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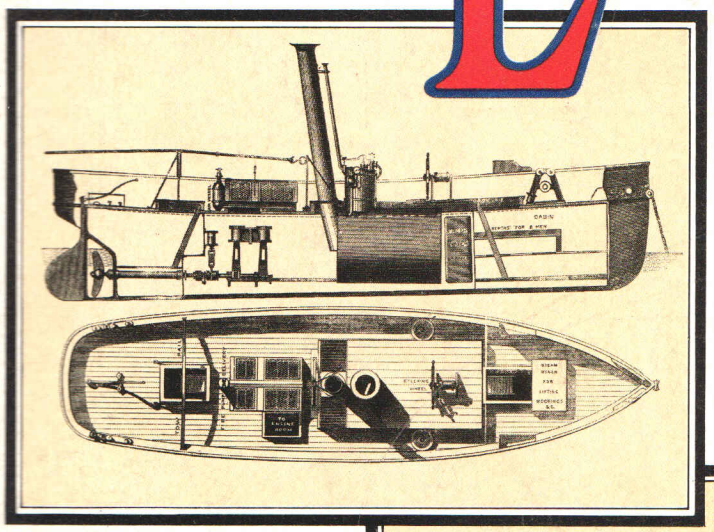

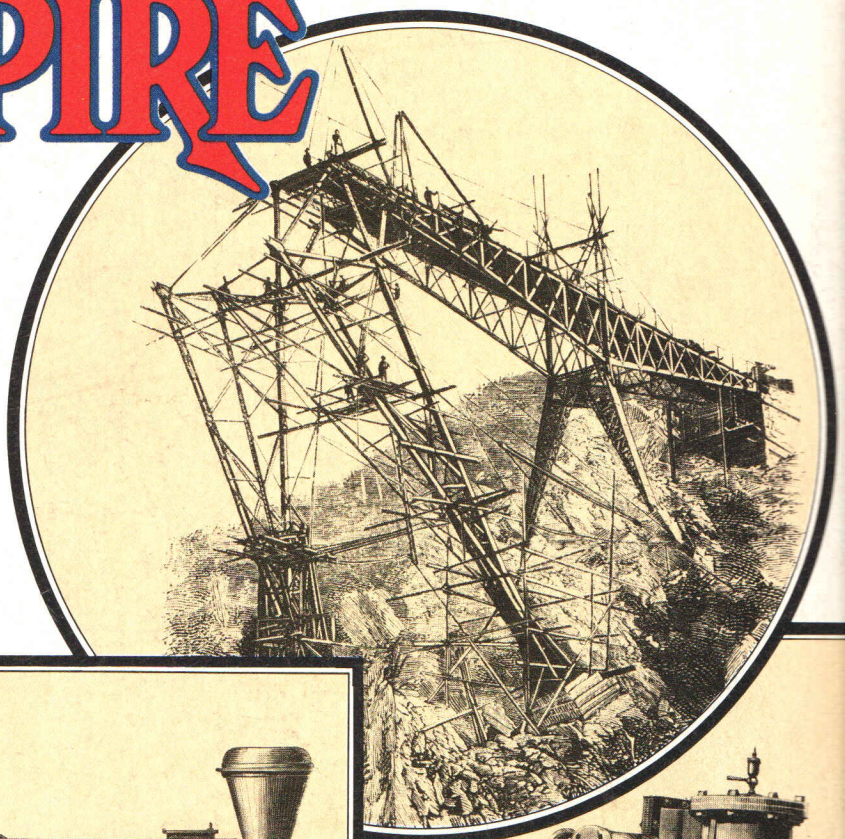

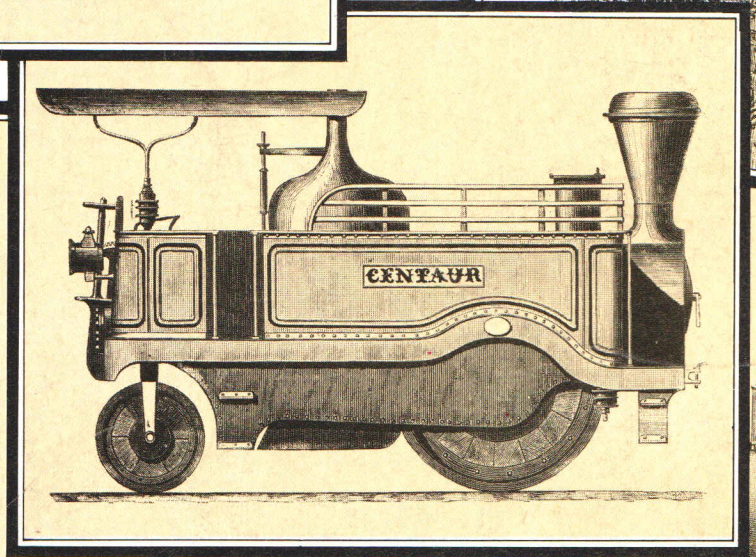

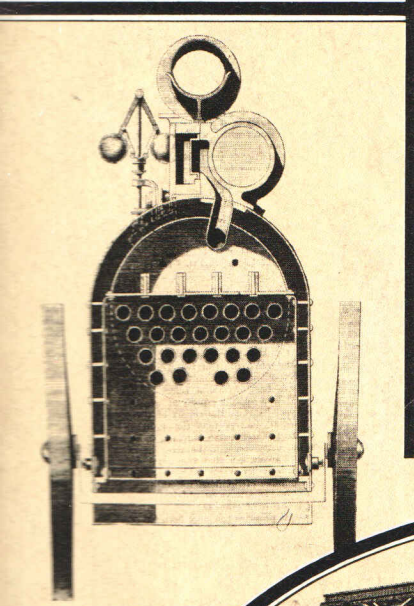

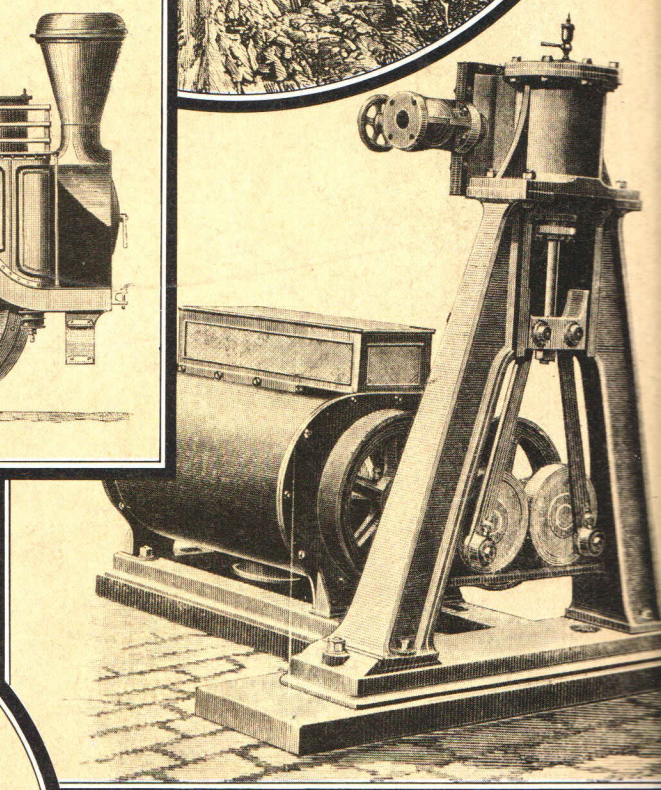

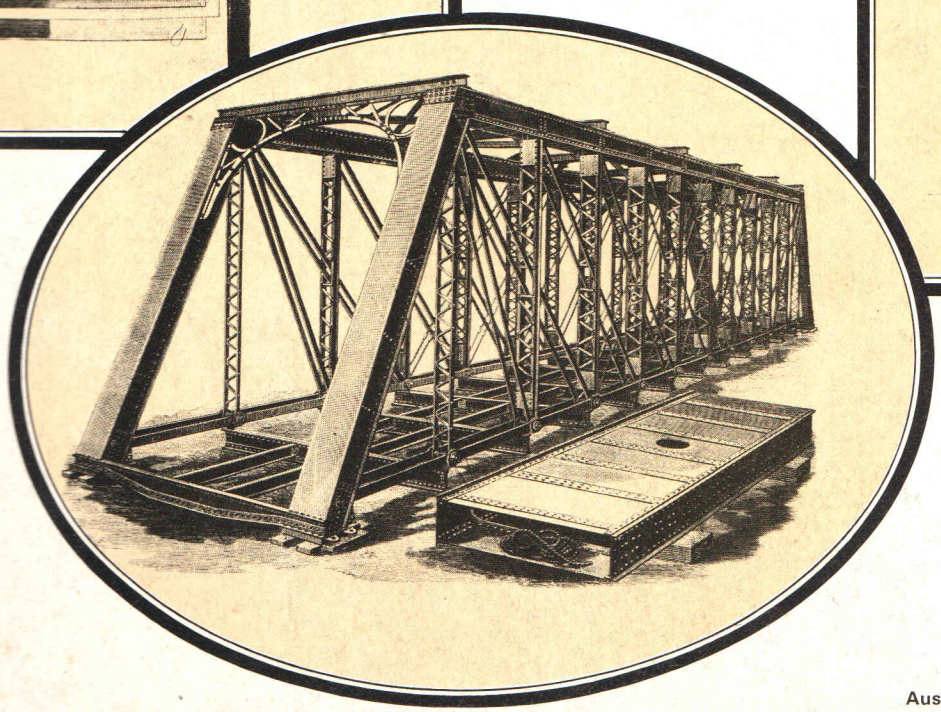

EMPIRE OF IRON & STEEL

Australia & New Zealand 70c South Africa 70c Canada 95c

THE BRITISH EMPIRE

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JIM HICKS, author of the text sections of this issue, is a product of Britain's First Empire, America. Born in Texas, he received an MA from Northwestern University where he read political science and history. As London Bureau Chief for LIFE magazine, he wrote an eyewitness report of the events accompanying Rhodesia's Unilateral Declaration of Independence. He now lives and works in London.

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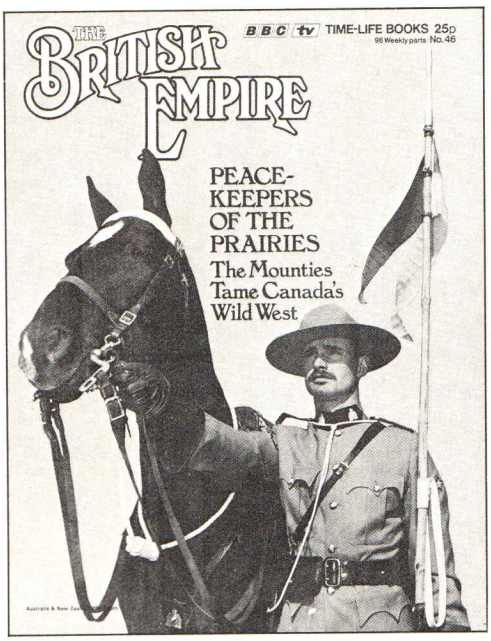
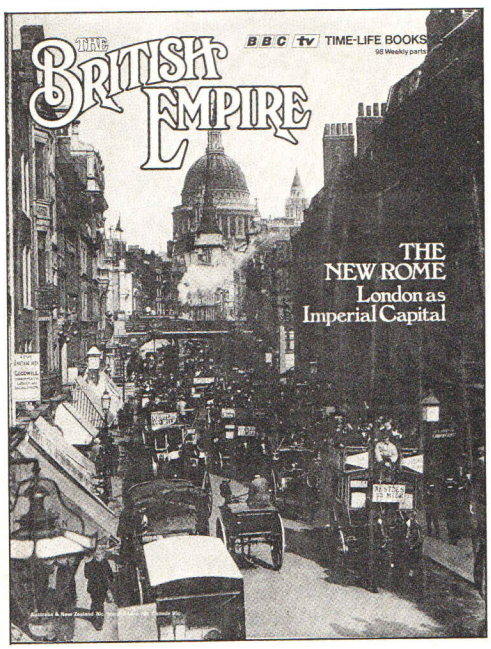




CONTENTS

Cover: Bridges, derricks, steam tugs; road locomotives, foundries and portable engines – these were some of the British manufactures exported to the Empire in the 19th Century.

EMPIRE OF IRON & STEEL

The most enduring monuments to British imperial rule are those of iron and steel. While political systems rise and fall, viaducts, railways, harbours and canals still proclaim the vanished power that the world's first industrial nation exercised in the confident years of her Victorian prime

The great Dufferin railway bridge, constructed in 1887 and named after the then Viceroy of India, stretched across the River Ganges at Benares for over half a mile.

By Jim Hicks

"Arthur Cotton's name will be venerated by millions yet unborn when many who now occupy a much larger place in the public view will be forgotten." That was the opinion confidently voiced by Sir Charles Trevelyan, Governor of Madras, in 1858.

He could not have been more wrong. Far from venerating General Sir Arthur Cotton very few have ever heard of him. A single paragraph in *Encyclopedia Britannica* is sufficient to satisfy posterity's interest in this Victorian Englishman. Yet Trevelyan's prediction was as justified as it was unprophetic. For by his work, Cotton saved millions of lives.

Cotton was an engineer. In India, he built dams and dug irrigation canals that made oases out of deserts and transformed agriculture. In one of India's many famines, in which four million people died, Cotton's works were credited with saving all the inhabitants of his district, and providing enough extra food to keep three million alive elsewhere.

His deeds were remarkable, but not unique. Cotton was but one of a special breed of 19th-Century Englishmen who worked wonders so regularly, and with such apparent ease, that the world came to accept their miracles as commonplace. Like him, most are now forgotten. They did their work, took their scattering of knighthoods and lesser honours, and disappeared into yellowed old parliamentary reports and discarded company files. But these engineers of the British Empire transformed the world.

They carried the industrial revolution to the limits of Empire and beyond. They built railways in lands that did not use the wheel and strung their electric telegraph through jungles just emerging from the Stone Age. They curbed rivers which had terrorized man from the beginning of time and used them to make deserts bloom. They dug mines. They built harbours which turned rude villages into thriving international ports, and sanitary systems which drove disease from cities notorious for pestilence. To those whose power was the ox, they introduced the marvel of machines.

In a century of furious activity they created for Britain's subject peoples the infra-structure of modern life, the very foundations upon which today's nations function. Some now believe the price these nations paid in British domination was too dear. But they cannot devalue what they received from the British engineers.

These were the Englishmen who joined mad dogs in the noonday sun. They helped give Great Britain a national superiority complex, hardly surprising when Victorians read over their breakfast-tables stories like this one from the *Daily Mail*, describing the engineer William Willcocks's work on the Great Nile Dam, completed in 1902.

"A knot of sheiks and reis [boat captains] greet him with the courtly Eastern salaam. Bedouin and fellaheen work like ants, and dark-skinned, smiling, good-natured Sudanese ram home the concrete, as if they took the whole thing as a huge joke. Here and there, under broad sun helmets, may be found a wily Greek or excitable Italian, acting as a useful lieutenant to the solitary Englishman perched yonder on an elevation of masonry, apparently an idle spectator, and yet seeing all."

Each evening, said the *Mail's* patriotic correspondent, the workmen headed for the bazaar to "indulge in the nightly fantasia and the everlasting tap of the tom-toms," but not our stalwart engineer. If one peeped into his window, "one would see a picturesque group of gaily dressed Arab sheiks and reis standing around one man of a foreign race, making reports and receiving them till midnight strikes, when this representative of the Dominant Power encloses himself within his mosquito curtains, and the dam has risen two feet within the last twenty-four hours."

Whatever they thought in London, life for a British engineer abroad was not mainly a matter of striking poses for journalists on pieces of masonry. "They mostly cursed their work," said Rudyard Kipling, "yet carried it through to the end, in difficult surroundings, without help or acknowledgement." Deprived of their families or – sometimes worse – seeing them suffer the same gruelling hardships, they struggled against disease, sudden death, hostile climates and frequently hostile populations.

