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The Early use of Reinforced Concrete in India

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The question of what were the early reinforced concrete buildings in India generally evokes mention of the city of Chandigarh and the involvement of Le Corbusier. But that was built from the mid–1950's, are there no reinforced concrete buildings from the first half of the 20th century? If there were, where and how was reinforced concrete used? Who were the designers? What was done to suit Indian contexts such as climate, materials and skills?

Apart from the buildings designed by Lutyens and Baker for New Delhi there has been little interest in any aspect of India's buildings from the first half of the 20th century. One reason is that the buildings of this period began to take on a more international appearance, replacing the exoticism of the Indo-Saracenic buildings from the late–19th century that was, and remains, so appealing to writers on India's architectural history. Another reason is that many of the buildings were designed by architects who are almost unknown outside of India and so have not attracted the attention of western architectural historians.

What has been written on the built environment has generally concentrated on the architect and stylistic issues. For works on Indian buildings from the first half of the 20th century the writer will mention the architect if he (there are no references to female architects) was sufficiently important and will focus on whether a particular building fits into a particular Western-generated category such as Art Deco or Modern Movement. Apart from journals and publications written at the time there are no works on the engineers and builders, or details of the structure of the buildings.

There are contemporary and modern references to concrete buildings or the use of pre-cast concrete that do not fit into the chronology for the uses of these materials. By looking at the buildings in India in the broader context of the development of reinforced concrete elsewhere in the world it is possible to see if these references are correct. We can also begin to understand why different structural solutions were chosen for similar building types and have an indication of what we might expect the form and condition of the structure to be for buildings of a particular date.

This study ends in 1947 at the end British rule in India and close to the end of the «pause» in building industry caused by World War II. This was also a period of transition for building in India. Although Anglo-Indian architects continued to practice after the war they were eclipsed initially by Le Corbusier and Louis Khan —high-profile names brought in to help promote a modern India— and then by Indian architects such as Charles Correa, Balkrishna Doshi and Raj Rewal.

Buildings from the first half of the 20th century form a large and important part of India's built environment and it is important for economic, environmental and conservation reasons that their

form, condition and qualities are understood. There is a small but growing awareness in India, as elsewhere in the world, that the conservation of good quality buildings, including those from our recent past, is important for the well being and prosperity of its cities and its citizens. Mumbai has taken the lead with planning legislation in 1991 to protect individual buildings and areas within the centre the city. There are however, other important buildings that deserve to be recognised for the positive contribution they bring to an area or neighbourhood. As we shall see, a number of these buildings are also important for their place in the development of reinforced concrete construction in India.

A note on place names; Bombay is now called Mumbai, Madras is Chennai and Calcutta now Kolkata. The original name has been where a historic reference is given, e.g. «materials testing in the 1920's was carried out at colleges in Madras, Roorkee and Sibpur».

What is Reinforced Concrete?

In the second half of the 19th century a number of ways of combining iron and concrete, and later steel and concrete, to produce more efficient, and hence, cheaper structures were developed. The origin of reinforced concrete in England is generally accepted as William Wilkinson's patent in 1854 (Hurst, 1996, 290). His system was not widely adopted however and most of the early developments and successful patents came from Germany and France. The method of reinforced concrete flooring patented by Francois Hennebique in 1892 was the most widely used, such that by 1909 nearly 20,000 structures had been designed using the Hennebique system and the company had 62 offices including four in Asia (Newby 1996, 267 & Bussell 1996, 297).

The patented system meant that the contractor paid for a structural design, licence for the materials and instructions on how to build to a particular system. For the early engineers and contractors in India without the education and experience of using reinforced concrete this method of procuring a design and then constructing on site with unskilled labour had obvious advantages. India followed the UK in adopting a standardised approach to the design and construction of reinforced concrete following the introduction of regulations, codes and standards from 1915 (Bussell 1996, 319).

Reinforced concrete was used in the 19th century, mainly for foundation work. As early as 1869 hoop-iron was put in the concrete foundations of the High Court in Calcutta (Anon 1, 1869, 857). In general, most references to pre–20th century concrete buildings in India need to be treated with care since they will almost certainly be unreinforced concrete. One example is «Concrete-Building at Simla, India» published in 1886. This refers to the construction of two large buildings, the Secretariat and the Army Headquarters. Both are iron-frame structures using mass concrete for the foundations, the walls, and the floors where it was cast onto curved corrugated iron spanning between beams so that the concrete worked as a series of arches. The concrete used was made manually on site from lime burnt in local kilns and crushed brick (Smith 1885, 391).

