Construction History Vol. 12. 1996

Colonial Connections: Royal Engineers and Building Technology Transfer in the Nineteenth Century

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Introduction

During the nineteenth century, officers of the Corps of Royal Engineers carried out construction duties for the army and a number of civil service departments, both in Britain and its overseas colonies. In the course of their colonial assignments, Royal Engineers played an important role in the global diffusion of advanced building technology. Surprisingly, this significant historical phenomenon has been barely explored by scholars.

Engineer officers had considerable theoretical knowledge gained from education at the Royal Military Academy, Woolwich and further studies at the Royal Engineer Establishment, Chatham. And, although officers of the Corps were not as well trained in practical skills as civil engineers, they proved particularly adept at learning on the job. The application of Royal Engineers' knowledge in the colonies involved a complex interaction of European experience with indigenous environments, traditions and skills. Through several case studies, this article illustrates how military engineers contributed to the process of building technology transfer in various seats of Britain's colonial empire.

R. A. Buchanan has shown how British civil engineers moved into foreign lands from the late 1830s, carrying with them the influences of advanced technology. This movement of skilled persons overseas was not the result of a conscious strategy of government or other central authority but rather the consequence of individual decisions and aspirations. Civil engineers' impact varied greatly depending on the receptivity of the host country or territory and on its ability to assimilate Western technology.[1]

It has not been generally recognized, however, that military engineers were well ahead of their civil engineer countrymen in establishing a significant presence in foreign territories. British colonial adventures were well underway in the Caribbean by 1700 and military engineers served there as part of the armed forces, especially in the construction of naval dockyard defences. Military engineers were active in India from the mid-eighteenth century as a separate branch of the army in the service of the East India Company. From 1798, officers of the Indian corps (Bengal, Madras and Bombay) received part of their training and kept in close contact with the Corps of Royal Engineers, and were amalgamated with it in 1862. The British conquest of Quebec in 1759 brought the Engineer Corps of the Ordnance Board to Canada; the Royal Engineers took over in 1787 and by the beginning of the nineteenth century they were well established. Royal Engineers were first sent to Australia in 1835 to build military garrisons, convict establishments and public works.

Military engineers were a deliberate instrument of British imperial authority. Control was exercised principally by the War Office, the Admiralty, the Colonial Office and the East India Company. Engineer officers usually had little or no choice in their posting and regularly played a variety of roles – military commanders, governors and officials, builders of military works, and staff of public works departments. As instruments of British imperial policy, their engineering work was affected by a number of factors: the purpose, timing and duration of their colonial assignments; regulations respecting the procurement of materials, building standards and other aspects of construction; directives on plans and specifications for certain building types; and the policy and procedure for project execution, including source of labour and contractual arrangements. At the same time, they shared with the private sector the problems of working on the frontiers of European overseas expansion – remoteness from an established scientific community, lack of testing and experimental facilities, absence of manufacturers, and a chronic shortage of skilled labour.

Materials Testing

Perhaps the most fundamental aspect of the engineer officers' role in the global diffusion of building technology was the testing and application of new materials in the colonies. Experimentation with limes, cements and concrete led the way. It was stimulated to a great extent by the publications of General Charles Pasley, Director of the Royal Military Establishment at Chatham.[2] Pasley undertook extensive experimental work on cementatious materials during the 1820s and 1830s. This followed upon the development in the late eighteenth-century and first two decades of the nineteenth of hydraulic limes and cements, initially natural and then artificial. These were stronger and more durable than ordinary lime mortar and were used principally as mortars for engineering works under water, in mortars and stuccoes for building brickwork and, in the case of hydraulic lime, for mass concrete in foundations and in backing masonry retaining walls. British military engineers stationed in the colonies nevertheless exercised considerable initiative on their own and often consulted other sources besides Pasley, particularly the writings of French experts.

One of the foremost engineer officers in the colonies to experiment with limes and cements was Captain John Thomas Smith of the Madras Engineers. In 1837 Smith published a translation of Louis J. Vicat's seminal work on artificial limes and other cementatious materials (1828) under the revised title, *A Practical and Scientific Treatise on Calcareous Mortars and Cements, Artificial and Natural.* The translation included certain valuable contributions based on Smith's own experiments. It was only the second work in English on mortar and cement (the first being by Higgins in 1780) and was well received by civil engineers and architects.

From Vicat, Smith developed a preference for hydraulic limes, the French practice, over the English choice of natural cements or artificial cements advocated by Pasley and others. Smith emphasized the advantages of hydraulic limes over natural cements. Whereas natural cements were made from stones which had to be pulverized by machinery at specialist manufacturers, hydraulic limes could be produced without grinding the raw material and could be employed by the mason himself or by an ordinary workman, and at about the same cost as common lime. On the frontiers of the empire in India, the use of hydraulic limes over cements was largely governed by the simplicity of the preparation process.

A new material with which Smith and others experimented in India was 'magnesia cement', more accurately described as a natural hydraulic cement made from magnesian limestone. Pasley tested specimens of magnesian limestones from northern England in the 1830s and found they had hydraulic properties.[3] Even so, Pasley was anticipated in discovering the hydraulic properties of magnesia by Dr. Macleod, a British colonist in India; the doctor first brought this to the attention of the Madras government in 1825. Tests were undertaken by the Madras Engineers, comparing a mixture of sand and magnesia cement with one of lime and iron stone as well as with common 'chunam plaster' (made by calcinating sea shells). After a heavy monsoon, magnesia cement proved strongest and hardest, and was thought to be fully equal to the English made Parker's cement.[4] In 1825 the cost of this remarkable material was about equal to Parker's product, but only 1/6th fifteen years later following the discovery of major magnesia deposits at Salem and Trichinopoly.[5]

Engineer officers in India were quick to take up magnesia cement for irrigation works, a field of engineering in which they were to make a major contribution to the "Jewel of the Empire".[6] Arthur Thomas Cotton of the Madras Engineers first tested the material in 1834. He made cubes of brickwork and found that "*... it set very rapidly, and in a few months it became so hard, that it was impossible to separate it from the bricks ....*"[7] Cotton later tried a great variety of experiments using magnesian limestone from various quarries and employing different proportions of sand and other additives. He first tried magnesia cement in plastering a dam for an irrigation channel. On the basis of his experiments and practical experience, Cotton had no hesitation in recommending and using the new product.[8]

Cotton was soon made responsible for the design of an important irrigation project, constructed in 1847-52, which included a great dam across the Godavery River at Dowlaish and an aqueduct of 49 arches of 40 feet span each. This undertaking was considered daring at the time.[9] By the mid-1850s Cotton had a reputation as " *... practically the great authority and referee on all matters connected with irrigation ....*"[10] Since effective hydraulic limes and cements were critical to irrigation engineering, the link between Cotton's experiments with magnesia cement and his dams and aqueducts is indeed significant.

Shifting the story of materials testing to Canada, Royal Engineers stationed in Nova Scotia demonstrated remarkable initiative in trying the relatively novel Portland cement for mortar, ahead of their brother officers at home. In 1851, the Commanding Royal Engineer at Halifax requested a supply of Portland cement but encountered incredulity from superiors in England. The Inspector General of Fortifications' office searched for a supplier and wrote back to Halifax asking to know why the product was wanted. This was understandable. Portland cement was first specified in a major project for the harbour works of Cherbourg, France in 1848-53. At that time the manufacture of the product was still confined to England and to six firms. Supplies of Portland cement requested by the Corps at Halifax were eventually procured from Messers. J.B. White and Sons, one of the largest and most reputable companies then making the material.

Portland cement concrete was specified for new fortifications at Halifax Citadel beginning in the early 1860s, slightly ahead of the mainstream of British military construction. The Royal Engineers in Nova Scotia resorted to concrete because of the lack of skilled labour for conventional masonry construction, and making a virtue of necessity proved quite successful. Initial concrete work was in the replacement of foundations for gun platforms, but shortly after it was used as a replacement for brick arches in galleries and for expense magazines at Fort Charlotte, Fort Ogilvie and the York Redoubt. Engineer officers soon felt confident in trying concrete above foundation level for an escarp wall at Fort Ogilvie in 1864. This predated by a year the concrete revetments at Newhaven Fort, the first use of mass concrete in fortification superstructures in Britain.[11]

Another central aspect of the Royal Engineers' materials testing in foreign lands was their experiments on the strength and durability of colonial woods. The theoretical basis for the Corps' tests lay in Peter Barlow's, *An Essay on the Strength and Stress of Timber* (1817) and Tredgold's, *The Elementary Principles of Carpentry* (1830). Barlow was clearly the major influence; he taught at the Royal Military Academy. Barlow's and Tredgold's works gave practical rules for the calculation of the strength and deflection of timber using the direct application of a mathematical constant which was derived from tests on small sections of comparable timber. Royal Engineers tested a variety of foreign woods in a host of colonial locations around the world. The Corps was also interested in gathering information by way of personal observation and through reports from local inhabitants. In many ways this was a more important contribution than their "scientific" experiments. Through their observations, close attention to local informants and testing initiatives, Royal Engineers encouraged the adoption of native woods for construction projects in foreign territories, and in some cases promoted the importation and use of these woods at home.

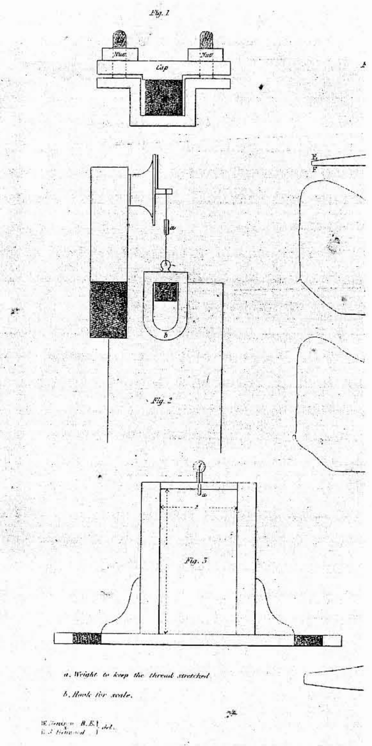

Fig.1: Denison's Apparatus for Testing Canadian Woods, from *Transactions of the Institution of Civil Engineers* Vol. II (1838)

One of the Corps' most interesting experiments on colonial woods took place in Canada. The engineer officer responsible for experiments on Canadian woods was William Thomas Denison, later founder and first editor of the Royal Engineers *Professional Papers*. Denison was stationed from 1827 to 1831 at Ottawa where he took part in the construction of the Rideau Canal. He undertook his timber testing in the last two years of this posting.