Cotton suffered devastating fevers which again and again forced him temporarily to abandon India and his work. Alex Taylor, who built the Punjab section of the Grand Trunk Road across north India, was blind for months on end – a common affliction for engineers in the Indian sun. They were drowned in floods, maimed in construction accidents, and over the years more than a few of their bodies were found mutilated at the farthest reach of a telegraph-wire or at a lonely railhead miles from civilization.

Robert Stephenson sits at the centre of the team that helped him build the Britannia Tubular Bridge across the Menai Straits in Wales (background). Completed in 1850, it was a pioneering feat whose principles were at that time being repeated by British engineers all over the world.

A British survey officer relaxes with a cigar and a drink after a long day in the blazing sun of India in 1840, while assistants update the books and dismantle a theodolite.

Yet they stuck to their jobs, inspired by the selfless motivation of service to mankind. As the Victorian essayist, Thomas Carlyle, said, history itself had assigned Englishmen "the grand industrial task of conquering half or more of this terraquaceous planet for the use of man." And of course it was true, since Britain was the world's first industrialized nation. For a time she was the world's only workshop, the world's only massive trading power and the world's only foreign investor. The exhilaration of conquering nature was hers alone, and her engineers were the missionary pioneers of modern civilization. In their hands they held the power to transform continents. Their job was of world importance, and they took it seriously.

"There was a glow of work about us in the Punjab such as I have never felt before or since," wrote Alex Taylor. "I well remember the feeling when I went on furlough to England; the want of pressure of any kind, the self-seeking, the dulling and dwarfing of high aims."

Their efforts were not always welcomed by the beneficiaries, but fortunately some engineers demonstrated a genius for bridging cultural gaps. Zakka Khel tribesmen of India's North-West Frontier were adamantly opposed to the construction of the Khyber Pass Railway. "A railway through our land?" roared the Chief. "It is forbidden."

"Listen," said Victor Bayley, British engineer. "A train through the hills must crawl slowly up steep gradients. It would be laden with rich merchandise. And the Zakka Khel do not always pay for their goods. Consider the many chances there would be . . ." The Chief got the message. "The Sahib builds the railway; we loot the trains," he repeated thoughtfully. "Build that railway quick, Sahib."

Nowhere were the engineers more successful than in India. The Victorians, in their enthusiasm, called that country "the greatest achievement of the English race." The achievement was actually that of a very few men, most of them from a single school, the East India Company's college at Addiscombe, near Croydon. In 52 years, Addiscombe trained some 3,600 cadets for Indian service. Of those, only about 500 were engineers.

One of those graduates was Arthur Cotton. Had Galsworthy wished to portray the other archetypal Victorian family – one as devoted to public service as were his Forsytes to property – he would have looked no further than the Cottons. Arthur Cotton was the tenth son of the tenth son of a fourth baronet, a nice pedigree, but one which puts you a long way from the money, which may be why his family worked so hard.

Among his brothers were two more generals – one an engineer like himself, the

other a fighting soldier who commanded at Peshawar during the Mutiny; an admiral; a colonel in the Royal Engineers; a member of the Indian Civil Service; and the family representative in the Anglican Church, who became Provost of Worcester College, Oxford.

Arthur was born in 1803 and spent his childhood – or so his family inevitably recalled later – making canals in his bread and milk. At 15 he went to Addiscombe to study war and engineering, and by 23 had considerable practice in both. He found the Burmese War of 1824–26 "a very melancholy business, inconceivably mismanaged" (throughout his life he maintained a healthy disrespect for his superiors' abilities), but made a name for himself by leading seven storming-parties against enemy fortresses.

Besides bravery, Cotton demonstrated other qualities which distinguished him as an exemplary Victorian: priggishness and Evangelical religion. Having gambled away £20, which he lost to a superior officer, he announced that he abhorred card-playing and thereafter would not allow a pack in his house. He made no secret of his religious beliefs either. On a voyage to India, he amused and annoyed fellow officers by inquiring in the gin-soaked saloon if anyone had a Bible he could borrow.

Soon his facility for handling great watercourses was recognized and he was put to work on the Cauveri, the largest river in southern India. Enough of its water escaped unused into the sea to irrigate ten times as much grain as the area was producing. Cotton had a scheme for capturing this flow, but the fevers which were to hound him throughout his career interfered. In 1830 he returned to England on sick-leave.

Bored with "time-wasting county society" he asked the East India Company to give him a letter of reference so he could visit and study irrigation projects while recuperating. He learned, as other engineers would learn, that the bureaucrats who employed them could be as capriciously frustrating as the natural elements with which they wrestled. After a long delay and without explanation, he laconically noted to a friend, "this proposal was negatived."

At least the Company was generous with travel time. In 1832 he began a 12-month overland journey back to India and confirmed along the way his already missionary-like conviction that the world sorely needed the kind of civilization only Britain could offer it. In Alexandria, he was disgusted with the 19th-Century equivalent of hippies – Europeans dressed like Arabs, squatting on the ground smoking peculiarly fragrant pipes. "It makes me quite sick," he said, "to see Englishmen and Christians ashamed of their own dress and customs."

After a near escape from death on the Persian Gulf, when he suffered so violent a fever that his companions dug a grave for him, he reached India again and in 1836 fulfilled his plans for the Cauveri. Nothing like it had ever been seen, not even in Europe. The scheme involved two major dams and canal systems. According to an official, the province considered it "the greatest blessing that had ever been conferred on it." His employers, who measured blessings by a different standard than did Indian farmers, were equally pleased. Water charges and navigation fees on one of the systems were soon returning 69 per cent annually on capital invested, the other 100 per cent annually!

By 1838 he again had to leave India to stay alive and this time took his sick-leave in Australia. There he indulged his engineer's passion for machinery, designing a centrifugal steam-engine much like later steam-turbines. It was not entirely successful. He wrote to a friend: "the boiler burst and injured both my legs, taking off the flesh of one of them, but I succeeded in getting 150 revolutions a minute." He also indulged another passion, Elizabeth Learmonth. "If God would give me so great a gift," he exclaimed, "I would marry that girl." After another visit in 1841 he took her back to India as his bride.

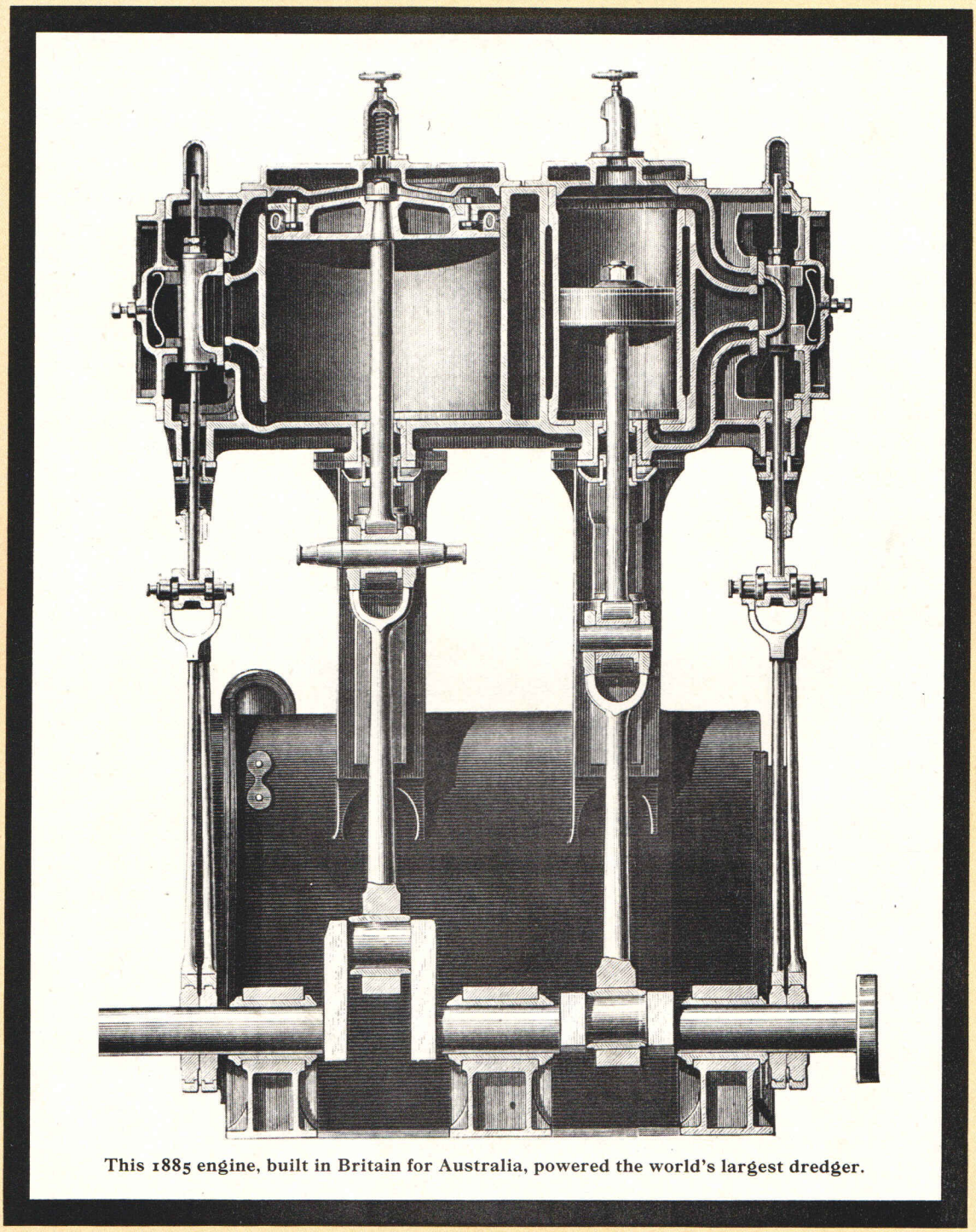
Jackals prowled outside the young wife's door and snakes plopped from the rafters into her babies' cradles. She was always near her husband's work – he was able to rush home one day to shoot a cobra which had taken over the nursery – but that proximity also had disadvantages. Almost every day she had to call the children indoors so blasting could begin. Stones showered the roof, walls split, and more snakes slithered into the house to escape from Cotton pounding nature. When an unexpected flood washed through the home, she barely managed to rescue the family's two most beloved possessions, *Madam Guyon's Autobiography* and her husband's cocked hat. Cotton expected his family to suffer such calamities without complaint, and to work hard. "If you want rest," he told his children when they were growing up, "vary your employment."

He also instilled in them those other cherished Victorian virtues: religion and patriotism. He led church services at six each morning – any later would have been too hot. Patriotism was an equally serious matter. His daughter told of the family once standing on the deck of a ship in Mauritius Harbour, tears in their eyes, while "to our loyal and devoted ears came the welcome strains of *God Save the Queen*." Wherever they travelled, they believed they were secure in Empire's protective bosom. They were often proved right. On one journey across India, Cotton's wife and daughter were stranded at a rest-house without food. But, camping near by was an English gentleman traveller. He sent a parade of liveried servants bearing lunch.

In 1844, Cotton took on India's third biggest river and his biggest job, the Godavari. The area south of Madras through which it flowed was one of the poorest. A series of famines had littered the roads with human corpses. Peasants sold their daughters to strangers for a few days' supply of food. Wagons bringing relief supplies of grain needed armed escorts. Cotton was called in to assess the problem. "I could not help seeing what it wanted," he said, "which was simply everything."

It mainly wanted irrigation from the Godavari, but damming the river would be a monumental task. Its flow was one and a half million cubic feet per second, three times that of the Nile at Cairo, 200 times that of the Thames at Staines. He asked for six officers and eight sappers to assist in a detailed survey and was allotted by the tight-fisted Company a staff of "one young hand to teach and two apprentice surveyors"

POWER TO MOVE MOUNTAINS



This 1885 engine, built in Britain for Australia, powered the world's largest dredger.

Between 1880 and 1900, the worth of Britain's machine exports doubled to £20,000,000. To the Victorians, this was heady stuff, further proof that Britain was the world's leader in mastering nature. But it was a superficial judgement. The engines that scraped, dredged, puffed and clanked their way so effectively across the Empire and the whole wide world merely served to conceal Britain's increasing weakness. For they supplied other nations with the means to build rival economies.

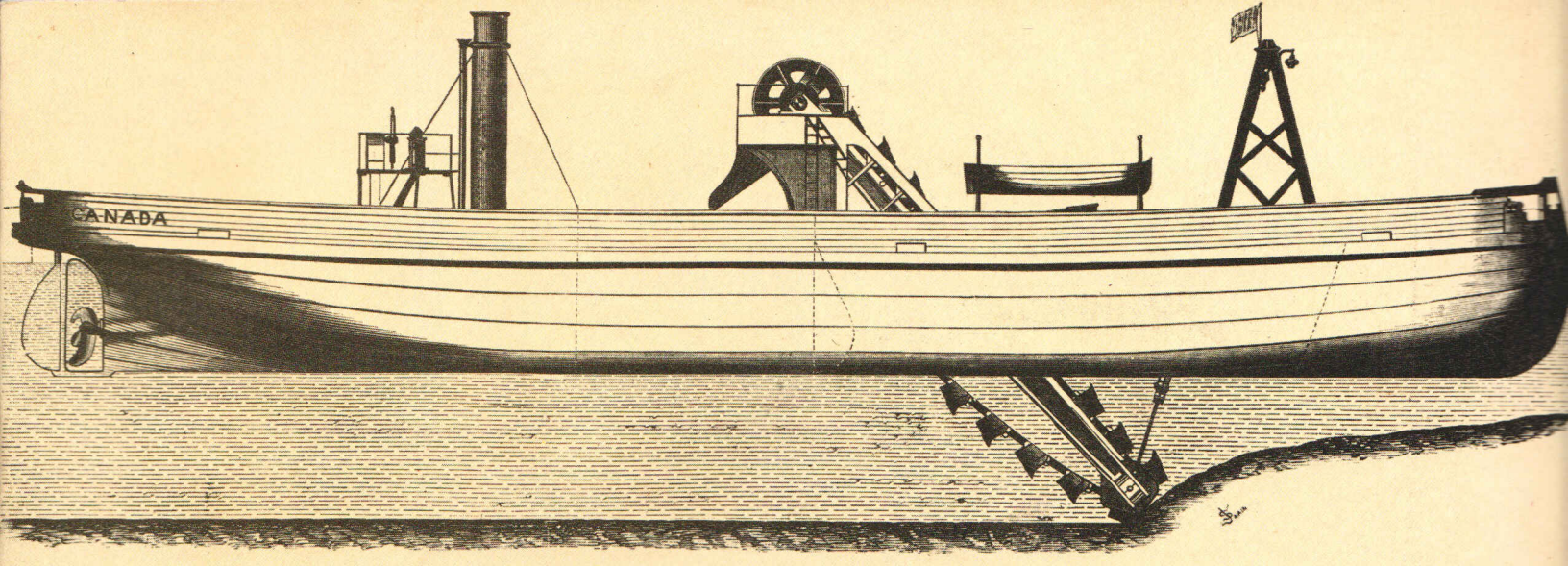
Changing the Face of the Earth

There was no limit to the optimism the Early Victorians felt for the God-like powers they seemingly held in their hands. They were, in the words of Sir Humphry Davy, "powers which may be almost called creative." Canals, mines, deep-water harbours: these proved that progress was possible, that hard work produced lasting results for the general good. "God helps those who help themselves," wrote Samuel Smiles, the biographer whose faith in this dictum led him to make heroes of Britain's engineers.