Materials

Two of the basic components of reinforced concrete, Portland cement and steel, are formed by industrial processes that require a large initial investment in manufacturing plant together with a trained workforce. The early reinforced concrete buildings in India used imported cement and reinforcement, with only the aggregate being obtained from within India.

The Indian Cement Company was the first to start producing cement, in 1914 at a factory in Porbander on the Gujarat coast. This was marketed as «Ganapati' Best Portland Cement» (Kotasthane, 1919, 3). In 1914 India manufactured 945 tons of cement and imported 150,530 tons and the demand was such that London agents were buying German cement to re-export to India (Anon 2, 1911, 143). A second factory opened in 1915, in Katni in the Central Provinces —now Madhya Pradesh— that was able to produce up to 35,000 tons of cement per annum. Other factories developed around the country so that by 1929, although the total weight of cement used in India more than quadrupled since 1914 to 632,653 tons, the ten Indian companies were able to produce nearly 90% of the total (Anon 3, 1929).

The steel reinforcement was initially imported from the UK though agents in Bombay and Calcutta.[1]

Tata were the principle manufacturer of reinforcement in India from circa 1914.[2] Their quality was such that the Indian Public Works Department Handbook for 1931 notes that «reinforcement . . . should be best British or Tata's mild steel plain rounds or squares with an ultimate tensile strength of at least 60,000lbs/sq. inch». (Marryat 1931, 375).

The testing of materials to comply with the relevant Standards was initially at the Engineering Colleges at Roorkee, Madras and Sibpur (Stokes-Roberts 1910, 129). An example of the concrete quality comes from the construction of the road bridge over the river Nerbudda, built between 1929 and 1935. The compressive strength of the cubes ranged from 24–35 N/mm^2 (Dean 1936, 185), which compares favourably with a design compressive strength of 20 N/mm^2 in the 1933 revision of BS 12.

There is a reference to bamboo being used in place of steel for the reinforcement of piled foundations in the Far East in 1929, and for a small, undated, experimental structure in Nagpur with a 90mm deep flat roof slab reinforced with 12mm square solid bamboo splints (Bose 1950, 26). There is no evidence of the widespread use of bamboo.

Who were the designers?

The early reinforced concrete structures were designed by British military engineers, with Major Stokes-Roberts R. E. referred to as «instrumental in introducing the use of reinforced concrete and brickwork for Government purposes in India» (Marsh 1904, 522). The first structures were small-scale but this early knowledge meant that members of the Royal Engineers were also involved in designs for commercial clients such as the reinforced concrete flats for mill workers at Spring Mills, Bombay built in 1916 (Anon 4, 1917, 163).

The buildings constructed by India's regional governments had been designed and built by the Public Works Department (PWD) since the mid-nineteenth century. There is little reference to the PWD when it comes to buildings constructed in reinforced concrete and the early part of the twentieth century saw the formation of commercial architectural and engineering practices and building contractors. By 1929 there were 25 architectural and 36 engineering practices, and 76 contractors who advertised themselves as specialising in concrete including a number who offered themselves as both the engineer and contractor.

The geographical spread of these firms gives a picture of the use of reinforced concrete in India in the late 1920's. Bombay had 33 contactors able to build in reinforced concrete, Calcutta had 12 —reflecting the preference of steel-framed construction— and there was just one in Delhi where the tradition of building in load-bearing masonry continued. Concrete was used in smaller towns and cities, such as for the Bombay Life building in Udipi completed in 1936 where workmen had to be brought from Bombay to train the local workforce (Anon 5, 1937, 207 & 1939, 15).