Denison's stated purpose was to establish some proportion between the strength of different kinds of North American timber, and then by reference to Barlow's test data, between these and European woods, in order to establish the constant factors which were part of the formulae for calculating the correct dimensions of timber for construction. He also hoped to ascertain the difference, both in dimension and strength, made by seasoning, or by age, or by position of a specimen in a tree.[12] Denison's testing apparatus consisted of two blocks of oak about 6 inches square by 4 feet high, mortised into a 3 inch plank and supported by struts (Fig.1). The blocks were tied together at the top by a cross bar which served to support at its mid-point a circular gauge for indicating the amount of deflection. A scale was suspended from the cross bar for holding weights applied as load on the specimens. Into the top of the uprights a groove was cut to receive the specimens. The groove was lined with iron in order to fix the ends of the specimens by screws and caps.[13] Denison's experimental process involved placing the specimen on supports of the apparatus and adding 20 lb. weights one at a time and measuring the deflection after each addition. Once it was thought that the limit of elasticity was reached, weights were added more gradually and allowed to remain longer, and the weight often was removed to see whether the specimen would return to its original state. When the limit of elasticity was passed, weights were added quickly until the specimen gave way. The specific gravity of the specimen was taken after the process was completed. Denison tested 26 species of Canadian woods. He resumed his experiments on Canadian woods at Chatham in 1833-34, using scantlings he obtained from the Admiralty dockyards. Twenty-three species were tested and results compared with those from tests on timber sent to Denison by Lieutenant-Colonel Brown from Ceylon as well as specimens from New Zealand, Van Diemen's Land, New South Wales and Rio de Janerio.[14]

On 27 February 1837, Denison presented a paper to a meeting of the Institution of Civil Engineers on his Canadian wood experiments, for which he was awarded the next year the Institution's prestigious Telford Medal.[15] Denison's paper was hailed by the award jury as an exemplary contribution:

> *"They pointed out the above communication with especial pleasure, as an example to other Military Engineers, of the very valuable services which their opportunities will enable them to render to the science of the Civil Engineers."*[16]

Notwithstanding the fact that Denison's experiments on Canadian woods were not of major scientific significance, his work did stimulate a considerable amount of research and discussion by the Royal Engineers at a number of the Corps' global stations. In his position as editor of the Royal Engineers' journal (under various titles, but generally known as the *Professional Papers*), Denison facilitated the publication of several articles on colonial timber testing.

In Western Australia, during the period 1851 to 1856, Royal Engineers Edmund Henderson, Edmund Du Cane, Henry Wray, and Edward Grain undertook a variety of experiments and recorded their observations on the use of 'jarrah' (eucalyptus), a wood native to the Swan River area. They found that this hardwood had properties which made it peculiarly applicable for works in the tropics and on sea coasts, because it was resistant to white ants and sea worms and extremely durable in a hot, moist atmosphere.

Captain Wray, with clerk of the works James Manning, made tests on jarrah for strength and elasticity at Freemantle and found it equal to Riga fir.[17] Henderson and Wray, possibly with Manning's assistance, specified jarrah for a laminated timber arch roof in the Freemantle Prison chapel (1857).[18] Wray used over 3,000 loads of the new material in buildings, jetties and bridges.[19] Captain Grain sent samples of jarrah to Frederick Able, Chemist for the War Department at the Royal Arsenal, Woolwich, to determine why this wood was so resistant to insect attack. Able concluded from experiments on mice that jarrah's resin was toxic and that its chemical properties probably were responsible for the wood's proof against white ant and sea worm damage.[20] Du Cane promoted jarrah as an ideal structural timber for tropical conditions and pointed out that its price was less than teak.[21] These Royal Engineers demonstrated notable ability to adapt local materials to considerable profit in Australia; they also established jarrah's credibility for Europeans through scientific experiment.

Bridges

Transportation technology was one of the vital tools of European expansion in the nineteenth century. The Royal Engineers constructed countless colonial transportation facilities; many were built primarily as military works in the service of imperial defense but several were conceived almost entirely as public works. Regardless of purpose, roads, railways and canals could not have been built without bridges. The design and construction of bridges tested military engineers' ability to respond to colonial environments and remoteness from home.

Colonel John By, best known for the Rideau Canal (1826-32), was the designer of the first substantial span over a major Canadian river. Construction of the canal at its Ottawa terminus required the erection of a chain of bridges to provide access to the forge and sawmill at the town of Hull across the Ottawa River. The longest and most significant span was a 212 foot wooden arch through truss over the "Great Kettle" of the Chaudiere Falls (Figs 2-3). Completed in March 1828, the bridge consisted of three sets of arches, 12 feet apart, forming a double roadway. Each arch was formed of two concentric curves connected by braces and king posts which formed a series of trusses from end to end. The lower string pieces were made of two thicknesses of red pine, making a rib 30 inches deep and 12 inches wide. Timbers were cut to the curve, scarfed and bolted together. Upper string pieces were made the same way only with smaller dimensioned timber. Braces were of red pine, king posts of oak, and the roadway of white cedar logs. Colonel By's bridge began to fail in the first year of operation. Captain Denison's diagnosis of the problem was that there was a lack of proper abutment for the upper string piece and a design flaw which threw all the weight on the lower string piece. New wooden braces and iron straps were added in 1829 but six years later the bridge had settled dangerously and it was proposed to strengthen it with chains. The bridge finally collapsed in May 1836.[22]

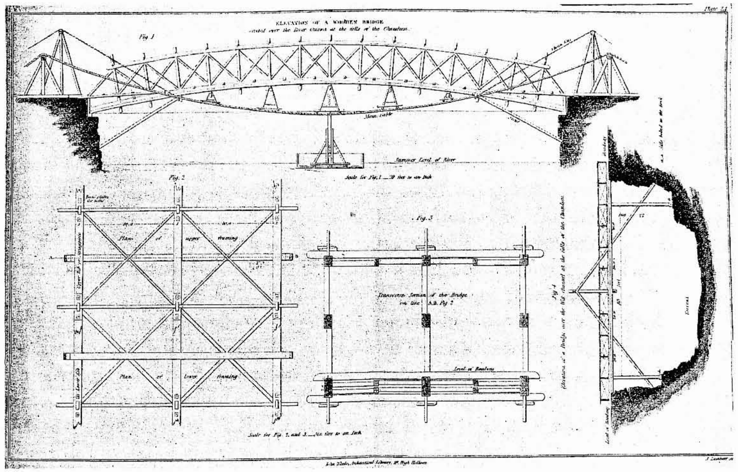

Fig. 2: Colonel By's Wooden Bridge, Ottawa, 1828, showing the method of erection, from *Papers on Subjects Connected with the Duties of the Corps of Royal Engineers* Vol. III (1839)

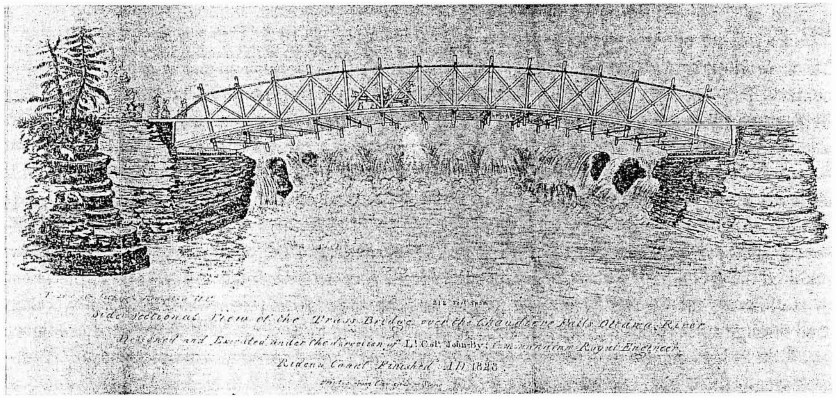

Fig. 3: View of Colonel By's Wooden Bridge. Engraving from sketches by John Burrows (Queens University, Special Collections, Kingston, Ontario).

By's wooden arch span was a type of early Palmer bridge with counter braces. Timothy Palmer of Massachusetts was the most distinguished designer of the through truss with panel bracing in American wooden bridges of the 1790s. It appears that By became familiar with American wooden truss construction during a posting in Newfoundland from 1802 to 1809. Later, while in charge of the main United Kingdom gunpowder mills, By made a model of a 1,000 foot span truss bridge of the multiple king post arrangement and exhibited it in the Repository at the Royal Military Academy, Woolwich and at the National Gallery of Practical Science. Rennie and Telford both commented on it. General Sir Howard Douglas spoke highly of Colonel By's celebrated model in his book *Military Bridges* (1853).[23]

Captain Denison succinctly explained the virtues of the bridge building material that By had adopted: *"In Canada, timber is cheap and easily wrought; people capable of executing all the common description of carpenters' work are easily found. On the other hand, iron work, especially heavy castings, are dear, and the difficulty of transporting them to points where they are required is very great, by which, of course, the expense is much enhanced ...."*[24]

Colonel By had clearly selected American wooden bridge technology for the Chaudiere Bridge because the advantage of such construction was obvious on the Canadian frontier.

A dramatic new departure was taken by military engineers in India during the mid-1840s. They introduced the British wrought iron chain suspension bridge. In the process, engineer officers became embroiled in the debate over the taper chain suspension system which had been patented in England by James Dredge.

The standard method of chain suspension bridge construction, called the "uniform system", featured an equal number of links between the pins giving the chain an unvarying cross sectional area throughout. In Dredge's design, the cross section of the chain decreased progressively from the points of suspension towards the centre of the span. The uniform system also had vertical rods whereas in Dredge's bridges the rods were at an oblique angle. Taper chain suspension bridges actually depended more on the longitudinal deck beams for strength and stability. Dredge claimed a superior strength to weight ratio for his system and made experimental models to demonstrate the system's performance in 1838 and 1840 which were much publicized in the technical press. Three years later he published a mathematical analysis and graphic statics to support his design. The civil engineering profession nevertheless remained sceptical about Dredge's novelty.[25]

The engineer officer most responsible for introducing the taper chain system in India was Major Henry Goodwyn of the Bengal Engineers. Goodwyn followed Dredge's example in using model tests and mathematics to prove the safety and efficiency of the taper principle. As well as other officers of the Bengal Engineers, Goodwyn designed and built or reconstructed a number of bridges on the taper chain system.

Goodwyn's first suspension bridge was a 250 foot span at Ballee Khal near Calcutta, begun in the spring of 1844[26] (Fig.4). In June 1845, Ballee Khal bridge partially collapsed during construction. A committee of Bengal Engineers was formed to investigate the incident and to report on the soundness of the principle which had been adopted in its design. While the committee deliberated, Goodwyn tried determining the cause of the failure himself through model tests and mathematical calculations. Essentially, he concluded that the principle itself was sound but that material needed to be added to the wrought iron longitudinal deck beam, the element upon which the strength of taper chain suspension spans most depended.[27]

Engineer officers in India had inspected a few taper chain suspension bridges before the partial collapse of the Ballee Khal bridge and some of the officers were not entirely convinced of the design's safety. Major Frederick Abbot of the Bengal Engineers, Superintending Engineer of the North West Provinces, was especially concerned about the soundness and safety of these novel bridges. In a letter he told Captain Denison that he had inspected a 120 foot span suspension bridge on the Dredge principle which had been erected at Meerut. Abbot said he was *" ... struck by the extreme tenuity of the wrought iron girders which in those bridges profess to do so much."*[28] He undertook graphic statics analysis of the taper chain principle but was not