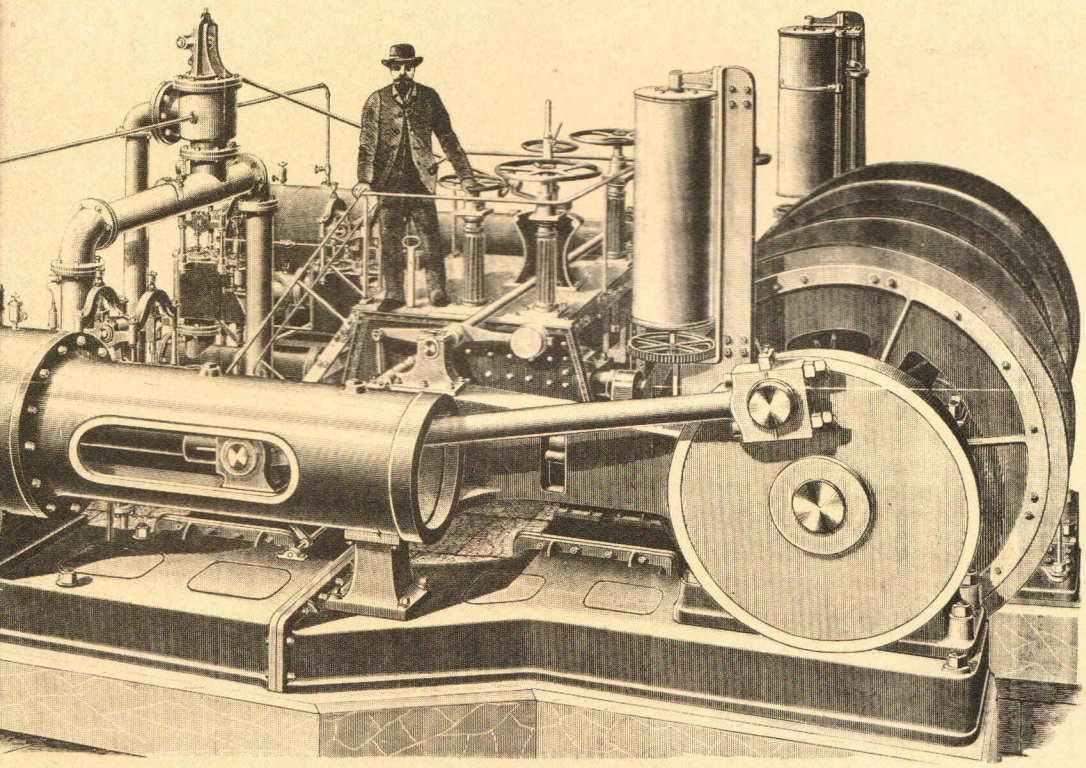
Many of his heroes lived in the 18th Century, and it was an 18th-Century optimism that bore up the Early Victorian engineers. Railways and canals had knitted a diverse country together, brought mobility to millions, shown how the application of steam could perhaps lay the foundations of Utopia in Britain.

Now, in the latter part of the century, she could do the same thing all over again with the Empire, a raw estate ready for the hand of the developer. Starving millions awaited dams, canals and railways. British settlers awaited water-pumps, winders and presses. The mother country had helped herself at home and God had rewarded her with a great Empire. It was now her duty to ensure the same rewards for her imperial children.

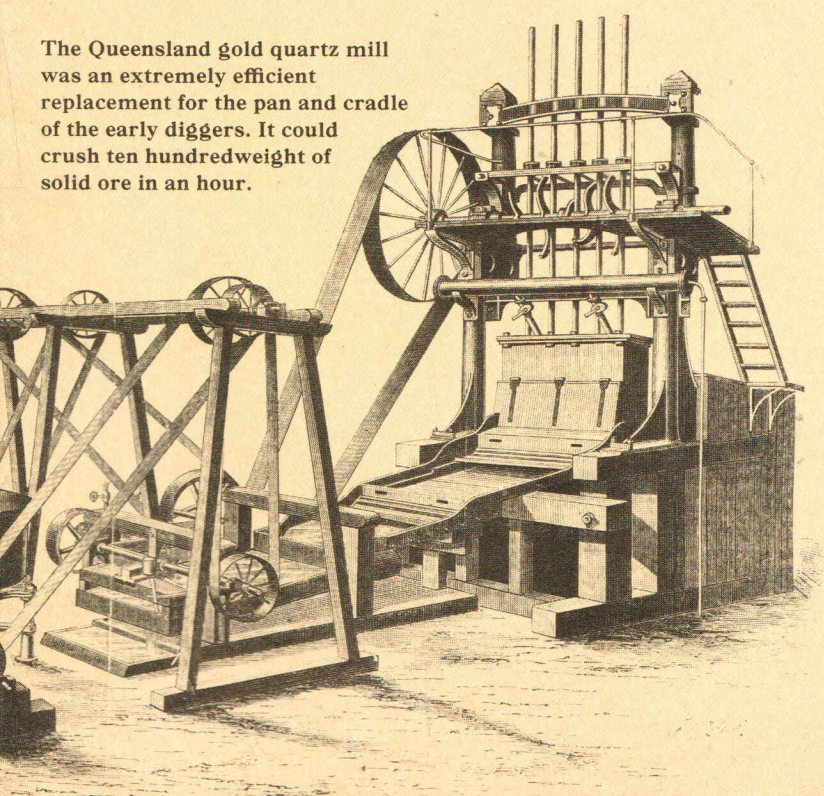
The sonorously named combined excavator and steam crane which ran on rails was used for quarrying, for ditching and dredging waterways and for excavating canals.



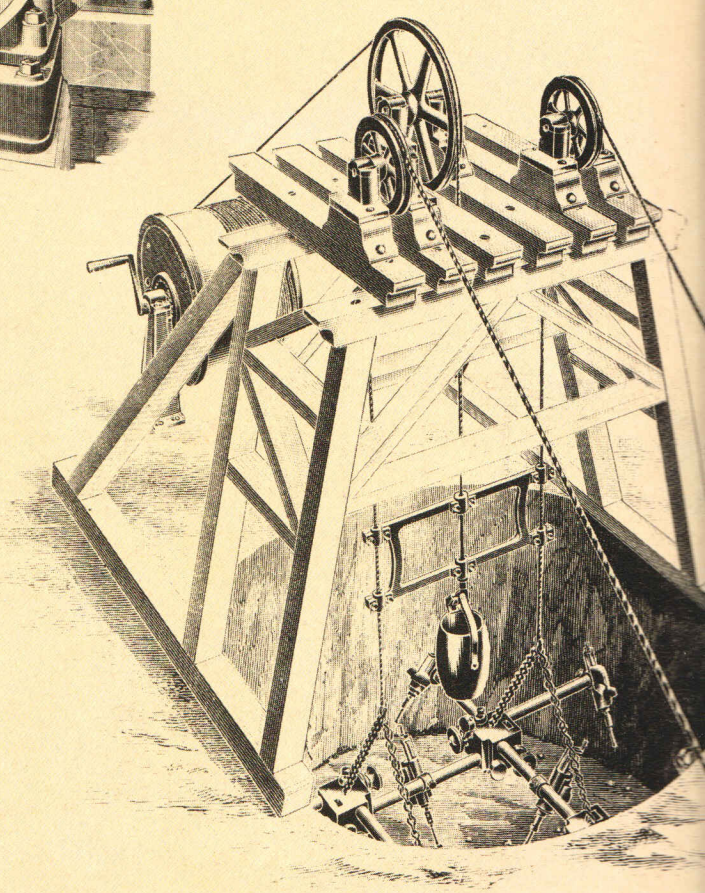
This "hopper dredge", built on the Clyde for use in Canada, combined the functions of dredger and attendant hopper barge (which carried off a dredger's waste). The 24 buckets on the chain filled the hopper cavity with 200 tons of mud and gravel, which were deposited at sea through hinged iron doors.



Birmingham was the birthplace of this steam-driven colliery winding engine, made for the Australian Agricultural and Mining Company of New South Wales.



The Queensland gold quartz mill was an extremely efficient replacement for the pan and cradle of the early diggers. It could crush ten hundredweight of solid ore in an hour.

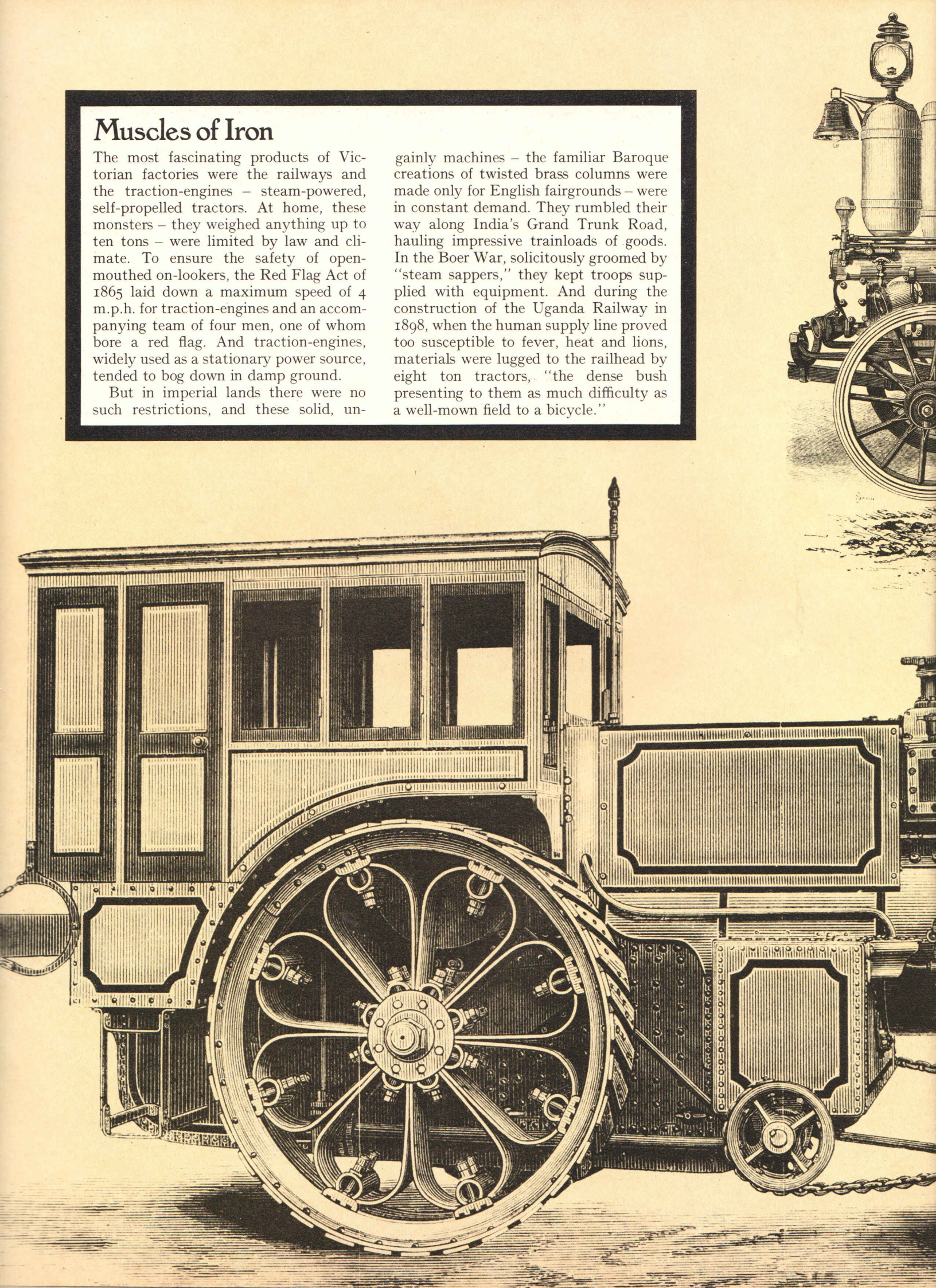


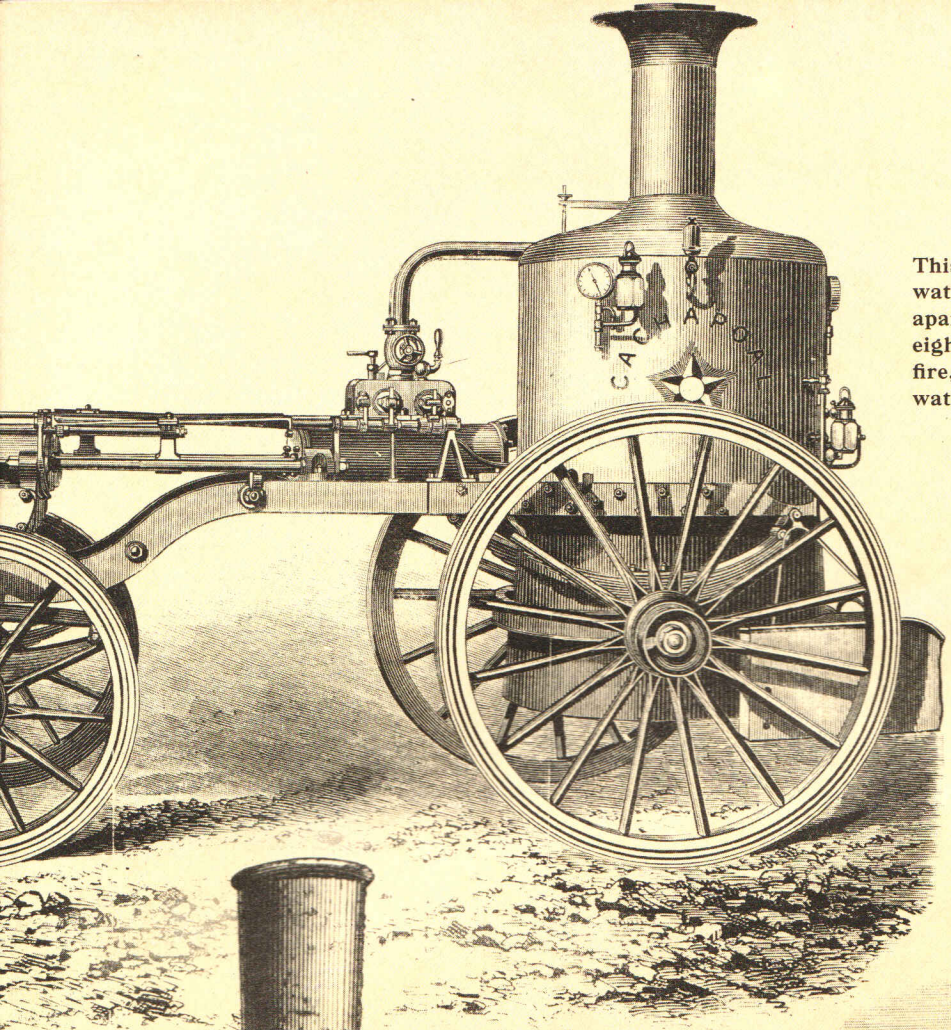
On this adjustable drilling-frame for sinking mine-shafts, the drills that made the holes for blasting-charges were held on rigid extending rods pressing against the shaft.

Muscles of Iron

The most fascinating products of Victorian factories were the railways and the traction-engines – steam-powered, self-propelled tractors. At home, these monsters – they weighed anything up to ten tons – were limited by law and climate. To ensure the safety of open-mouthed on-lookers, the Red Flag Act of 1865 laid down a maximum speed of 4 m.p.h. for traction-engines and an accompanying team of four men, one of whom bore a red flag. And traction-engines, widely used as a stationary power source, tended to bog down in damp ground.

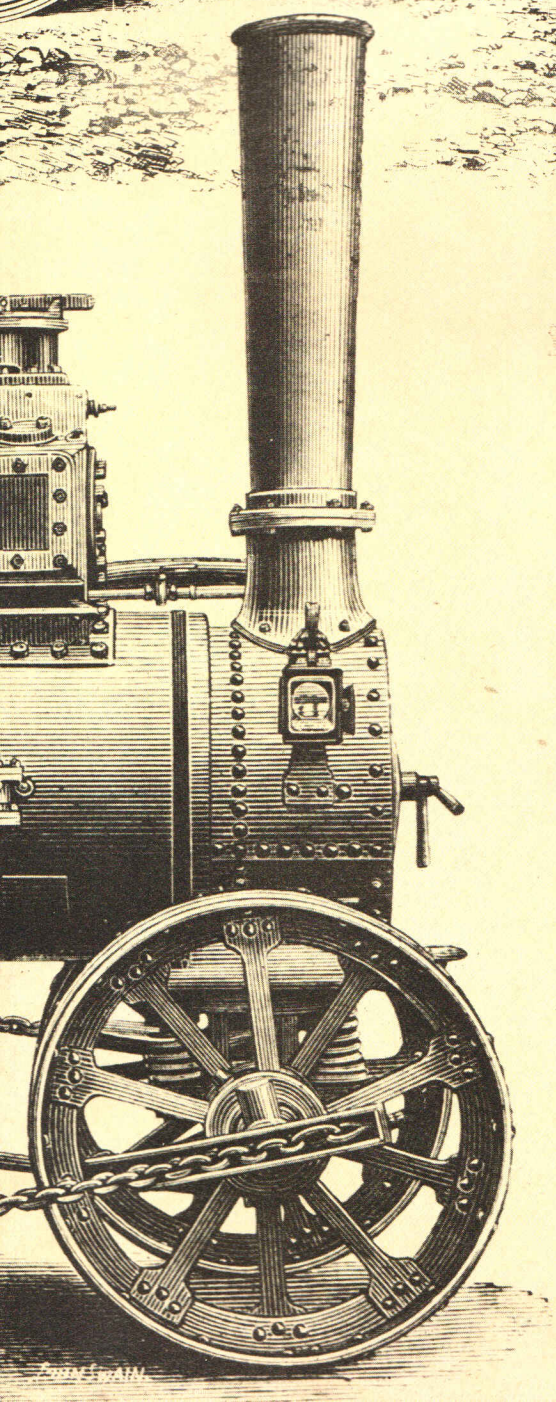
But in imperial lands there were no such restrictions, and these solid, ungainly machines – the familiar Baroque creations of twisted brass columns were made only for English fairgrounds – were in constant demand. They rumbled their way along India's Grand Trunk Road, hauling impressive trainloads of goods. In the Boer War, solicitously groomed by "steam sappers," they kept troops supplied with equipment. And during the construction of the Uganda Railway in 1898, when the human supply line proved too susceptible to fever, heat and lions, materials were lugged to the railhead by eight ton tractors, "the dense bush presenting to them as much difficulty as a well-mown field to a bicycle."





This fire-engine with a steam-powered water-jet was used in locations as far apart as Chile, India and Singapore. Just eight and a half minutes after lighting the fire, a working pressure was raised and water could be thrown 250 feet.

This traction-engine was designed for use in India to bale cotton into one-seventh of its original bulk and so cut out the danger of its catching fire during transit. Uncompressed cotton destroyed in this way cost one railway £30,000 during one year alone.



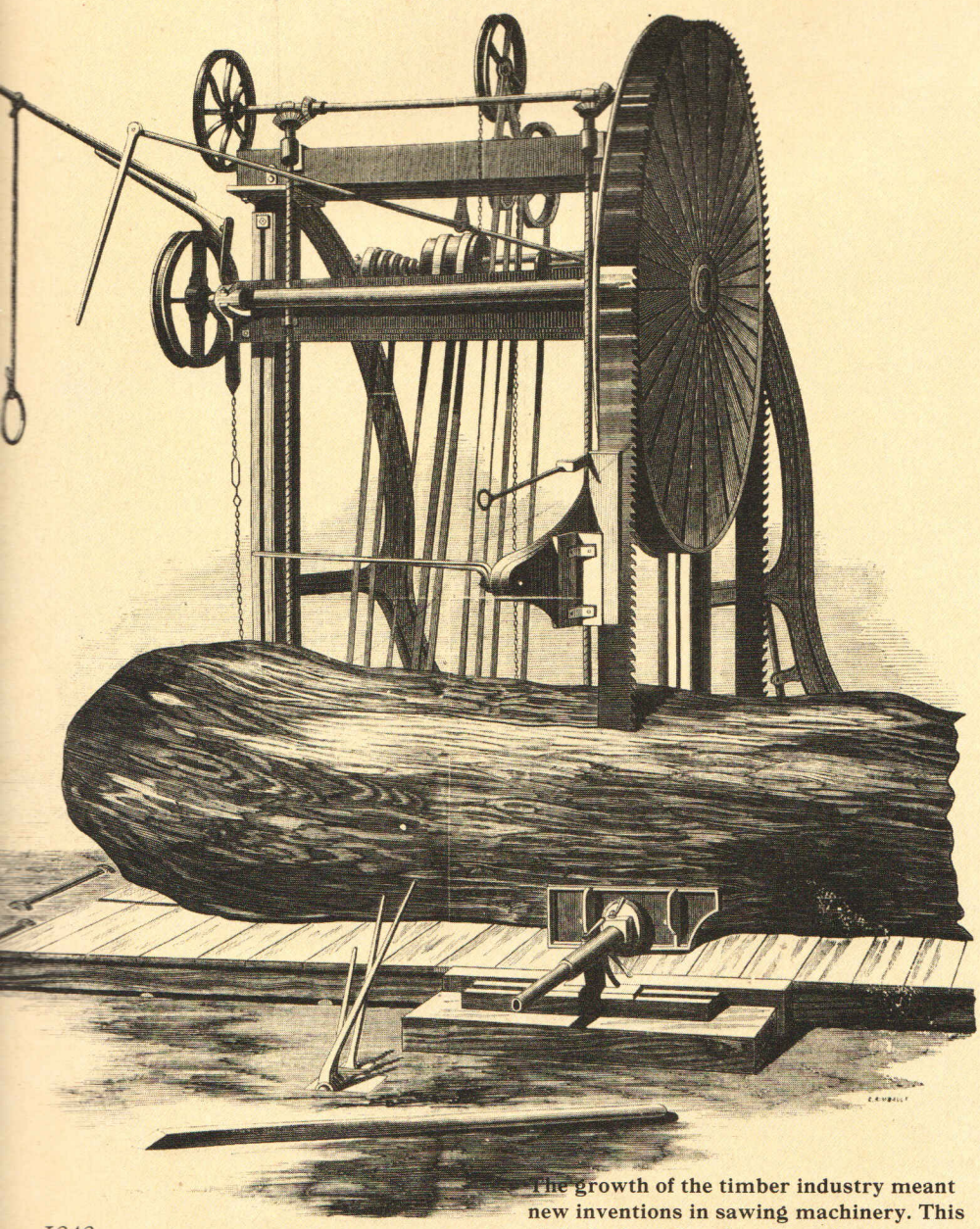
Designed to travel at "high speed" – 8 m.p.h. – on wheels cushioned by coil springs this engine, built in Leeds for passenger service in India, could pull three tons.

Gadgets Galore

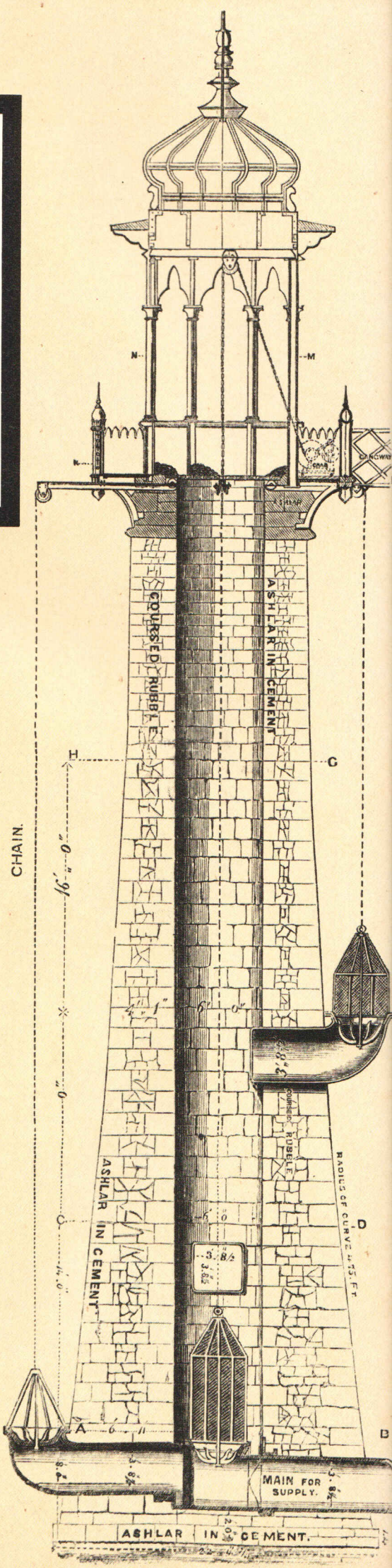
Huge band-saws that sliced through the forests of Canada, stone-crushers that hammered out the gold from the Rand and Australia, lighthouses that glimmered along the sea-routes of the world: to the British public, such devices proved that British expertise was paramount.

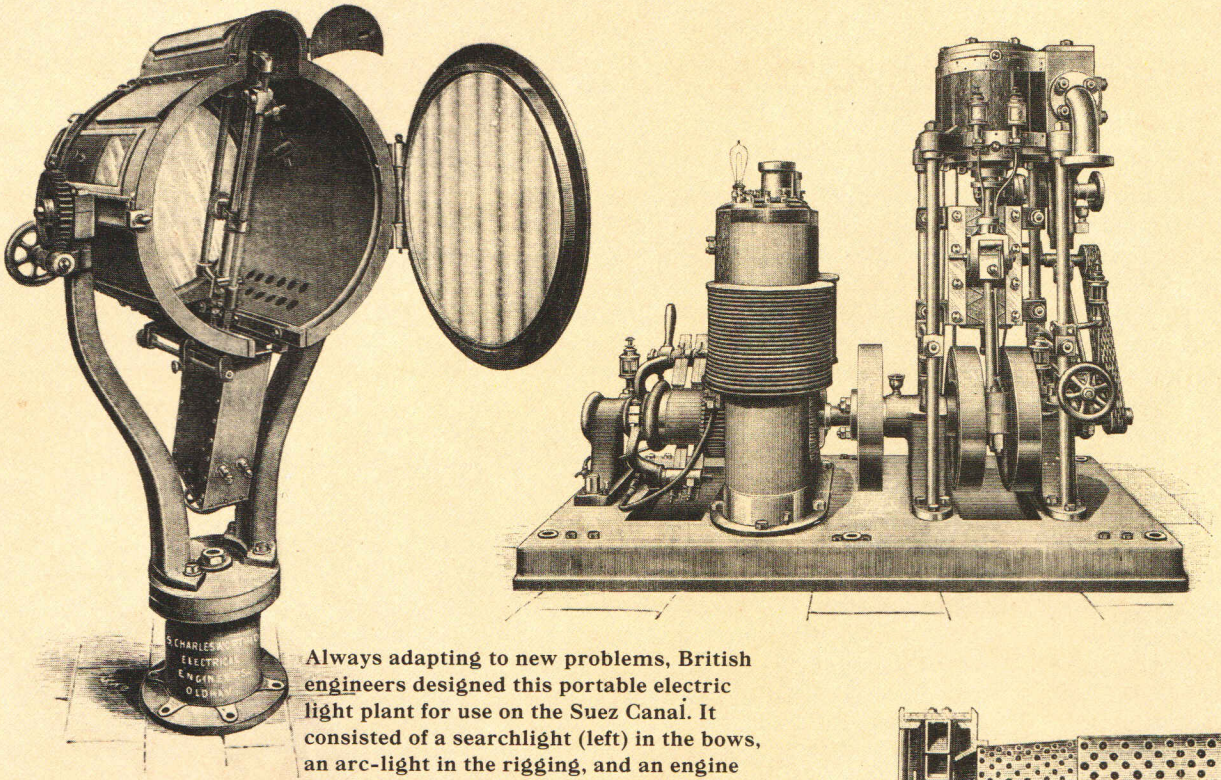
It was true. But there was another side to the coin. Because of the swift success of Britain's technical engineers, there had grown up a split between pure science and engineering that was eventually disastrous for British technological leadership. In the 1860s, an eminent civil engineer could dismiss scientific formulae on the proportions of retaining-walls in a mine-shaft as "having the same practical value as the weather forecasts for the year in *Old Moore's Almanac*."

But while technicians and scientists derided each other – convinced nevertheless of British supremacy – and gentlemen recoiled from trade, German, French and American scientists were busy building the future – on the basis of British-pioneered techniques. Britain's success in transforming her Empire merely allowed the old complacency to live on until Britain was more the world's industrial museum than its workshop.



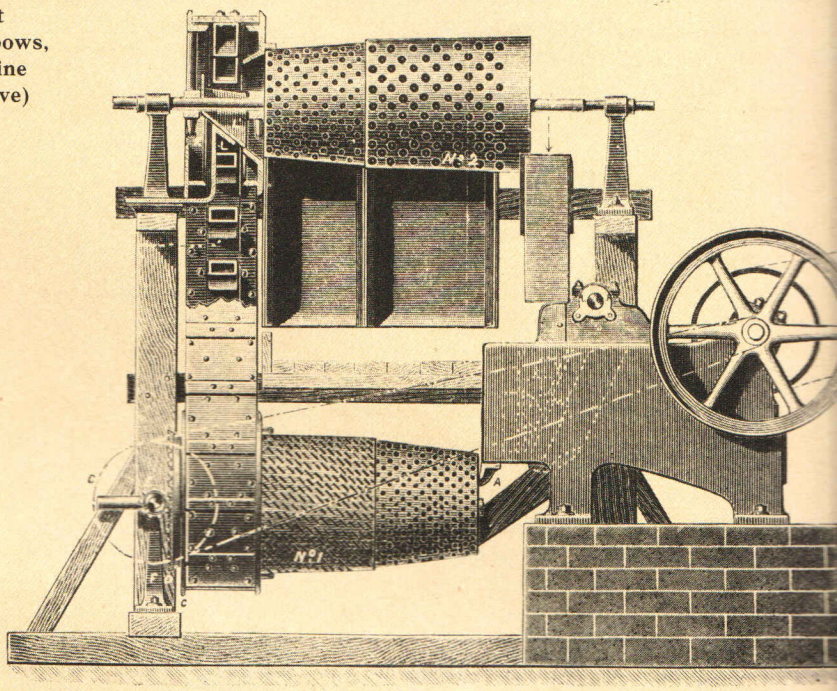
The growth of the timber industry meant new inventions in sawing machinery. This eight-inch endless band-saw kept turning while the log travelled on moving tables.



