Bridge-Building in Nineteenth Century India:
Indigenous Empiricism and European Technology *

Jean Deloche

Ecole française d'Extrême-orient

Introduction

In this paper on bridge-building in nineteenth century India, I shall not focus attention on how European science and technology were used for imperial purposes, nor indicate the close links existing between the two. It is true that railway bridges were marvels of engineering skill, that they symbolize "the British capacity to reshape the Indian environment",[1] as shown by Rudyard Kipling's short story *The Bridge-Builders*, published in 1894, which admirably illustrates the European ambition to impose technological diffusion on colonized societies. But my purpose is different.

The aim of this study is to highlight the special value and significance of the noteworthy achievements of the Indian bridge-builders and the boldness and soundness of the indigenous system of hydraulic architecture.

Emphasis here is given to the fact that, until the present century, no technological change occured in the Himalayan region regarding the manner of crossing rivers by rope, cane or wood bridges and that, in the Indian peninsula, during a good part of the nineteenth century, masonry road bridges of brick and stone were still founded on old native methods which had been practised in India for centuries, and were subsequently improved and developed by British engineers.

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* This paper is mainly based, for the indigenous bridges, on my two books: *Les ponts anciens de l'Inde* (Paris 1973), translated into English under the title *The Ancient Bridges of India* (New Delhi 1984) 121 pp., 20 fig., 75 photographs, and *La circulation en Inde avant la révolution des transports, Vol. I, La voie de terre*, pp. 124-141 (chapter on river crossing), and, for British engineering, on G. W. MacGeorge's book, *Ways and Works in India* (Westminster 1884) which is a detailed account of Indian Public Works. The references given here are reduced to the minimum; the interested reader might always consult these publications in order to obtain more information.

1 M. Adas *Machines as the Measure of Men, Science, Technology, and Ideologies of Western Dominance* (Delhi 1990) 235.

1. Himalayan Bridges and Traditional Techniques

In the Himalayan mountains, during the entire nineteenth century, transport was exclusively human and animal. The little trade that existed was carried by porters, mules, yaks and even sheep. It is therefore not surprising to note that the picturesque bridges mentioned by observers of Himalayan life[2] were still constructed according to the same ancestral techniques, testifying to the sound technical knowledge possessed by the people living on "the roof of the world".

These works can be classified in two categories: suspension bridges (made of rope, cane, iron chains) and beam and cantilever bridges of wood.

1.1 Suspension bridges

Suspension bridges consisted of ropes made from various kinds of raw material: birch, grass, raw hides, in the western part of the chain, and cane, ratan or bamboo in the eastern part.

These ropes were stretched across rivers in two ways: firstly in the form of a

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2 For the nineteenth century we may mention the following accounts:
- Baden Powell, B.H. *Handbook of the Manufactures and Arts of the Punjab* (Lahore 1872).
- Bellew, H. W. *Kashmir and Kashgar, A Narrative of the Journey of the Embassy to Kashgar in 1873-4* (London 1875).
- Cunningham, A. *Ladak, Physical, Statistical, and Historical, with Notices of the Surrounding Countries* (London 1854).
- Drew, F. *The Northern Barrier of India, A Popular Account of the Jummoo and Kashmir Territories* (London 1877).
- Forster, G. *A Journal from Bengal to England* (London 1798).
- Gerard, A. *Account of Koonawur in the Himalaya* (London 1841).
- Hooker, J. D. *Himalayan Journals or Notes of a Naturalist in Bengal, the Sikkim and Nepal Himalayas, the Khasia Mountains* (London 1854).
- Hugel ,Ch. *Travels in Kashmir and the Panjab* (London 1845).
- Hutton Th. 'Journal of a Trip through Kunawur, Hungrung and Spiti undertaken in the year 1838', *J.A.S.B.* IX (1840) 489-513.
- Lloyd, W & Gerard, A. *A Narrative of a Journey from Caunpoor to the Boorendu pass in the Himalaya Mountains via Gwalior, Agra, Delhi and Sirhind* (London 1840).
- Moorcroft, W. & Trebeck, G. *Travels in the Himalayan Provinces of Hindustan and the Punjab from 1819 to 1825* (London 1841).
- Pemberton, R. Boileau *Report on Bootan* (orig. 1838: rep. Calcutta 1961).
- Thomson, Th. *Western Himalaya and Tibet, a Narrative of a Journey through the Mountains of Northern India during the years 1847-48* (London 1852).
- Traill, G. W. 'Statistical Sketch of Kamaon', *Asiatic Researches* XVI (1828) 137-234.
- Turner, S. *An Account of an Embassy to the Court of the Teshoo Lama in Tibet containing a Narrative of a Journey through Bootan and part of Tibet* (London 1800).
- Vigne, G.T. *Travels in Kashmir, Ladak, Iskardo, the countries adjoining the mountain course of the Indus and the Himalaya North of the Punjab* (London 1842).
- Wilcox, R. 'Memoir of a Survey of Assam', in *Selection of Papers regarding the Hill Tracts between Assam and Burmah and on the Upper Brahmaputra* (Calcutta 1873) 1-82.
- Wilson, A. *Abode of Snow, Observations on a Journey from Chinese Tibet to the Indian Caucasus, through the Upper Valleys of the Himalayas* (London 1876).
- Yule, H. 'Notes on the Khasia Hills and People', *J.A.S.B.* XIII. II (1844) 612-631.