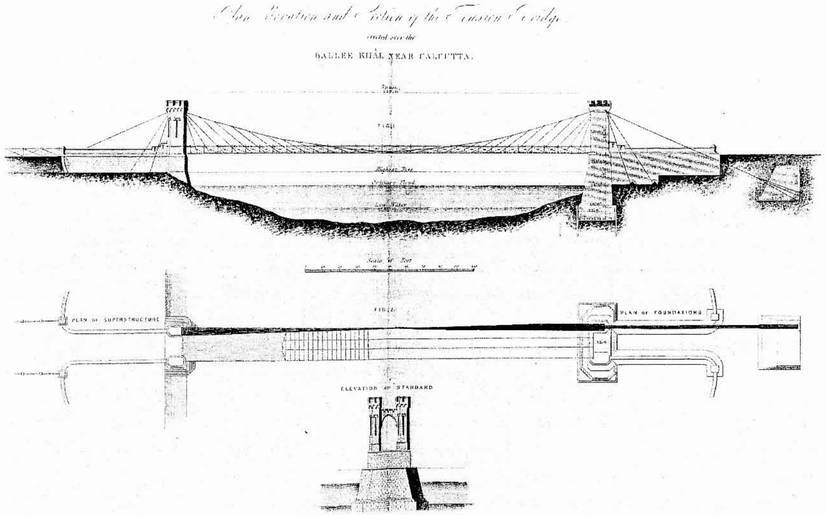

Fig. 4: Ballee Khal Bridge, Calcutta, 1845, from *Papers on Subjects Connected with the Duties of the Corps of Royal Engineers* Vol.IX (1847)

satisfied with this line of enquiry and asked Denison for help, complaining of his sense of isolation from the scientific world.[29]

Amidst this climate of uncertainty, Henry Goodwyn formulated his proposal for the reconstruction of the Ballee Khal Bridge. He wrote to Dredge in July of 1845: *"With the assistance of a very able and first-rate mathematician here, I have studied the theory of these bridges most thoroughly; and the model that I have made, 22 feet long and 4 feet width of platform is on so large a scale, that I have been able to test it in every possible way, and it withstood the utmost efforts to derange its parts."*[30]

The committee of Bengal Engineers which had been established to investigate the failure of the Ballee Khal Bridge agreed with Goodwyn's analysis of the taper chain principle and endorsed his proposal for reconstructing the bridge. Although it expressed doubts about model experiments in proving the soundness of engineering designs, the committee viewed the reconstruction of the Ballee Khal bridge as a means for Goodwyn to work out the details for applying this suspension bridge system at stations far from Calcutta where local Bengal Engineers would simply have to follow his instructions.[31]

During the period 1846 to 1849, Captain Goodwyn reconstructed six problem-ridden suspension bridges built originally on Dredge's taper chain principle. Despite the shortcomings of his applied research, Goodwyn had spearheaded the introduction of an advanced bridge technology to India and helped to keep alive the idea that a model could be part of an engineer's analytical equipment.[32]

Some thirty years later, Royal Engineers contributed to the diffusion of iron and steel bridge technology in India's northwestern frontiers through their road and railway works. The key figure was General James (Buster) Browne. In 1871 Browne took two years' furlough and travelled in Holland, Belgium and North America to study the art of iron railway bridge design. On his return to India, Browne was placed on special duty to construct iron road bridges in the Punjab and North-West Provinces. Amongst his projects was a suspension bridge (1873) across the Jumma River at Kalsi. It had a central span of 260 feet and side ones of 140 feet each, and was the largest span in India at the time.[33]

Browne's best known achievement, however, was with steel bridges on the Sind-Pishin Railway (1883-87). Many of these structures were designed, with his personal assistant, Colonel G.K. Scott-Moncrieff, as a series of short to medium span steel Warren truss girders resting on stone piers. The individual girders were designed and made in England, and simply had to be riveted together on the construction sites. Royal Engineers employed this ready-made, quick-assembly approach to secure a critical transport line along the Afganistan border in the face of a perceived threat of Russian invasion. Military engineers' first duty was often serving the needs of imperial defence.[34]

Prefabrication

Prefabrication was an ingenious and profitable solution to the building challenges of colonial expansion where local capacity could not supply needed accommodation or meet desired construction standards. It included two distinct yet often related developments – the wholly portable building, and structural components and frameworks. Pioneers of prefabrication worked with wood as well as with cast iron and wrought iron. The Royal Engineers made a remarkably early contribution with a system of prefabricated iron frameworks for barracks and military hospitals in the West Indies, first introduced in the mid-1820s.

Colonel Sir Charles Felix Smith, Commanding Royal Engineer in the West Indies, was responsible for proposing the system. On his arrival in 1823 he found that there were eleven different island colonies occupied by British troops but that he had only five Royal Engineers to direct the building and maintenance of military establishments. Mindful of his engineer officer staff shortage, the paucity of skilled building tradesmen in the West Indies and the usual factors of economy and efficiency, Smith proposed to the Board of Ordnance in 1824 " ... *a new system of barracks that should, as far as was practicable, insure uniformity of design.*"[35] It appears that Smith may have been the first Royal Engineer to propose a prefabricated iron framework for use in the colonies that would effectively tie together a structure of stone bearing walls (Fig.5). This carried to a logical conclusion the then well established use of iron components for the distinctive encircling galleries of barracks and military hospitals in the West Indies. Smith assigned Captain Henry Rowland Brandreth to the job of working out the details.[36] Brandreth was later to serve as Director of Architecture and Engineering for the Admiralty; in this position he would make major contributions to the use of structural iron in the naval dockyards.