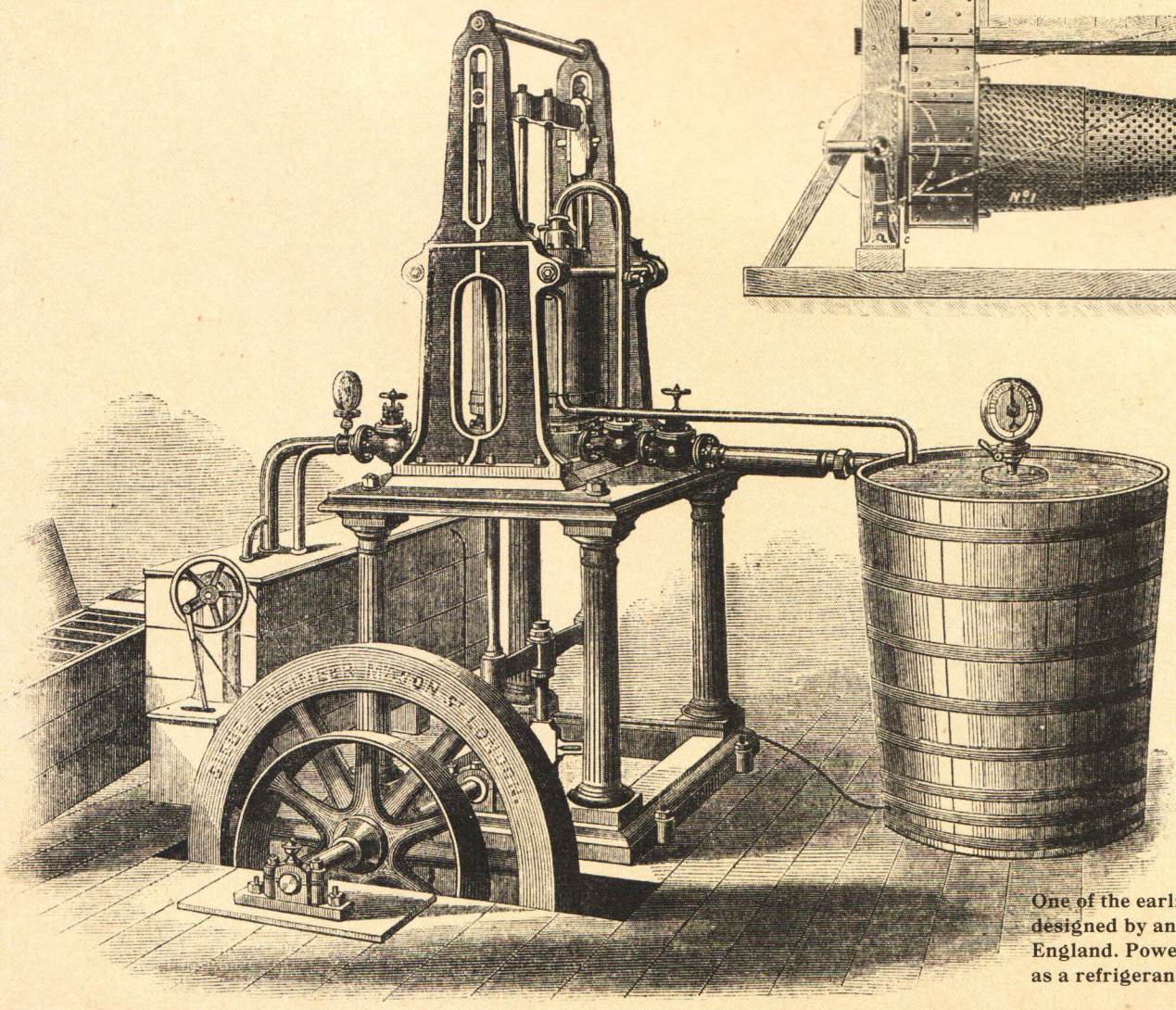


Always adapting to new problems, British engineers designed this portable electric light plant for use on the Suez Canal. It consisted of a searchlight (left) in the bows, an arc-light in the rigging, and an engine and dynamo fixed to one bedplate (above) which connected to the ship's boilers.

This tower, which strained contaminated water before passing it through to the main reservoir, was one of four the British built to keep Bombay's water pure.



India was the recipient of this stone-breaking and delivering machine, used at quarries to s out different sizes of stones, particularly those for use on r



One of the earliest refrigerators was designed by an Australian, though built in England. Powered by steam and using ether as a refrigerant, it was efficient if expensive.

II. A Wild Land Tamed

Arthur Cotton's biggest project, the damming of the Godavari, took eight years to complete. Much of the time Cotton was ill, but he did not allow that to slow the work. The main dam was a full two and a quarter miles long, and he daringly built it of rubble encased in masonry rather than of solid stone. His colleagues jibed that he was "founding the cheapest school of engineering in the world," but the Company Directors in London were delighted. The low cost meant the project would pay 30 per cent a year on capital invested.

It irrigated 364,000 new acres, created 340 miles of navigable channel, insured millions of people against starvation and was called "the noblest feat of engineering skill which has yet been accomplished in British India." Cotton hoped that it might increase India's "appreciation of a Christian Government."

The Godavari was a triumph, but he had little time to enjoy his glory. In 1853 the Governor of Madras named an infantry captain to oversee construction works, saying there were "no capable engineering officers available." Cotton objected angrily, was accused of insubordination, resigned and returned to England. Two years later he came back, but got into another row and left India for good in 1860.

He had earned a knighthood. It was small enough reward, but as he told a House of Commons Committee some years later, "I have never asked for an appointment, or for anything else, except to be allowed to irrigate India."

Even before Cotton retired, other engineers were surpassing his great works with larger and bolder projects. When the 530-mile Ganges Canal opened in 1854, it was the biggest work of engineering in the world. It was built by Sir Percy Cautley, another Addiscombe graduate, who was given such a meagre budget that he had to do his own surveying. Even so, he found time to make himself one of the great Victorian amateurs of science, in palaeontology. He wrote numerous papers with titles like *On a Sivalik Ruminant Allied to the Giraffidae* and eventually presented to the British Museum his collection of fossils – all 40 tons of them.

In the spectacular Periyar project in Southern India, British engineers outdid themselves. They dammed a river with a flood as great as Niagara Falls, drove it through a mountain in a mile-long tunnel and made it flow down the other side of the sub-continent. It took eight years. For half of each year it rained four out of every five days. Floods washed away the foundations several times. First malaria, then cholera swept through the community of engineers and workers, requiring them to burn one camp and later move the new one. Tigers prowled the surrounding jungles. Elephants knocked down tents and houses. Herds of bison stampeded the workmen from their posts. But on October 10, 1895, the Periyar River began flowing towards an ocean it had never seen before and 100,000 acres of barren land were brought to life.

The engineers would try anything. They carried canals over rivers and, when necessary, carried rivers over canals. Two rivers cross the Ganges Canal on super-passages, one of them 300 feet wide. Not all these wonders were mechanically created. Some of them proved cheaper to build by labour – intensive methods. The most important equipment employed on the Sirhind Canal in the Punjab was three jails, housing convicts who removed 900 million cubic feet of earth in baskets on their heads.

It would be wrong to say that Britain "gave" India water – or anything else. The dams were viewed as commercial propositions, and in fact paid an average of 7 to 8 per cent, an excellent return on capital in a period of consistently low interest rates. Non-paying works were

The Ganges irrigation canal (above), with its sleek bridges and stone lions, was built between 1848 and 1854 by Indian army sappers and men of the Royal Engineers (right). From the 810-mile main channel, 2,266 miles of irrigation canals reached out into the countryside, bringing life-giving water to the parched soil.

often undertaken because they directly benefited the British themselves. In Lahore, a filthy place "full of stagnant water," malaria was killing too many British troops. For this reason the streets were paved and a modern drainage system installed, and "the most malodorous of native capitals" gained repute for its cleanliness. In building roads – and later, railways – a primary purpose was to facilitate troop movements.

The greatest road-building achievement of the British – perhaps the greatest the world had seen since the Roman Empire – was the Grand Trunk Road which ran from Calcutta to Delhi and was later extended across the Punjab to Peshawar on the borders of Afghanistan. "The Grand Trunk Road," wrote Rudyard Kipling, "is a wonderful spectacle; a stately corridor; all India spread out to left and right. It runs straight, bearing, without crowding, India's traffic for fifteen hundred miles – such a river of life as nowhere else exists in the world." For the most part it was three roads, one on either side for heavy carts and a middle carriageway for fast traffic, all shaded by four lanes of trees.

It was a mammoth task and took 40 years, on and off, to complete. In one 264-mile section, between Lahore and Peshawar, engineers had to build 103 major bridges, 459 smaller ones, tunnel through six chains of mountains and erect immense embankments to carry the road over two great river-beds. It was a job for exceptional men – men like Alex Taylor, who at the age of 24 was supervising the work of 60,000 labourers over an area four times as large as Scotland. In temperatures that hovered around 120 degrees Farenheit, he lived on horseback, commuting between the seven separate sections under his control.

Sometimes it seemed that nature resented the engineers' efforts. James "Buster" Browne, building a bridge on Taylor's part of the Grand Trunk Road, was awakened by shouting one night. "I saw the river coming down in a huge wave, about 200 feet wide: one wall of roaring water." His most precious machine, a giant pile-driving engine, broke from its moorings, "sending coolies in all directions with cut faces and bruised bodies." Browne and four others plunged into the flood and chained the engine to a ram, a great piece of iron held between two floating wooden beams. A carpenter swam out with an axe and they chopped away at the beams. Five miles downstream, the iron ram, freed of its timbers, finally sank and anchored the pile-driver, five minutes short of a waterfall.

"The worst part of it was I had to walk five miles without my shoes," said Browne, "in my nightshirt."

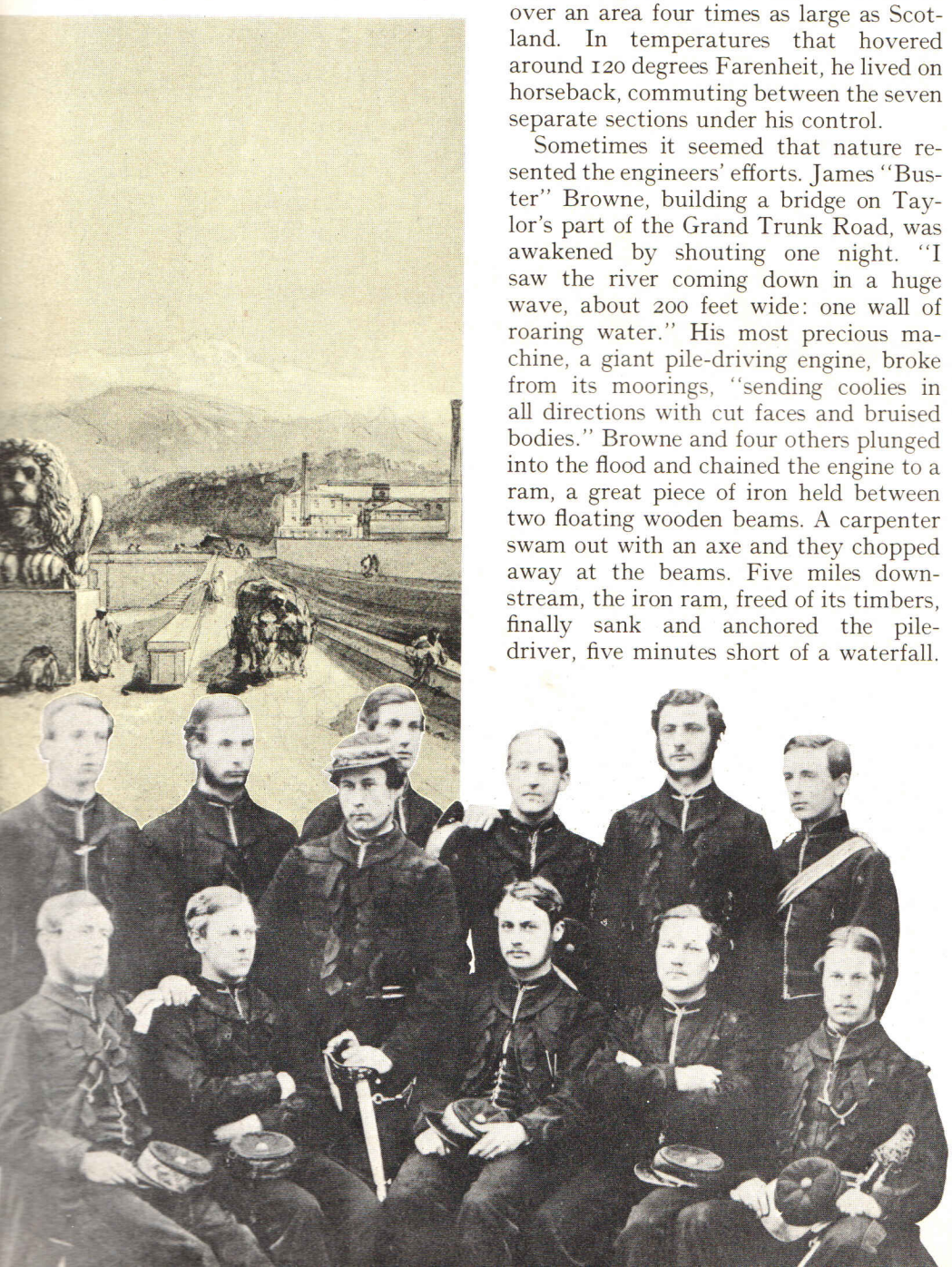
The real turning-point in India's history was the coming of railways. "Railways may do for India," wrote Sir Edwin Arnold in 1865, "what dynasties have never done – what . . . Akbar the Magnificent could not effect by government nor . . . Tipoo Sahib by violence – they may make India a nation."

Until the Mutiny in 1857, the Indian government was not very interested in railways. Thereafter it viewed them as a military investment. It took six months to march a regiment from Calcutta to Peshawar. By rail it could be done in 100 hours. "After all," Arnold wrote, "the first condition of improving India is to hold it."

To build railways, the British had to build harbours where they could land heavy equipment: rails, sleepers, locomotives and bricks. Madras was an open roadstead where cargo was landed through the surf, Calcutta a few jetties 100 miles up a river. Skilled labour was non-existent. "Our ballasting and wagon work," an engineer told a government inquiry, "is conducted and managed by men who never in their lives before saw a wagon. Our bridges with scarcely an exception are superintended by men who do not know a brick from a stone."

Rebels and bandits harried the crews. Two engineers named Limnell and Evans were surveying for a new line in 1859 when rebels ambushed them, decapitating Evans. Limnell was made to carry his friend's head until he dropped from exhaustion. Then he too was murdered. Nor did India's endemic diseases do railway-builders any favours. In the autumn of the same year, a cholera epidemic in one district killed 10 per cent of the work force per week. Four thousand died before it finished.

And yet, the railways were built. By 1869, 4,000 miles of track were in operation. The social and economic consequences were enormous. Soon Thomas Cook & Sons were running package pilgrimages to Mecca from India, and branch railways to Hindu shrines were showing a big profit. "The chances of a god doing a large and increasing business," one Englishman observed,

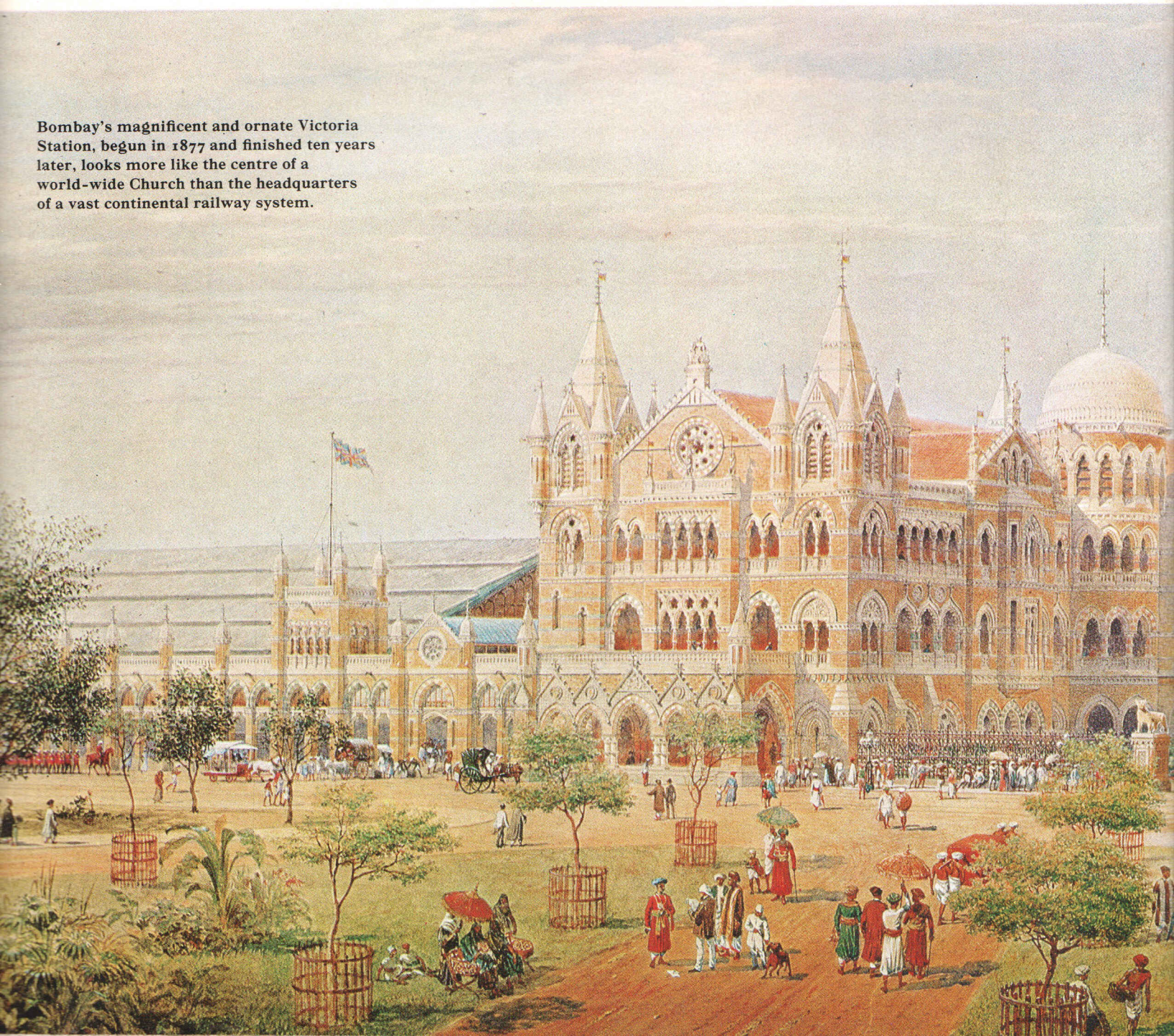


"are greatly improved by a railway station." Internal trade flourished and, able to move her products to ports, India became an exporter. In famines, large amounts of food were transported quickly. And in a wild land without communications, the railway had a unifying, civilizing effect. Matthew Arnold called it the "most persuasive missionary that ever preached in the east." By 1940, India had 43,000 miles of track.