cable which is used as a footpath with two ropes used as handrails; secondly, as a stout cable along which a wooden piece is hauled by means of a rope.

a. *V and U-section and tubular bridges* (Figure 1)

The former, termed *jhulas* in the western part of the mountains, consisted of a series of roughly twisted strands which were thrown across to form the footpath; two other ropes were then suspended about a metre higher, one on either side, as handropes or rails. The three cables formed a V or U-section; they were secured at either end by several stakes driven into a pile of stones or were attached to a framework made of two vertical posts and longitudinal pieces, firmly attached to tree trunks sunk in blocks of stone. The wayfarer crossed, grasping a rope on either side. In the details, these structures were more or less elaborate, according to region.

In western Himalaya (Figure 1, a & b), the sides were sometimes fitted with interlaced ropes or twigs forming a parapet and the platform covered with flat stones; in Ladakh, in order to keep the upper cables equidistant, a cross bar of sticks was laid in the middle of the bridge; in Kashmir, the cables were connected and kept in place by solid supports in the form of a V; in Garhwal, the roadway was made of two sets of cables suspended to the upper ropes.[3]

In eastern Himalaya (Figure 1, c), like in Sikkim, cross pieces were uniformly placed, hung below the flooring, suspended from the two upper canes, which they thus served to keep apart; in the Khasi and Naga hills in Assam or in Bhutan, they were often constructed with interlaced creepers and bamboos forming the shape of a cradle allowing of easy passage; and, in the northern frontier of Assam, where the Abor tribes live, there are even now very elaborate bridges formed of a continuous "tubular" structure [4] (Figure 1, d).

b. *Cableways* (Figure 2)

The second type, or cableway, termed *chhinka* in the western part of the mountains, consisted of a strong rope of many strands suspended across the river and fixed at each end to stout wooden beams which were either weighed down with stones or attached to tree trunks. From this was hung a piece of wood in the shape of an upside-down V or a ring. Drag ropes were fixed from either side of

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3 Vigne, G.T. *Op. cit.*, I, 199; Drew, F. *Op. cit.*, 84-5; Cunningham, A. *Op. cit.*, 170; Wilson, A. *Op. cit.*, 182; Baden Powell, B. H. *Op. cit.*, 234; Hugel, Ch. *Op. cit.*, 175-176, 182, 184; Bellew, H. W. *Op. cit.*, 47-8; Traill, G. W. *Op. cit.*, 142-143.
The *jhula* at Srinagar in Garhwal, 72 m long, had been constructed with great care, probably because of the important traffic plying on these pilgrim routes towards the source of the Ganges, as shown in Daniell's drawing: *Oriental Annual or Scenes in India* (1838) 211-217.

4 Hooker, J. D. *Op. cit.*, I, 49-50, 152, 297, 333-334, II, 30-32, 100; Yule, H., *Op. cit.*, 613-614; Wilcox, R., *Op. cit.*, 48-49; Chater 'