord Morley had built a roadway to join Saltram House to Laira bridge. He also improved several turnpike roads including a southern road between Sequer's bridge, near Modbury, and Totnes, the road from Plymouth to Cornwall via Saltash and the road from Devonport to Liskeard via Torpoint. In 1826 he constructed Bowcombe bridge over a creek of the Kingsbridge estuary with four masonry arches and an opening span which originally was a drawbridge and where the first use of hydraulic power was applied to machinery to operate bridges.

The Cann Quarry tramway built for Lord Morley was a short branch of 4ft. 6in. gauge (1.38 metres) off the Plymouth and Dartmoor Railway leading to the quarry. A two-span cast iron tramway bridge crosses the River Plym on the Cann Quarry route. The bowstring girders of 7.6 metres span are 2.9 metres apart, have cast iron cross girders carrying a longitudinal sleepered deck for the railway. In 1828 Rendel commenced a survey for a suspension bridge across the river Dart at Dittisham, but this project was blocked by the landowner, James Elton.

Rendel then turned his attention to a proposal for pulling a boat along a fixed chain using steam power and in 1831 a floating bridge was constructed for crossing the river Dart at Dartmouth. The ferry comprised two pontoons side by side with a steam engine between them that hauled on chain using a wheel with sockets shaped to lock onto the links. The chain was adjusted for length by weights at each end in vertical shafts so it would normally lie on the river bed but be sufficiently taut to maintain the ferry's direction of travel. Two chains were used and the wheels, located outside the pontoon, were connected to the engine by a shaft. This, now known as the Higher Ferry, also required 2.4 kilometres of new road to Hillhead, where the road from Brixham meets the Churston to Kingswear road.

After building a similar ferry across the Tamar at Saltash in 1832–1833, which lasted until the suspension bridge was built in 1961, he established another floating bridge across the Tamar at Torpoint in April 1834. This crossing, now known as the Torpoint Ferry, is now so busy that there are three parallel units. Two more ferries were built to his designs, one at Woolston, Southampton, and the other at Gosport. While these two are no longer working, such ferries can be found today at Cowes, Poole harbour and Trellisik near Truro.

In January 1830 he applied for the post of County Surveyor of Somerset, without success, and in January 1831 he offered, in Devon, to do the work for £300 against James Green's salary of £550. Green retained his post but at the reduced salary of £300. During his time in Plymouth, Rendel reported on nearly every harbour in the south west of England, which founded his mastery of this branch of civil engineering on which his fame largely rests. In 1829 he designed the harbour at Par, in Cornwall, and in 1835 he enlarged the sea lock and basin of the Bude Canal.

In 1836 he designed the harbour and breakwater at Brixham in Devon, using the rock obtained from Berry Head; the breakwater has since been lengthened twice. In 1839 he was engaged in preparing various schemes for a railway from Exeter to Plymouth over Dartmoor, via Dunsford, Chagford, near Princetown, Sheepstor and Roborough Down, and in 1841 he constructed the Millbay pier, Plymouth, a work of considerable difficulty, owing to the great depth of water. Here he first introduced the method of construction, since employed with so much success, at the great harbours of Holyhead and Portland. This was the end-tipping of large blocks of stone from railway trucks and the progressive building of the railway on the stone so as to move forward with the construction.

A paper published in Transactions, 1838, earned Rendel a second Telford Medal from the Institution of Civil Engineers and about this time he moved to London, leaving Mr Beardmore as his partner in Plymouth. Rendel then concentrated on harbour works, although he also acted as a consultant on railways in India.

He was President of the Institution of Civil Engineers in 1852 and 1853 and died in November 1856.

James Meadows Rendel devoted much of his life building roads fit for the ever-increasing traffic in Devon. His legacy to the 21st century is evident in many of the 8,800 miles of road (14,200 kilometres) now established in the county.

A B George