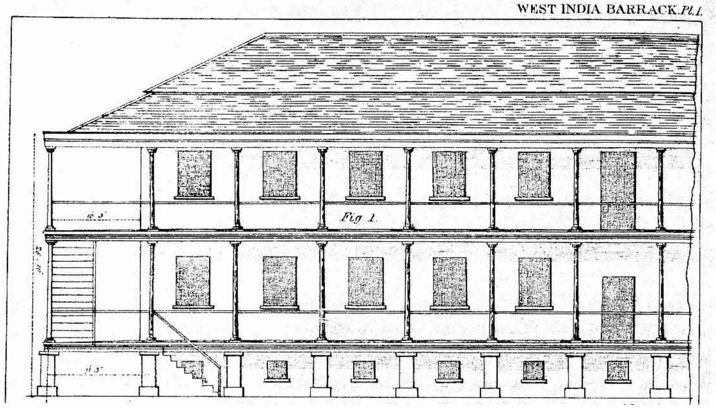

Fig. 5: Colonel Smith's Prefabricated Barracks System for the West Indies, from *Papers on Subjects Connected with the Duties of the Corps of Royal Engineers* Vol. II (1838)

During the next three years, Brandreth was stationed at Birmingham to supervise the ironwork manufacture. He conducted crushing tests to determine the best section for cast iron elements. As a result of his experiments made at the foundry, Brandreth reduced the sections specified in the original design and changed the method of connecting the parts from flanges and bolts to dovetails and pivot joints, further secured with lead. Brandreth explained his reason for the alteration in connecting technique:

> *"By this simple mode, bolts and bolt-holes, (which require nice adjustment), and the danger of any irregular pressure on flanges, are avoided. The junction of wrought iron and cast iron is also avoided, a circumstance of importance in a climate where the union of the two conditions of iron occasions greater liability to the decay of each, than when they are used separately."*[37]

The Smith-Brandreth iron framework barracks consisted of a basement and two floors, with a 10 foot gallery surrounding each floor of the 156 foot long building. Walls and piers were of brick or stone. Girders, joists, columns, cornices or ranging plates, staircases, doors, jalousies (louvred shutters) and ventilators were of cast iron. The roof truss was hardwood but with wrought iron bars for the king post and transverse tie. Wrought iron was also used in the stairway and gallery tie bars. The building's floors had hardwood bridging joists slotted into the cast iron girders, and were covered with wood. Gallery floors were finished with York flags. The roof was slate. Interior floors were divided into rooms to accommodate 18 to 20 men each (the barracks was for 200 men). Partitions were formed with jalousies in the upper part. Barrack hospitals used the same cast iron framework system but were shorter and sometimes were only a single storey.[38]

In 1827 Captain Brandreth supervised construction of the Antigua hospital. It was 66 feet long, 25 feet wide with an 11 foot gallery all around both of its two storeys. Brandreth explained in a letter to Colonel Smith dated 8 May 1827, that construction was proceeding well and confirmed the success of component standardization and modular co-ordination.[39] A hospital for Barbados was completed in 1828. Ironwork was from the same molds as those of the Antigua hospital, but the building was one storey instead of two. Colonel Smith supervised construction and was especially pleased with how well the components fit:

> *"I have had the parts put together, and find that they correspond so that in fact I may once pronounce its success is no longer problematical."*[40]

In a letter to General Gother Mann, Inspector General of Fortifications, Colonel Smith could hardly contain his delight at the application of the system:

> *"...I am able to report that the Iron Work has succeeded beyond my most sanguine expectation. In an experimental Work, it would be hard to expect that perfection in all the most minute details should be stumbled upon in the first suggestions ...."*[41]

Following the success of the Antigua and Barbados hospitals, barracks were built at St. Lucia between 1829 and 1831 and some of these still survive at Morne Fortune. All of the iron framework buildings withstood the great hurricane of 1831 and another torrential storm a few years later.[42] Hospitals and barracks on Smith's system continued to be built into the next decade. Even so, the Corps' pioneering work of prefabrication in the West Indies was soon forgotten.

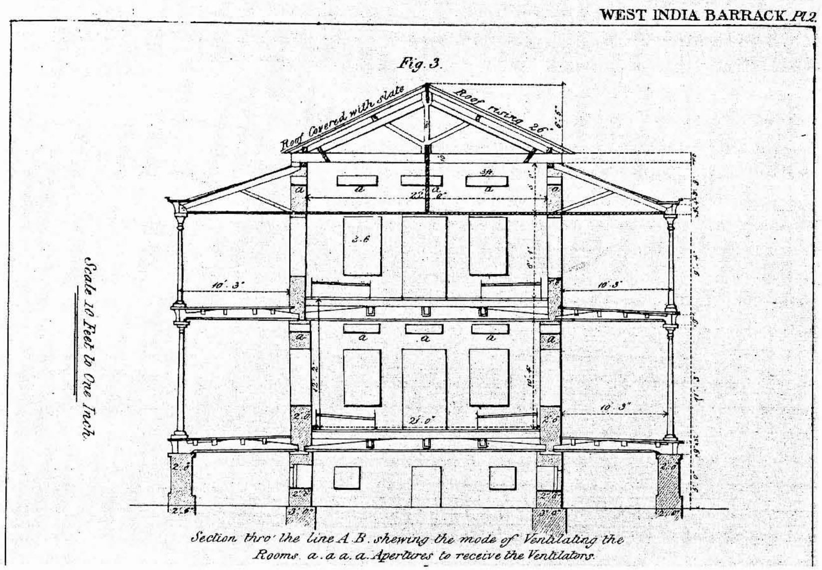

Fig. 6: Colonel Smith's Barracks System for the West Indies, showing the Method for Ventilating the Rooms, from *Papers on Subjects Connected with the Duties of the Corps of Royal Engineers* Vol. II (1838)

Dwellings for Tropical Territories

British military engineers were often stationed abroad in hot and wet climates where the adaptation of building forms and details became a practical necessity for health and even survival. The chief challenges were cooling, rain-proofing and ventilation. Architectural responses combined native traditions with advanced technology imported from Britain. Since military engineers were amongst the first British builders with some kind of formal education to work in many of the tropical colonies, their solutions to constructing dwellings there for Europeans are of considerable interest.