The most successful engineer/contractor of the inter-war period was John Gammon (1887–1973), a British-educated civil engineer who before the First World War had worked for the PWD in Bombay and wrote «Reinforced Concrete Design Simplified».[3] After demobilisation he return to India in 1919 and rejoined the PWD where he designed the pre-cast concrete piled foundations and in-situ r.c. domes to The Gateway of India, designed by George Wittet.[4]

While working on The Gateway in 1922 he formed J. C. Gammon Ltd. One of their first projects was to design and construct 178 warehouses for The Bombay Port Trust in Sewri. These are daring structures that were influenced by developments in structural analysis and building technology in Europe. The buildings, which are now mostly derelict, are the first reinforced concrete shell roofs in India, using a 150mm thick curved roof supported on columns to provide over 76,000 square metres of open-plan storage (Anon 6, undated, 1).

Within the metropolitan areas of Bombay and Calcutta over half of the engineering practices were led by British engineers with the majority of the design and draughting work carried out by Indian engineers and draughtsmen educated at colleges in Madras, Roorkee, Howrah (Calcutta), Pune and Karachi.[5] The private companies tended to attract the best architects and engineers and so they were also called on to design buildings that would traditionally have been dealt with by the PWD. One of the largest projects in Bombay in the late 1920's was the building of Bombay Central Railway Station, designed by the architects Gregson, Batley & King (Mehrotra & Dwivedi, 2000, 110). It was built by The Ferro Concrete Construction Company and it is likely

that they also designed the reinforced concrete structure.

A number of the documented reinforced concrete buildings refer only to the architect. For these, and the majority of undocumented buildings from this period the structure was designed and detailed by the builder/contractor.

What were the Design Guides?

For the pioneers of reinforced concrete in India the design was based on patents or empirical methods and load testing. In 1910 Major Stokes-Roberts wrote to suggest that reinforcement be added to mass concrete footings where the quality of the underlying ground is poor, but that «until trials have been made and data collected . . . it is impossible to say how much or how little steel should suffice» (Stokes-Roberts, 1910, 11).

As the understanding of the material increased the British Standards and Codes of Practice were adopted by the British administration in India. The cement could be imported or manufactured in India, but had «to comply in every respect with the latest British Standard specification for slow setting Portland cement» (Marryatt 1925, 377). This resulted in some curious requirements. For example the 1920 revision of the British Standard for cement, BS 12, required testing using sand provided by a contractor in Leighton Buzzard, with Indian cement manufacturers having to import the sand to achieve compliance (Davy 1921, 149).

Alongside the British Standards most offices were equipped with British textbooks that were augmented with Indian publications like Gammon's book referred to previously and «Reinforced Cement Concrete Construction» by Kotasthane published in 1919. The PWD Handbooks also provided advice on design, good working practices and standard details of Indian-style building elements (Davy 1921, 384).

There was an awareness among engineers of the problems caused by the high temperatures in India. In 1929 H. F. Davy produced a paper referring to a discussion as early as 1895 at the Society of Engineers in London on the accelerated setting time of cement in the tropics. Davy showed that the higher temperatures in India than the UK meant that the specification for Portland cement needed to be adapted in order to slow down the curing time (Davy 1921, 144). There is however no indication that changes to the specification were made during this period.

Another area where the British Standard was adopted without proper consideration for the Indian climate or the unskilled workforce was the amount of concrete cover. The guidance for cover to the reinforcement given by the PWD in 1925 (Marryatt 1925, 384) was:

- For columns: not less than 1_ inches (37mm) to the vertical bars.
- For beams: not less than 1 inch (25mm) to the longitudinal bars.
- For slabs: not less than _ inch (12mm) for any bar.
- For other members (such as lintels): not less than 1 inch (25mm) to any bar.

For columns and beams this meant that the secondary reinforcement, typically 6mm diameter link bars that wrap around the main bars, had a very limited amount of concrete cover. The use of aggregate up to 63mm wide was permitted (Marryatt 1925, 130), so if the guidance was followed without question, there would be insufficient space for the wet concrete to flow between the steel and the formwork. What seems to have happened in many cases is that once the formwork was removed a sand and cement render coat was applied to fill the voids left in the concrete.

There were also quality issues arising from how the concrete was batched, carried and placed in small quantities. An unnamed representative of a concrete mixing plant reported in 1915 that the cheap labour costs meant he saw only one mechanised mixer in Bombay and that the concrete was mixed on the ground, and then placed into small baskets to be carried on the heads of «cooley women» (Twelvetrees 1915, 440).

The Concrete Association of India, formed in 1927 to promote and develop the reinforced concrete market in India, published 39 booklets during the 1930's on subjects like concrete fences and gateposts, cement plastering and concrete roads. Volume 4 «Floors and Footpaths» describes how concrete will keep out rats, and that «concrete pavements are unperishable (sic) and last for ever. They can stand the vicissitudes of the Indian climate and once laid

never need repair» (Anon 7, 1937, 3). Apart from their unrealistic claims, a fundamental problem of these publications is that they suggest building elements can be put together without a proper understanding of the materials, the overall structure or the care needed during the construction. This «kit of parts» approach to building has led to many of the problems that can be seen on reinforced concrete buildings.

The Uses of Reinforced Concrete in India

The majority of contemporary accounts in architectural and engineering journals on the use of reinforced concrete in India refer to its use in buildings, structures and civil engineering works such as roads and bridges. It was also extensively employed for more mundane items such as lamp and fence posts, and railway sleepers (Stokes-Roberts 1910, 39; Anon 8, 1923, 667). There was also mention that India should build reinforced concrete ships for the coastal trade to save on imported steel (Anon 9, 1919, 310).

The following is a summary of buildings and engineering structures and other miscellaneous uses, selected to illustrate the various forms and applications of reinforced concrete. These have been organised into broad categories based on the use of the building and arranged chronologically.

Civil Engineering works

Bridges

The earliest documented reinforced concrete structures in India found to date are two small bridges constructed in 1901 to designs by Major E. R. B. Stokes-Roberts, R.E. (Marsh 1904, 522). Each 9.15m arch was constructed without aggregate using a cement and sand ratio of 1:3 and carried pedestrian and narrow gauge trams across a small, unnamed river.

Less than 10 years later the much larger Afzal Ganj Bridge was built across the Musi River in the centre of Hyderabad. After a flood in 1908 had destroyed the previous masonry bridge a new reinforced concrete structure, designed and built by Messrs. Marland, Price and Co. from Bombay was completed in 1911. It was, at the time, the largest reinforced concrete bridge in India with four elliptical arches that span 16.46m onto piers built off masonry foundations. The arches are between 375 and 600mm deep at the crown and were cast in-situ with a cement: sand: aggregate mix of I: 2:4 and two layers of 25mm square reinforcement bars at 250mm centres supplied by the Indented Bar and Concrete Engineering Co. in London. The approach roads to the bridge are on reinforced concrete boxes grouped together and infilled with lime concrete and stone (Anon 10, 1912, 145).

A number of submersible bridges, i.e. bridges where the road deck was liable to flood during the monsoon were built. The earliest in India is the Manimalai Bridge between Travancore and Cochin in Kerala, built in 1915 with eight 8.5m span reinforced concrete arches (Anon 11, 1955, 41). The first pre-stressed concrete bridge in India is Napier Bridge, built between 1939 and 1943 near the Fort area of Madras. A second bridge, based on the 1939 bowstring girder design, was opened on the 5th February 2000.

Harbour Facilities

The Port of Madras constructed over 1400 metres of wharfing between 1905 and 1910 using pre-cast piles and retaining walls that were driven into the sand. The wharf wall was anchored in place with steel ties that were encased in concrete for corrosion protection. The 31 cranes were each founded on a group of four, 375mm square, driven pre-cast concrete piles (Spring 1911, 427).

Water Tanks and Towers

The first recorded reinforced concrete water tanks were designed in the early 1900's by Major Stokes-Roberts. These had a mass concrete base sitting on the ground and brick walls with reinforcing bars formed into hoops, tied together with telegraph wire, in the bed joints. The tanks were topped with a reinforced concrete dome between 37–50mm thick (Marsh 1904, 524). Included in the article were drawings that showed the timber centring to support

the roof during its construction and a method of removing the props once the concrete has gained strength. As well as demonstrating an awareness of the need to consider the construction process it seems that Stokes-Roberts was keen to use his work as an exemplar for other engineers in India and elsewhere.

The aesthetics of water towers were discussed following a presentation to the Institution of Indian Engineers (Temple 1929, 112). A contribution by G. Bransby Williams, who said he had «probably designed and erected more water towers than anyone else in India», was that it extremely difficult to achieve an aesthetically satisfactory design without making them look «entirely unlike a water tower». An example of this is at Puri where the structure of the tank is hidden behind a «New Delhi style» exterior designed by the PWD architect, J. F. Munnings. These «architectural» water towers were considerably less robust than the more honestly expressed structures. The dome to the Puri tank is a steel frame with a 75mm concrete layer reinforced with a diamond-shaped steel mesh. An even thinner structure is the 55mm thick curved roof to the southern reservoir at Muzaffarpur made by «throwing cement plaster» onto wire mesh fixed to a steel frame (Temple 1929, 118).

Roads

The early concrete roads were unreinforced, such as the road over Law's Bridge in Madras constructed in 1914 that is described as «probably the oldest in India» (Anon 10, 1955, 11). There is however a reference to concrete road in Rangoon, Burma, then within the boundary of British rule in India, said to date from 1907 (Anon 12, 1934, 67). «Concrete Roads in India», published by The Concrete Association of India (CAI) in 1931, promoted the benefits of concrete against other road-building materials and reinforced concrete was and remains the main method of road construction.

Buildings and structures

Housing

The first reinforced concrete buildings were also probably designed and built by Military Engineers and Stokes-Roberts is referred to as the engineer for the posts, beams and rafters on an un-named army barrack constructed prior to 1905, (Winn 1905–7, plate E). The same paper also shows a roof design by Captain Traill, R.E. that combines rafters that were pre-cast on the ground and covered with 50mm thick slabs reinforced with 3mm bars. These slabs were also pre-cast, onto bamboo plastered with mud to provide a level surface, and then covered with oiled paper.

The earliest civilian reinforced concrete buildings were probably built in Bombay. In the suburb of Byculla a four-storey students hostel built in 1907 for the Victoria Jubilee Technical Institute is described as the «earliest reinforced concrete structure in India» (Anon 11, 1955, 11). The Indian practice of Messrs. Taraporvala, Bharoocha & Co. provided the architectural and engineering design.

The Spring Mill Worker's Chawls, Naigum Road, Dadar in Mumbai were built between 1915 and 1917/18 to provide low-rent accommodation for workers at the nearby mill. There are five buildings; each three stories high with rooms arranged each side of a central corridor. Each 3 m × 3.6 m room and 1.35 m deep verandah was intended to house four people with communal toilets and washing facilities in the centre of each block (Anon 4, 1917, 158).

The plan of the buildings is attributed to J. F. Watson, a civil engineer who was serving with the Royal Engineers in France during the construction. It is likely that he prepared the general arrangement drawings and that the unnamed contractor carried out the detailed structural design. The structures are an early form of a reinforced concrete frame with square columns supporting beams that span front to back. The 90mm thick floor is carried on secondary beams, referred to as joists in the article, at 1200 mm centres. The dividing walls between each room, and between the rooms and the communal corridors, are also constructed in concrete. These are only 75 mm thick, with reinforcing bars tied to steel hooks cast into the adjacent beams and columns. A gap has been left to the underside of the beam above to provide cross ventilation. The flats also had two reinforced concrete shelves in each room, so it is possible that the buildings were used to show the potential for what was then a relatively new building material in India. The buildings remain in full use but the structures are now in a poor condition, with extensive areas of

spalled concrete and corroding reinforcement due mainly to the inadequate concrete cover to the reinforcement and a lack of maintenance. A programme of repairs is needed soon to safeguard this important group of buildings.

By the mid 1930's most of the larger apartment blocks in Bombay were reinforced concrete framed structures. Flats designed by G. B. Mhatre at Byculla, Bombay, now called Ready Money Building, were completed in 1935 (Anon 13, 1936). It has r.c. columns, beams and slabs, with the brick walls only acting as partitions between rooms. Mathre studied Architecture in London from 1928–1931 and on his return to India he joined Poonegar and Billimoria (Iyer 2000,10). Poonegar was a civil engineer, so the practice was able to offer a full design service to clients.

Many of the smaller apartment blocks and houses built in the 1930's also made use of reinforced concrete such as The Governor's House, now Raj Bhavan, in Hyderabad by Eric Marrett, 1936.[6]

Offices

Reinforced concrete quickly became established as the preferred method of structuring office floors, and for the larger buildings it was also used to form the main structural frame. Bombay House, Homi Mody Street, Fort, Bombay was built in the early 1920's as the headquarters and offices for the Tata group of companies on an empty site in the centre of Bombay's commercial district. It is a five storey, reinforced concrete framed structure that is externally clad in Malad stone.