Not all the great builders of the Empire were, strictly speaking, engineers. Sir William O'Shaughnessy was a physician, pathologist, Professor of Chemistry and Deputy Assay-Master to the Mint, who just happened to have an insatiable interest in the electric telegraph. His first experiments showed it simply would not function in India. If fierce winds failed to blow down the poles, white ants ate them hollow or bandicoots uprooted them. The telegraph's greatest enemy was the atmosphere itself. Thunderstorms poured such heavy charges of natural energy into the wires that the magnetic polarity of the instrument was deranged.

"I was driven step by step to discard every screw and lever and pivot, and foot of wire, and framework, and dial, without which it was practicable to work," wrote O'Shaughnessy. "I successively tried and dismissed the English vertical astatic needle telegraph, the American dotter, and several contrivances of my own invention."

In 1851, "when almost driven to despair," he devised, "the little single needle horizontal telegraph," which would work without interruption in all weathers. An experimental line was strung from Calcutta to near-by Diamond Harbour on bamboo posts; these would bend with the wind and hold up through hurricanes that destroyed brick houses and drove steamships ashore. Impressed, the Company approved a plan to connect Calcutta, Agra, Bombay, Peshawar and Madras by wire. O'Shaughnessy was appointed Director-General of Telegraphs and work began in 1853. He worked fast. The 800-mile line to Agra was opened within six months. In another year, 3,050 miles were operating, and in 1856 the entire 4,000-mile system was completed – just in time for the



Bombay's magnificent and ornate Victoria Station, begun in 1877 and finished ten years later, looks more like the centre of a world-wide Church than the headquarters of a vast continental railway system.

Mutiny which began the following year.

"The telegraph," declared Lord Lawrence, "saved India." A mutineer on his way to execution agreed, calling it "the wire that strangles us." News of the uprising was flashed instantaneously across thousands of miles, and enabled the British to concentrate their troops where they were most needed.

During the Mutiny, the man who kept the wires functioning against all the odds was Lieutenant Colonel Patrick Stewart, who succeeded O'Shaughnessy as Director-General in 1856. An Addiscombe boy, Stewart had been working for two others from the school, Cautley on the Ganges Canal and Taylor on the Grand Trunk Road (Stewart wrote home that he hoped to finish his section within 12 weeks, but still had 20 bridges to build). He loved sport nearly as much as engineering, and the former proved much more dangerous. Shooting in 1853, he was attacked by a wounded tigress who chewed his legs. But he saved himself by playing dead instead of calling for help. The next year he was thrown from his horse at full gallop while chasing bustards and was hospitalized again. In 1856 he was struck by a racket-ball which cut an artery near his left eye.

Thus he was a battered old man of 24 when he took up the telegraph appointment, but his injuries had not slowed his work. He restrung the wires as fast as the rebels could pull them down. He was the first man to lay telegraph wire under fire, through hostile territory. Wherever the commander pitched his tent, Stewart was near by, setting up a makeshift station. The Governor-General allowed him to participate in the relief of Lucknow, but told the commander that Colonel Stewart "was, if possible, not to be killed."

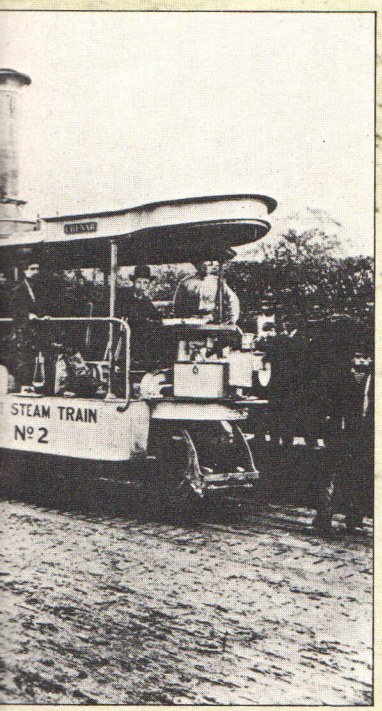
In 1862, when Britain was just starting to lay an international cable system, Stewart was assigned the job of connecting India to Britain by telegraph. He worked westward, laid the cable across the Persian Gulf, and then went to Turkey to negotiate for that section. There, in 1865, he fell ill and died. In such cases, there was little interest in the precise cause; it was explanation enough that he was a British engineer working in the tropics. Stewart was then 32 years old ❧

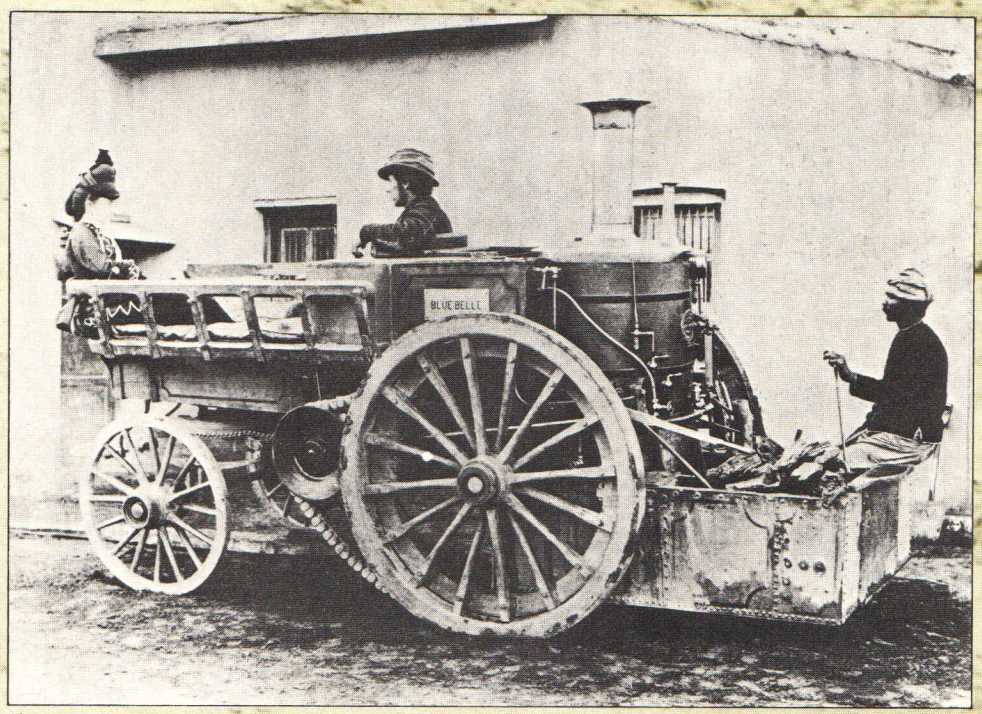
THE WELDING OF INDIA

The soldiers and statesmen of the British Raj brought a certain unity to the Indian states, but it was the engineers who really laid the foundations of modern India. By building good metalled roads, such as the mammoth, east–west Grand Trunk Road started in 1839, they began to open up the country. It was along this road that R.E. Crompton, later famous as an electrical engineer, pioneered a new form of transport, the road steamer. His contraptions, illustrated on this page, far outclassed bullock haulage. But they were lost in a welter of engineering advances stimulated by Lord Dalhousie, who as Viceroy in 1848–56 had set up India's first Ministry of Public Works. By the 1870s a vast railway network and an equally vast irrigation system had become the most powerful forces for the prosperity and unity of India.

Crompton drives a party of dignitaries for a trial run in 1871 in *Chenab*, which soon replaced bullocks on the Grand Trunk Road, pulling "Government Steam Trains."

The *Ravee*, a monstrous, 100 horsepower road steamer that went into service in 1872, prepares to haul a train of wagons and a passenger coach along the Grand Trunk Road near Rawalpindi. R.E. Crompton, who designed the machine, watches proudly (foreground, right), though suffering from a workshop injury with his arm still in a sling.



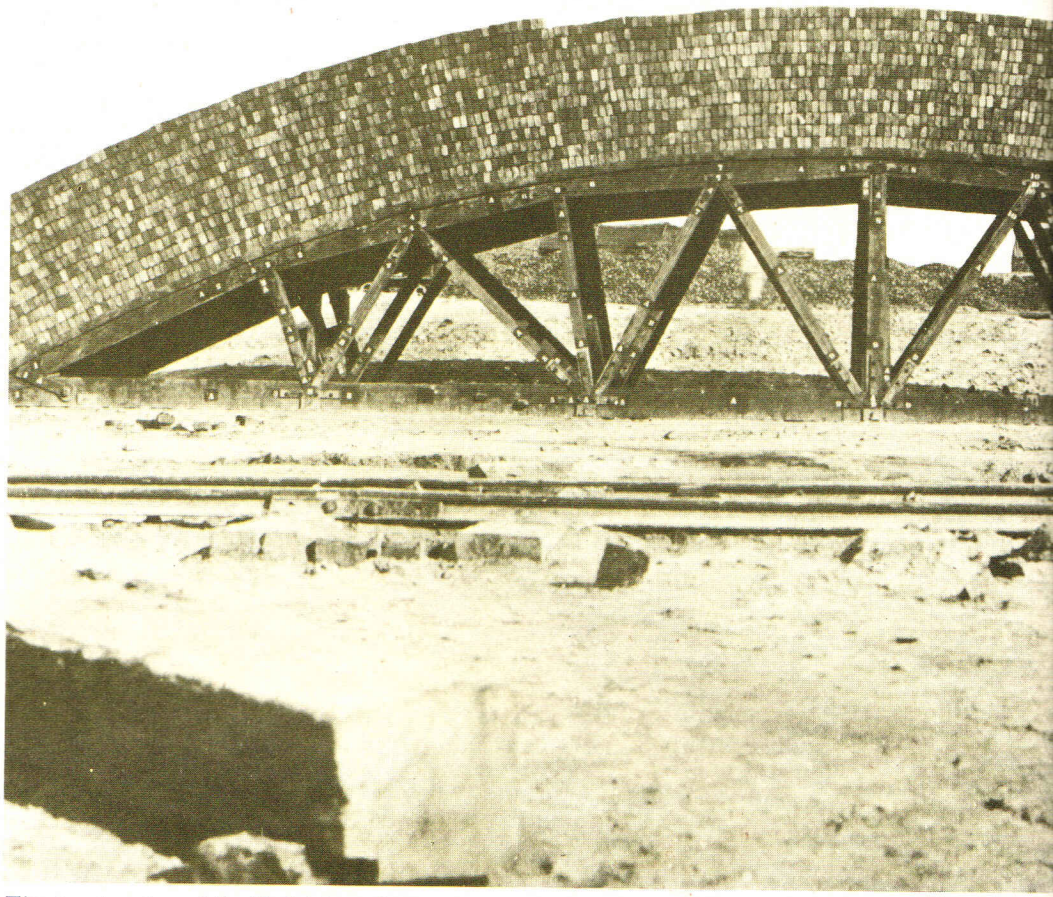


Crompton sits with his wife on his beloved *Bluebell*, the road steamer he started building when he was at school at Harrow. It was the first powered vehicle used in India.

Watering the Wastelands

The British could be justly proud of the great irrigation systems of India, particularly in the north. In one of the earliest and most massive projects, the Upper and Lower Ganges systems, over 8,000 miles of running water drawn from the Ganges flowed in canals through the state of Uttar Pradesh, transforming the desert between Delhi and Allahabad into fertile land. Lord Dalhousie, the reforming mid-Century Governor-General, described the achievement as "unequalled in its character among the efforts of civilized nations." It was true. And as the illustrations on these pages show, the engineers grew increasingly ambitious. The second Nadri Aqueduct, built across the Kali River not far from Delhi, was four times larger than the original one washed away by floods in 1884–85.

Another great project was in the Punjab, in the north-west, where rain was so sparse, it was said, that, even when it did fall, it would water "only one horn of a buffalo." The new irrigation system, planned in conjunction with railways and modern villages, turned the area into the most prosperous in India.

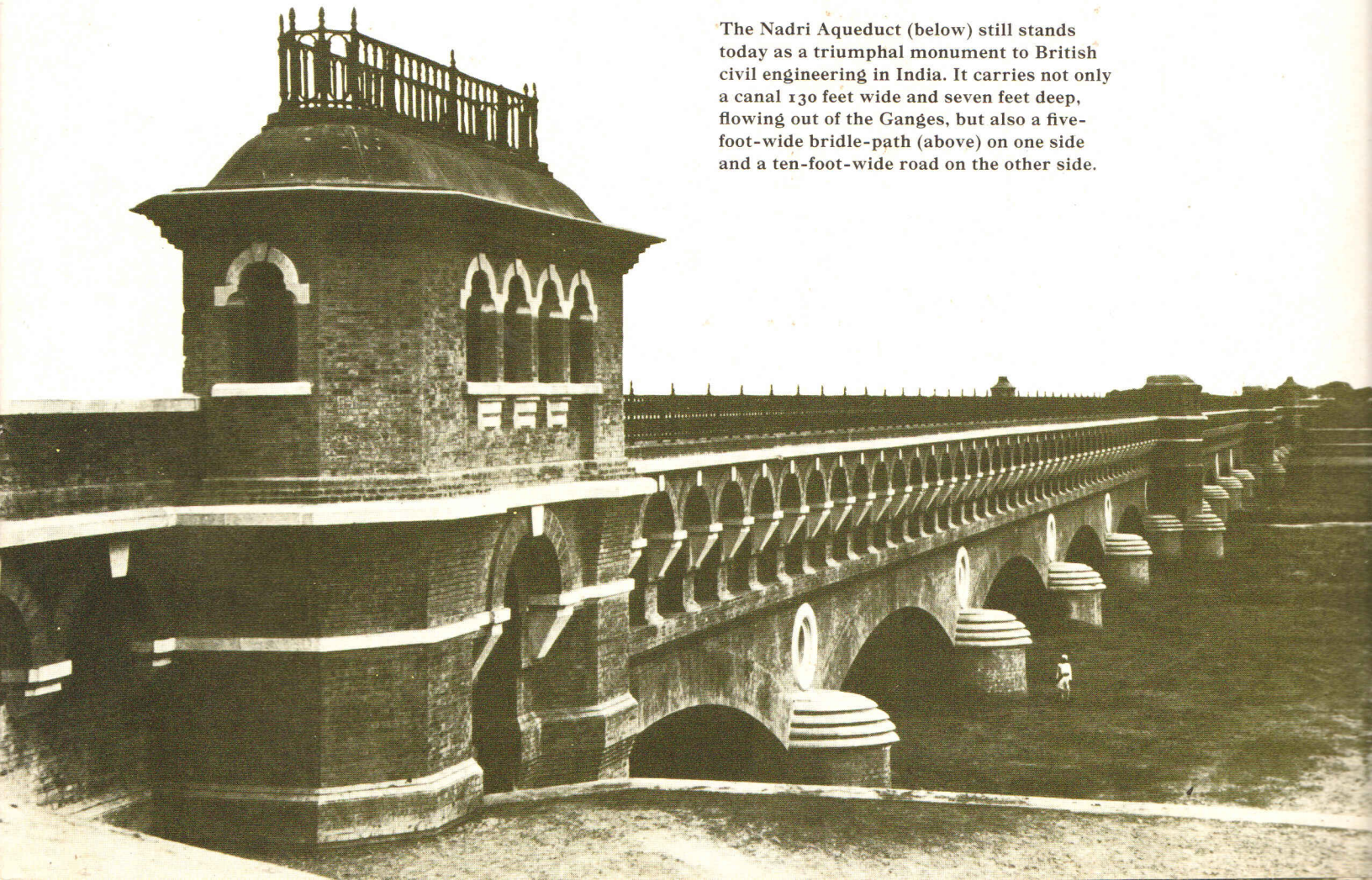


The great arches of the Nadri Aqueduct were constructed on supports which enabled each completed

Workmen swarm busily over the half-completed arches of the Nadri Aqueduct, laying some of the 58 million bricks it took to complete them.

section to be moved bodily on tramrails.