The high incidence of disease and rate of mortality suffered in the West Indies during the French Revolutionary and Napoleonic Wars were critical motivating factors for the Corps in the search for appropriate architectural responses to the tropical climate. The miasmic theory of disease, that saw contagions borne in the soil, water and air, became a crucial factor in the Corps' architectural measures for promoting good health. Indeed, architecture was considered by some Royal Engineers to be even more important than the various dress and behavioral measures recommended by medical experts of the time to facilitate tropical seasoning and acclimatization.

In the West Indies, as well as the Bahamas, Bermuda, and British Guiana, Royal Engineers employed a number of architectural devices in pursuit of cool, dry, well ventilated and miasma free barracks and hospitals (Fig.6). They adopted the verandah (gallery or piazza), the raised ground floor and large windows protected by jalousies, design features that had been introduced during the late-seventeenth century by European planters in the Anglo-Caribbean cottage.

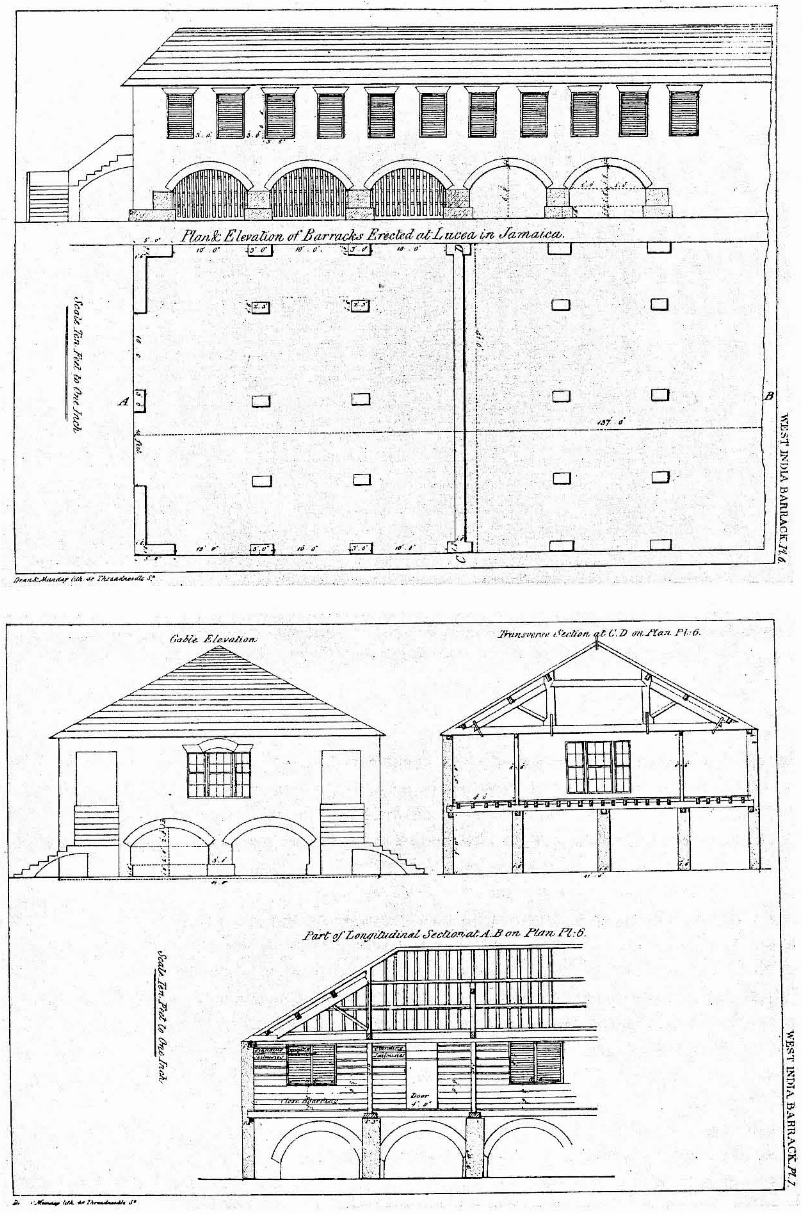

Fig. 7: Captain West's Proposed Barracks at Lucea, Jamaica, from *Papers on Subjects Connected with the Duties of the Corps of Royal Engineers* Vol II (1838)

The open verandah extending from eave to ground floor, and usually encircling, was the standard practice in Corps designs for providing protection from the sun and partial protection from the rain.[43] Some Royal Engineers, however, preferred enclosed verandahs on one or more sides with jalousies in windows.[44] The subject of verandah design was much discussed by Royal Engineers serving in the West Indies. In 1838 Captain West made a proposal for barracks where a gallery was incorporated within the main building structure rather than attached as an appendage. He submitted that this type of verandah provided better protection against wind and rain as well as for air circulation during the bad weather; he also claimed it would be less vulnerable to damage from hurricanes. Captain West said he developed his design from buildings "*... adopted by planters in some of the West Indian islands.*"[45]

The typical vernacular Caribbean house had its whole structure raised from the ground to allow free circulation of air for cooling and to protect the building's wood from insect attack. Royal Engineers adopted this technique throughout the nineteenth century (Fig.7). In some cases, the ground floor was raised almost a whole storey on stone arches which created a large vaulted space below. Most often, however, the ground floor was simply elevated a few feet on stone or brick pillars.