Original drawings are dated 11th November 1921 and signed by the architect George Wittet, who joined the Board of Directors of The Tata Engineering Company Ltd. in 1919. Detailed drawings of the reinforcement are also dated November 1921 and signed by N. T. Patel who was likely to have been the project engineer working for Tata.[7] The reinforced concrete frame divides the plan into a grid with columns at about 6m intervals supporting downstand beams, with an intermediate beam in each bay to reduce the span of the 100 – 140mm deep reinforced concrete slabs. Steel trusses and purlins are used to form the pitched roof. The building is founded on reinforced concrete pad footings below the internal columns and strip footings beneath the perimeter columns and the brick or concrete shear walls. The detailing of the reinforcement is typical for buildings of this type and age and is similar to the Hennebique patented system.

Another reinforced concrete framed building is the office of The Associated Cement Companies Ltd. opposite Churchgate Station in Mumbai. This building was the subject of an architectural competition in 1938, with Gregson, Batley & King as the assessors. The winning design by Ballardie, Thompson and Mathews of Calcutta is both a celebration and promotion of cement. The elevations and internal surfaces are finished with a cement render and the floors and stairs had a polished coloured cement or terrazzo finish to the floors. One of the special features was the main curved cantilevered staircase that «in order to illustrate what can be achieved in reinforced concrete technique when carrying out modern design . . . has purposely been made of somewhat intricate construction» (Anon 14, 1938, 24–27).

Many office buildings had load-bearing brick walls supporting the reinforced concrete floors, such as at Kasturi Buildings, Mount Road, Madras, built for The Hindu newspaper. Opened in 1940 the building was designed by H. Fellowes Prynne of the Madras-based architects, Jackson and Barker, with the structural design by N. R. Srinivasan working for the contractor, The Modern Construction Company. The main four-storey elevation has a rendered brick façade with a reinforced concrete cantilevered canopy over the main entrance. Internally the floors are reinforced concrete beams and slabs spanning onto masonry walls, with r.c. columns in one room only to break the spans of the beams in the open-plan Typist's Hall.

Industrial Buildings

One of the earliest reinforced concrete buildings in India is Swan Mills in Bombay. This was constructed in 1905 using stone external walls with r.c. columns internally that support a saw-tooth profiled roof of steel rafters and purlins with 50mm thick mesh reinforced slabs cast onto curved steel formwork (Anon 15, 1906, 10).

Public Buildings

There is no record of when reinforced concrete was first used for buildings such as schools, hospitals, churches or other public buildings but by the 1930's it had become the standard method of constructing many of these larger buildings throughout India.

The Freemason's Hall in Madras is a two-storey structure with load-bearing brick walls and steel beams that support a «Kleine» proprietary first floor and flat roof. The Hall was designed by the Madras-based architectural practice of Jackson and Parker and built by the Raman Menon Construction Company. The cornerstone was laid on 26 February 1923 and the Hall was completed in 1925.[8] The Kleine floor system was invented and patented in 1892 and introduced into Britain in 1896. It used hollow clay blocks laid end to end with thin, longitudinal strips of steel «reinforcement» in mortar filled joints between the blocks. The materials for the Kleine floor were all produced in India and the clay blocks used here were marked «Kollan Tiles, Quilon Tile Works», from Quilon in Kerala. There is no record of an engineer being involved in the building and it is likely that the floors were «designed» by the contractor using load-span tables provided by Kleine.

The J. N. Petit Library on Dadabhai Naoroji Road in Bombay is a rare example of a reinforced concrete extension to an existing building. Opened in 1898, the original pitched, timber roof was replaced by an r.c. floor and flat roof in 1936–38 designed by Tara Poorwalla.[9]

Kacheguda Railway Station in Hyderabad was designed by Vincent Esch in 1914. At a lecture in 1942 Esch admired «how very skilful the Indian craftsmen are with pre-cast and reinforced concrete work, and I think this railway station, designed in Indo-Saracenic style on this principle of construction, is a wonderful example of their skill» (Esch, 1942, 50). He also wrote «This architectural gem . . . is entirely built in pre-cast re-enforced concrete» (Tillotson 1993, 33). While Esch was right to praise the quality of the building, he is not correct in the description of its structure.