The Nadri Aqueduct (below) still stands today as a triumphal monument to British civil engineering in India. It carries not only a canal 130 feet wide and seven feet deep, flowing out of the Ganges, but also a five-foot-wide bridle-path (above) on one side and a ten-foot-wide road on the other side.



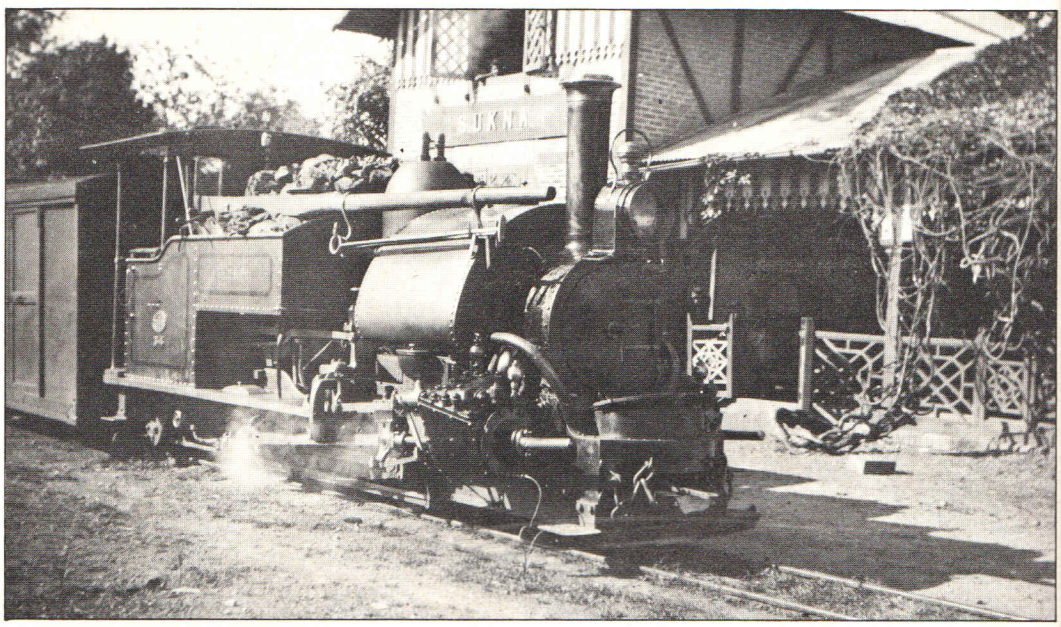
The Chappar Rift railway bridge, 233 feet above the ravine, was part of the line that was virtually the only way into the hostile lands on the southern borders of Afghanistan.

Tracks to the Future

Probably the most decisive act of Lord Dalhousie as Governor-General for India's future was his encouragement for the building of the railways. By the time of the Indian Mutiny in 1857, 200 miles had been laid. The military advantages of fast troop movements which became clear at the time did much to speed their development. By 1947 there were 43,000 miles of track in India and Pakistan, and about 900 miles in Ceylon.

Railways were vital for the economic development of the country because they could carry raw materials and finished products quickly and cheaply round the vast subcontinent. After 1850, the jute and cotton, coal and iron and the plantation industries developed fast. Famine relief, too, was revolutionized by the building of railways to bring food.

But perhaps the most important, though less obvious change the railways brought to the economic life of India was the breaking down of the tightly knit traditional village communities. As Indians became aware of opportunities and new life styles elsewhere in the subcontinent, India slowly began to acquire the labour mobility and modern outlook essential to a developing country.



A mountain train on the line from Calcutta to Darjeeling draws into a station. The struts on the building, reminiscent of timbered Tudor houses, are to prevent damage from earthquakes.

On this zig-zag descent near Poona, all trains were supposed to make a safety halt on the approach-line (left, hidden by rocks). Those that arrived too fast came to rest on the catch-siding (centre), and reversed back to the main line before going on their way.

The Walsh-Lovett Commissariat Railway, used mainly for bringing supplies to troops at the front, had tracks that could be lifted up and quickly moved as needed.

The Sensation Rock Incline of Ceylon was so named because of the spectacular drop of the mountain on which the railway was built. However the tracks themselves, switch-backing down the mountain, did not have an incline of more than 1 in 25.

III. The Eighth Wonder of the World

After the death of Patrick Stewart, the work of laying a telegraph cable from India to Britain was carried on by yet another Addiscombe graduate, Sir John Underwood Bateman-Champain, who was then in Teheran wrangling over the construction of the Persian section. The Persians insisted they would build it themselves, and would permit only one English officer to enter the country to direct the work. They were enraged at the "cool impudence" of the 30-year-old engineer when he arrived with three officers, 12 N.C.O.s and six civilians. They gave him five months to complete the 1,250-mile line.

One of his officers was Major William Henry Pierson (again, from Addiscombe), an engineer with a reputation for being a high-class chess-player, master of the piano, concertina and cornet, fine actor, excellent Hindustani scholar, outstanding architect, and "a mighty pig-sticker." He was also, luckily, a good shot. One day he was attacked by 20 Persians. His servant was killed almost immediately, but Pierson coolly fought them off single-handed and was able to proceed, carrying his servant's body across his horse.

Charmed by Bateman-Champain, the Shah eventually gave the project his support. When one remote tribe discovered the insulators on the poles were excellent for target practice, and did damage that required a month's work to be redone, he sent down a personal aide with a detachment of soldiers to administer justice. After the offenders were fined, and their village plundered for good measure, there was no more trouble with the line in that area.

Bateman-Champain could have as easily been a diplomat as an engineer. In St. Petersburg, negotiating for the line through Russia, he became a favourite of the Tsar. The concession was granted, and by 1869 messages which had taken three months were passing from England to India in twelve hours.

The wires with which British engineers were festooning the world created a wealth of new business opportunities, some unusual. Brahmin signal boys on the India-to-China telegraph cut a lonely stretch of the line and took the severed ends into a tent, where they had sending and receiving machines. They intercepted and passed on message after message from China until the Hong Kong opium quotations arrived.

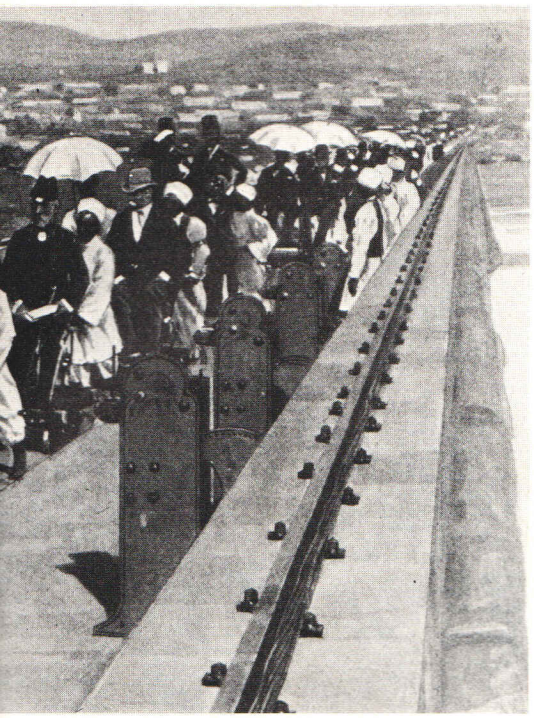
These they sent privately to an opium speculator who, if the Hong Kong price had risen, would buy up all the stocks in the Indian bazaar. When the signal boys later relayed the quotation on the public wire, he would sell at a fat profit. The conspirators were caught and punished, but not before they had built a nice stack of rupees out of this particular wonder of modern science.

There was one field in which an engineer, if he was lucky, could grow rich: mining. Many of the men who sailed from Great Britain to seek gold in South Africa or copper in Australia were not qualified engineers, of course. Until late in the 19th Century mining was less a science than a trade, or a gamble. The miner did not need a degree, but he required a large amount of fortitude.

"No more wretched existence can be imagined than that endured by the early diggers," wrote an engineer of the South African diamond-fields. "A malarial fever raged, water was dear, and bad, being carted in barrels from adjacent farms (even after wells were dug, it sold for as much as ten shillings a barrel) and so scarce I have seen diggers wash in soda water which has been imported 700 miles from Capetown."

South Africa owes its position as the world's richest gold-producer to a Glasgow man, J.S. MacArthur. Only three years after the rush began, in 1889, the gold-mines of the Rand hit a pyritic zone. This meant trouble. The processing mills were unable to extract enough gold

Herbert Kitchener (seated right) established his reputation as an able and conscientious soldier while acting as an Engineer on this survey in the island of Cyprus in 1878.



Travelling on trollies, British and Egyptian dignitaries inspect the mile-long Aswan Dam after opening it in 1902. It created a vast reservoir to water Upper Egypt.

from the pyrites, and began closing down. One-third of the houses in Johannesburg were soon on the market, and the town square was jammed with second-hand furniture for sale. The boom appeared to be over.

In 1890, MacArthur came to town with his new cyanide process. Watched by the industry's representatives "to make sure there was no humbug," he fussed with his vats and pipes and a sample of ore for two days and nights, until a gold ingot emerged from his little portable furnace. He had achieved 98 per cent extraction. The Rand was saved.

Britons were just as important to Australian mining. Cornishmen flocked down under, and their Cornish boilers, Cornish pumping engines and years of experience transformed the haphazard diggings into a rational industry. They were not always welcomed. At Ballarat, one had to defend his steam-pump with firearms because other miners thought it gave him an "unfair" advantage.

Richard Henry Hancock migrated to Australia in 1859 and became manager of its largest mine. His innovations made it the most mechanized and progressive in the industry. "Captain" Hancock became a legend. He was a religious man and a reformer, compelling his illiterate miners to attend four sessions of night-school each week before he would let them work the following week. Not very popular as a preacher in his church, Hancock had a pulpit built in his office and stood in it dictating letters and instructing foremen.

Among such British paragons there were, naturally, some rascals. An engineer from Somerset named William Bailey induced his boss to accept a stranger's offer of £13,500 for the Mount Egerton Mine, saying if he himself "had a cart of gold, I would not give more for it." Then as soon as the deal went through, a rich vein was "discovered," and it was revealed that Bailey had a secret partnership with the new owner. In just two and a half months his own share of the profits was £30,000.

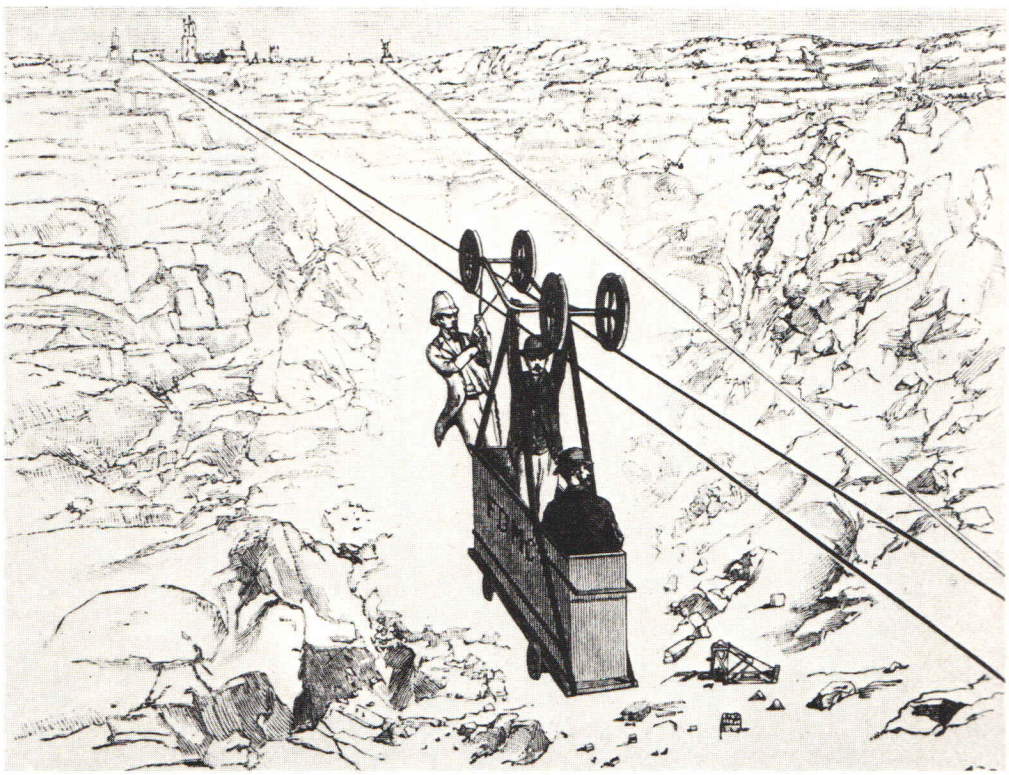
Accused of fraud, Bailey was so hurt that he wept, and was known thereafter as "Weeping" Bailey. He won the ensuing lawsuit – as he had "lost" the mine records nothing could be proved – built a fabulous mansion, and owned race-horses which twice won the Victoria Derby. Twenty years later, however, nemesis struck when a bank that he founded failed.

Often, engineers' work was the most important event in the current history of the country involved. Such was the Great Nile Dam at Aswan – not the one recently built by engineers from that other, newer empire, the Soviet Union, but the first one, which was completed in 1902.

To gain a foothold in the Nile, William Willcocks tried lowering four-ton stones into the stream. The water, which he said "rushed at a pace exceeding the fastest University crew," tumbled them away like children's bricks. He wired several stones together in a "basket," but even these could not withstand the torrent. Finally, he lashed them on to railway trucks, 50 tons at a time, and shot the loaded trucks down an incline into the river. They lodged.

When the one-and-a-quarter-mile-long dam was finished, it formed a lake stretching the same distance as London to Nottingham and sufficient to provide the entire population of Great Britain with water for a year. It gave Egypt 8 million irrigated acres and made that country wondrously rich for more than a decade – until the population caught up with the improvement. It was called the Eighth Wonder of the World.

Thanks to British engineers, the world was getting a surfeit of Eighth Wonders. Another Eighth Wonder was the Victoria Bridge which opened in 1859. Built by Alexander M. Ross, it carried a Canadian railway across the St. Lawrence at a point



Sir Hercules Robinson, Governor of Cape Colony, seated snugly in a cable-car, swoops over the "Big Hole" at Kimberley during a visit to the South African diamond-mines.