The jalousie was employed universally in the West Indies for blinding the sun, letting in air and keeping out rain from openings. Initially, jalousies were of wood but by the 1830s cast iron was commonplace.[46] In 1838, Captain Brandreth suggested the use of copper wire gauze in cast iron window frames in place of jalousie louvres, as protection against malaria bearing mosquitoes.[47] He specified a mesh of 1/24th of an inch and recommended copper over iron because of the exposure of the West Indies' buildings to the sea. His proposal was endorsed by Colonel Smith and by Dr. Arthur of the army medical staff, an authority on the use of wire gauze windows to mitigate malaria. Brandreth's technique was adopted for a new hospital at Demerara.[48] Royal Engineers' combining of European advanced technology with native building traditions was no mean feat.

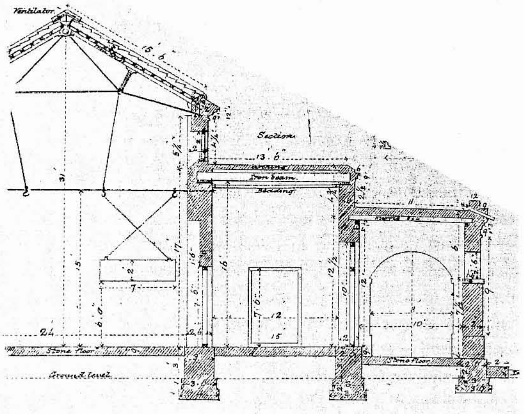

Fig. 8: Lieutenant Taylor's European Infantry Barracks, Nowshera, India, 1855, from *Professional Papers on Indian Engineering Series* 1, Vol. I (1864).

In India, the story of designing dwellings for Europeans begins with the bungalow. This distinctive building form has its origin in the adaptation of the Bengali hut by military engineers of the East India Company in the eighteenth century. The salient characteristics of the type were a free standing and single storey structure, on a plinth, fitted with a pitched, thatched roof and a verandah. British military engineers in India introduced architectural ideas which transformed the native design into the more substantially built, flat roofed 'classical' bungalow used particularly to house Company officials and army officers in the cantonment (a settlement segregated from native inhabitants). By the mid-nineteenth century, this had evolved into what was widely known as the Public Works Department's 'Military Board Style', which became a standard form for official government buildings.[49]

The issue of buildings in India suitable for Europeans became controversial, however, in the case of barracks and military hospitals for the men. A Commission on the Sanitary State of the Army (1859-63) looked into the causes of the staggeringly high mortality rate of British soldiers serving in India (compared to experience in Britain and abroad) and reported that barrack conditions were responsible for much of the unhealthy conditions and in particular poor ventilation.. The Commissioners concluded that roof ridge ventilation, together with the free admission of air under the eaves was the best solution to the problem.[50]

Many Royal Engineers stationed in India questioned the Commission's findings. Major J.G. Medley, editor of the *Professional Papers on Indian Engineering*, complained that only one member of the Commission was familiar with the considerable climatic differences among Indian territories, and that there were examples of recently built barracks that displayed a much higher standard of climatic adaptation than those visited by the Commissioners. Medley included in the first issue of the journal an article on the European Infantry Barracks (1855) in Nowshera, the Punjab, designed by Lieutenant F.S. Taylor (Fig.8). In an editorial comment, Medley explained: *"It is believed that no Barracks, as yet constructed in India, are better built or surpass these in comfort and healthiness"*.[51] Taylor's barracks was a single storey building that featured double verandahs and a pitched roof on iron trussed frames with a ventilator at the roof ridge. It was equipped with 'punkahs', heavy cloth devices hung from the ceiling and fixed to iron rods, which could be pulled to and fro by native servants. In the inner verandah, the iron tubular beams were left open at the extremities to admit a current of air through each beam into the building. The constructional and mechanical arrangements for cooling and ventilation were indeed works of engineering virtuosity on the fringes of the empire.

Empire and Technology

Nineteenth century Britain developed as the pivotal part of a global economy and as the centre of a vast formal or informal empire. Technology was a vital force in imperialism and British engineers were agents of the diffusion of technology occasioned by colonial expansion. The Royal Engineers participated in this phenomenon as individuals for short periods of time at various colonial stations, but more so as a continuous Corps presence in all parts of the empire throughout most of the last century and in India well into the present one. Engineer officers regularly communicated their ideas and experiences concerning construction duties in far away lands, through their own professional journals and the British technical press. They utilized technological advances in steamships and railways which permitted faster mails and later took advantage of transcontinental telegraphic cables to exchange information.

In the end, the Royal Engineers' contribution to building technology transfer to the colonies is best appreciated within the broad sweep of change effected by the maturation of industrial society in Britain. An unwavering belief in progress underpinned this transformation. It was a conviction rooted in an idea of history as the evolution of human abilities which built upon all the achievements of the past. While not given to philosophical discourse, Royal Engineers revealed in their technical writings and public statements, an unquestioning faith in the doctrine of continuous advancement. They applauded each step forward to scientific certainty and freedom from the mystery of craft tradition. Barely acknowledged, however, was their own influential position in society's pursuit of progress.

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