The ground floor walls and columns have a rendered finish, but from their size it is likely they are built in brickwork, and the underside of the first floor has steel beams supporting an in-situ reinforced concrete slab. Externally the absence of obvious joints in the projecting chajjas suggests these are also in-situ. The pre-cast elements are all likely to be non-structural such are the jalis, pierced parapets and internal screens.

Repair Works

The use of reinforced concrete in repairing India's historic buildings is now widespread but its use is not new. One of the largest concrete repairs was in 1936–37 on the Gol Gumbad in Bijapur. There, the Archaeological Survey of India found that the 2.6 metre thick, 41 metre diameter dome had large cracks reported to be caused by thermal movements. The repair involved stitching across the largest cracks and wrapping the outside face with bars that were then covered with a sprayed sand-cement mix (Dikshit 1940, 16).

Decorative Reinforced Concrete

The use of reinforced concrete for non-structural elements has already been discussed at Kacheguda Station, above. A totally Indian use of the material, also in Hyderabad is the jails, or pierced screens, that surround the courtyard entrances to the Gosha Mahal, or Freemason's Lodge. These were made circa 1934 of pre-cast panels reinforced with 5mm diameter steel rods under the supervision of Mehar Ali Fazil, the Superintending Engineer for the Hyderabad City Improvement Board (Anon 16, 1936, v).

Conclusions

The first uses of reinforced concrete in India were by British military engineers at the start of the 20th century. Officers from The Royal Engineers designed simple structures based on information from technical journals, patents from European companies and their own tests and trials. The first decades of the 20th century can be seen as partly a period of experimentation and learning, both for the engineers and for the Indian builders who had to learn new skills and techniques. Private architectural and engineering practices soon overtook the military engineers, and the governments Public Works

Department in the design and construction of reinforced concrete.

The first buildings used materials imported from the UK and it was not until the late 1920's that India had sufficient factories to produce the quantities of the cement and reinforcing bars needed by the building industry. Once this industrial infrastructure was in place the number of reinforced concrete buildings and the companies able to design and build in the material rapidly increased. The construction industry was steered towards using reinforced concrete by the strong promotion of The Concrete Association of India and The Associated Cement Companies formed from the various cement producing companies.

In common with other developing countries the low labour costs and the plentiful supply of cheap labour were also important and meant that reinforced concrete was, and still is, widely used for medium to large-scale constructions.

The growth in reinforced concrete construction during the 1920's and 1930's was largely an urban one, based on the demand for larger scale buildings that could not be structured using traditional materials. The centralised, factory-based production of cement and steel also tended to concentrate the use of reinforced concrete in the larger cities with their established transport links.

The use of reinforced concrete followed developments in the UK, where there was a more cautious approach to the potential uses of the material than elsewhere in Europe. As a result there was little of the engineering innovation in India that had existed during the 19th century expansion of the country's rail network. This conservatism was misguided in one key area —the adoption of British Standards without the necessary changes to suit the Indian climate. When this is combined with the use of poorly trained workers, a lack of adequate supervision of the construction on many buildings, and a subsequent lack of maintenance, the results are the commonly seen problems of staining, spalling concrete and corroding reinforcement on many of these buildings.

Notes

1. Advertisements in Kotasthane, Reinforced Cement Concrete Construction.
2. Interview with S. A. Reddi: Deputy Director of Gammon India Limited, February 2001.
3. Gammon, John c. 1913. Reinforced Concrete Design Simplified. Bombay. Crosby Lockwood and Sons.
4. Interview with S. A. Reddi.
5. Interview with N. B. Hadker: Director of Sterling Engineering Consultancy Limited. February 2001.
6. From a discussion with Ravindra Gundu Rao, Mumbai 2001.
7. From drawings in the Bombay House archive seen February 2001
8. Discussion with Professor M S Mathews, Chennai, March 2001
9. From a discussion with Ravindra Gundu Rao, Mumbai, February 2001.

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Anon 6. Undated, probably 1970(?). *Concrete Shell Construction by Gammon.* Liverpool. Ronald G. French.

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