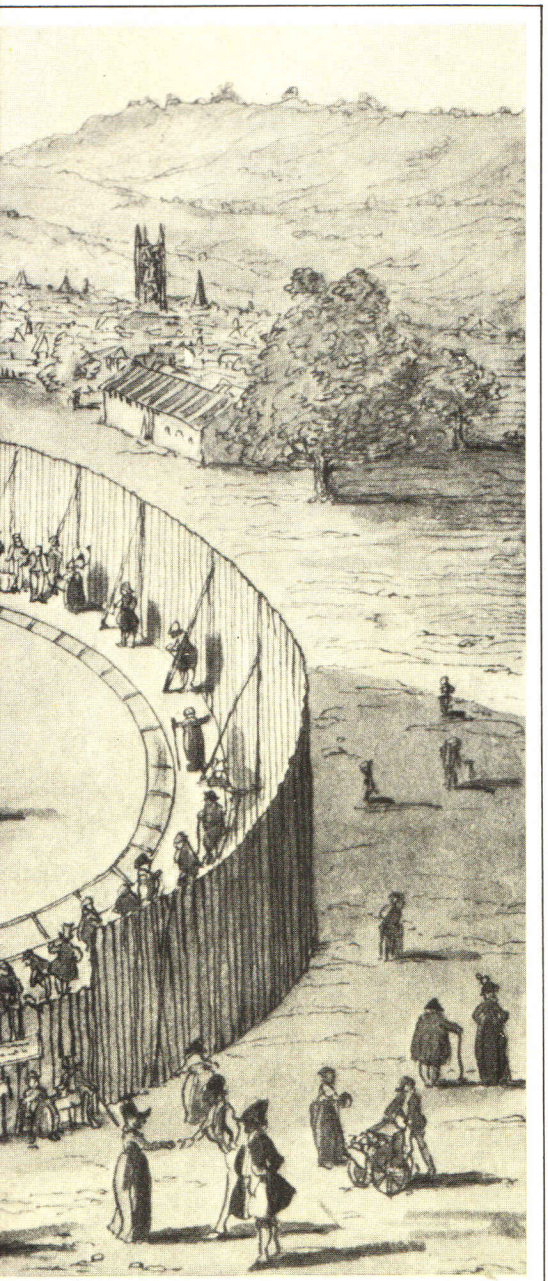
Steam Conquers the Empire

"The armies of the English ride upon the vapours of boiling cauldrons, and their horses are flaming coals," said the Turkish pasha in *Eothen*, a tale of travel in the East by the Victorian historian, Alexander Kinglake. It was a startling description of a locomotive revealing the wonder of non-industrialized peoples at the immense power of steam. That power, driving the railways, was as important to Empire as the Maxim gun.

Railways were a British invention. The first steam locomotive to run on rails was built in 1804 by a Cornishman, Richard Trevithick, and in 1808 he demonstrated an engine in London (right). But inexplicably, he then lost interest in steam locomotion and the title of "Father of Railways" went to George Stephenson, who built the world's first public railway from Stockton to Darlington in 1825. By the 1840s, railway-building had become a country-wide British mania.

Soon afterwards, the British railway boom spread rapidly into the virgin lands of Empire. Lines financed with British money, surveyed by British engineers and equipped with British rails and rolling-stock stretched into every corner of the globe. By the turn of the century, Britain had laid down over half the railways in Asia and five-sixths of those in Africa.

Without railways, vast areas of the Empire would have remained unsettled, untapped and perhaps uncontrolled. The horses of flaming coals brought trade and communications to the remotest wilderness, and troops to far-distant trouble-spots. Grand conceptions of epic new railways fired the British, especially Cecil Rhodes whose vision of through trains from the Cape to Cairo, though unfulfilled, was one of the most romantic dreams of the Railway Age. Many such projects were completed, and they are among the grandest achievements of Empire.



Richard Trevithick's locomotive *Catch Me Who Can* (above) performs for London spectators near Euston Square in 1808. It never went faster than 12 m.p.h. and frequently cracked its cast-iron track. Almost a century later the *Cecil J. Rhodes* (left) inaugurated the Umtali to Salisbury section of a line planned to run through British territory from the Cape to Cairo – but blocked by German East Africa which lay across its route.

where the river was two miles wide, an alarming distance in those days. American engineers hooted at Ross's scheme, saying blocked ice would topple the bridge the first winter.

It consisted of a huge rectangular tube resting on masonry piers. The ironwork was made in England in numbered sections, and shipped to the assembly site. The Prince of Wales, later Edward VII, opened it, and the ice did not bring it down. In fact, 25 years later other engineers found it perfectly capable of carrying a road-bed twice as wide as the original one. Their only complaint was the durability of Ross's work; they said it was easier to build the new part than to cut away the old.

Railways, with their bridges and tunnels, were the British speciality. They built them everywhere they were allowed to, and some places where they were not. Lord Napier took a complete railway with him when he sailed to invade Ethiopia in 1868. Lord Kitchener, himself an engineer, laid one on his way to Khartoum. Cecil Rhodes's most pressing imperial dream was to link up with that line from the other end of the continent, a dream he never realized.

British engineers had a knack for getting round small budgets with ingenious improvisation. Building a railway in New South Wales, John Whitton had to negotiate a steep precipice. Tunnelling would have solved the problem, but the Governor disallowed funds for that, suggesting instead that Whitton lay tracks on the existing highways and have horses pull the railway cars. That, needless to say, was no answer for a railway-man. Instead he built a gigantic zigzag. The train ran forward down one incline, stopped while a switch was thrown behind it, ran backwards down the next incline, stopped, and so on, traversing three miles of zigzag track to drop 600 feet, a gradient of 1 in 26.

The British railway-builder was ubiquitous. Richard Trevithick, in South America on a mining venture, planned a line from Lima to Callao as early as 1817. Had he been able to raise the finance, the world's first public steam railway would have been built in Peru rather than in Britain. British engineers tried to get permission to build the Trans-Siberian Railway, but the Russians insisted on waiting until they were capable of doing it themselves.

In China the British would not take no for an answer. The Chinese government, suspecting – no doubt correctly – that foreign railways would mean more foreign influence, rejected scheme after scheme put forward by British engineers between 1860 and 1875. Finally, one company got permission to build a 12-mile road from Shanghai to Woosung, without specifying what kind of "road" they intended to use to link the two towns.

As soon as the "road" was finished in January, 1876, Mrs. Gabriel James Morrison, the wife of the British engineer in charge, ceremonially laid the first rail on it. On February 14, a tiny, 22-hundredweight engine – all the syndicate could afford after paying for the land – made the first steam railway run in China, over three-quarters of a mile of completed track. Li Hung Chang, the Imperial Governor of the province, heard the news and ordered the British to desist. They agreed not to run the train for a month while he checked with Peking, but continued work on the track.

No word came, and the engine resumed operating. *The Times* reported that "literally thousands" of Chinese turned out to watch every day. On June 30, with a larger engine diplomatically named *Celestial Empire*, the first five miles to Kangwan was opened. Three days later, commercial service began: six return journeys daily, and all packed. Smelling success, the company ordered more cars. Their confidence, however, turned out to be premature.

On August 3, while travelling at 25 miles an hour, the engine driver saw a Chinaman walking on the tracks. He tooted his whistle, and the man moved off, but then suddenly turned and threw himself in front of the engine. The company suspected the authorities had hired the suicide to discredit the line, but could not prove it. The public grew angry; riots were threatened; and Her Majesty's Resident Minister, Sir Thomas Wade, ordered the railway closed.

Li Hung Chang, the Governor, said permission for a railway had never been given. The company replied that as China had no railway regulations, no one

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CLEOPATRA'S NEEDLE

One of the most dramatic engineering feats performed by the Victorians was the removal of the pink granite obelisk, known as "Cleopatra's Needle," from Egypt to Britain in 1878. The monolith, 70 feet high and weighing nearly 200 tons, had been presented to the British people in 1819 by Muhammad Ali, Viceroy of Egypt, in gratitude for Britain's expulsion of Napoleon from Egypt.

The Needle had led an errant life. Fashioned for Thotmes III in 1460 B.C., it was built at Aswan and shipped 700 miles down the Nile to Heliopolis and erected outside the Temple of the Sun. Then, many centuries later, and traditionally on the orders of the beguiling Cleopatra, it was uprooted and carried off to the Palace of the Caesars at Alexandria.

When Ali presented the Needle to Britain, it lay buried on the town's beach. Nobody seemed willing to put up the money to transport it to England, and not until General Sir James Alexander – a distinguished soldier and explorer – went to Egypt in 1875 to bring it home for the nation was it dug out of its sandy grave.

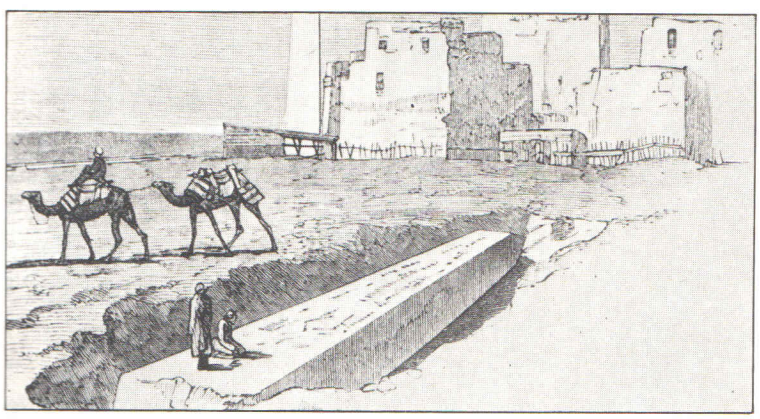
Alexander met an engineer named Dixon, who convinced him that the Needle could be cocooned in a round iron hull, rolled into the sea and with the addition of a deck and rudder towed to Britain. Sir Erasmus Wilson, a wealthy doctor and Egyptian antiquary, offered to finance Dixon and soon the craft was on its way in sections to Alexandria. Reassembled with the precious monolith inside it and named *Cleopatra*, it measured 93 feet long and "looked like an enormous boiler with the ends sloped off," as the General observed.

An artist's impression shows Cleopatra's Needle outside Parliament, a controversial site that was soon rejected.

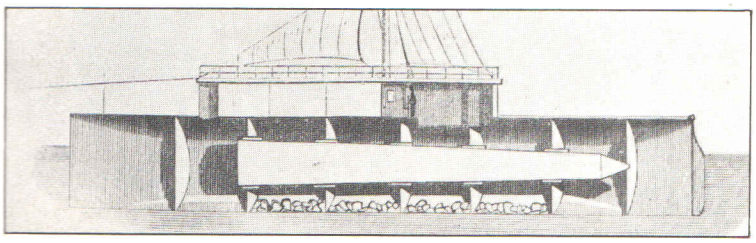
On September 21, 1877, with the Liverpool steamer *Olga* pulling her, *Cleopatra* forged out into the Mediterranean. All went well until the two ships ran into an Atlantic cyclone in the Bay of Biscay. Then disaster struck. The *Cleopatra*'s ballast of rails shifted, causing her to list dangerously, and the tow rope had to be slipped. Six men who put out in a boat from the *Olga* to rescue her crew were drowned.

When at last *Cleopatra*'s crew had been taken off, *Cleopatra* herself disappeared. It was only after some days that a Glasgow steamer found the abandoned vessel and towed her into El Ferrol to await a tug.

Finally, in January, 1878, the Needle arrived in London and, after months of furious debate over the siting, was eventually erected on the Embankment beside the River Thames.



The obelisk had to be dug up before it became *Cleopatra's* cargo.



A section through the *Cleopatra* shows the Needle secured by wooden wedges. The ballast below consisted of 12 tons of old iron rails.

The *Cleopatra* signals her towing vessel to go faster. Her bluff nose, which plunged deeply in swell, made it tricky to find the right speed.

During a storm in the Bay of Biscay, the *Cleopatra's* crew prepare to abandon ship and jump down into a boat sent out on a line from the Olga.

The paddle-tug *Anglia* retrieved *Cleopatra* from El Ferrol and towed her back through still stormy seas to the safety of the East India Docks. .

could say that this was not simply a "road." The dispute was settled by the government buying the line in instalments, allowing the company to complete it and operate it in the meantime.

In October, 1877, the final payment was made and the Chinese took over the railway, which by then ran all the way to Woosung. They immediately closed it, ripped up the tracks and shipped rails and engines to Formosa where they were left to rust on a beach. On the site of the Shanghai Station, they erected a temple to the Queen of Heaven. China, said Li Hung Chang, would have a railway when it was ready to build one for itself. A decade later it did, with the help of other British engineers.

As the 19th Century rolled towards the 20th, British engineers faced stronger and stronger competition from others, particularly Americans. They had not lost their expertise, but its exclusiveness began to slip as knowledge and technique spread. In Australia, Cornish miners were being replaced by graduates of Australian mining schools and Americans. Even a London consulting firm sent American engineers to work there; one was Herbert Hoover, later President of the United States. After J.S. MacArthur tried but failed to solve a copper-extraction problem in Australia, as he had that of gold in South Africa, an American devised the necessary process.

Building a railway in Burma, the British turned to an American firm for the most difficult task, the fantastic Gokteik Viaduct spanning a deep, half-mile-wide gorge. The construction of one of Empire's greatest triumphs, the Canadian Pacific Railway – which kept western Canada British and at last provided an "all-red" route to the Orient – was actually directed by an American engineer, William Van Horne. Now there were Arthur Cottons all over the world dreaming up canals at breakfast time.

The old pioneer himself was still busy trying to convince the British government to build more dams and canals in India, and less railways. The famines which kept recurring there seemed to substantiate his argument. "A patient is bleeding to death," he wrote in one of his many pamphlets, "and a spectator begins a long discourse on the best mode of treating him so as to restore his strength, but another says, 'Stop a minute, let us first stay the bleeding.'"

In fact, the bleeding was being stayed. Before Sir Arthur died, India had 55,202 miles of canals; by 1947, 70 million acres were irrigated there, three times as much as in the U.S.A. and a greater area than in any other ten countries put together.

Towards the end of his life, the man most responsible for this great achievement lapsed into another of those 19th-Century English roles he performed so well: this time, the old eccentric tinkering with his inventions. His strange experiments with a brass canoe made his family frantic with worry. And on the roads around Woodcot, his home near Dorking, he terrorized passers-by with a man-sized tricycle he was trying to perfect.

"Now you just watch me," he told one stranger, "and tell me how many turns this wheel makes in a minute." With that, the 70-year-old man wobbled down a hill, hit an embankment, and flew over the handlebars into a hedge. When the concerned stranger ran to his aid, Cotton waved him away. "Look after the machine," he said. "I can take care of myself." His wife begged him to get rid of it but he told her: "Rome was not built in a day. It will take me a long time to complete my patent brake." Learning of a missionary who lacked transport, Cotton made the noble sacrifice and sent his tricycle. The missionary returned it to him, after breaking an arm.

The Cottons managed to die in the same marvellous Victorian style in which they had lived. Galsworthy would have needed only a stenographer. Richard, the brother who became Provost of Worcester College, Oxford, at table one evening "raised his hands in adoration, and in a low voice began to utter sentences of praise and gratitude to God for all His goodness to him during a long life." He then fell forward, dead, into his dinner. Sir Arthur himself made his last public utterance in the letter columns of *The Times*. It was another condemnation of the government for "giving India iron instead of water." He died a few days later, June 14, 1899. In his lifetime, he and others like him had linked the past and future with a road of iron. And in a coffin draped with a Union Jack he was lowered into the soil of a very different world than the one he had been born into, a new world which he and other engineers who sprang from Britain had created.

In a *Punch* cartoon of 1853 the Chinese block the path of progress symbolized by a locomotive, cursing it as a "Great barbarian dragon!"

A foot soldier, 1793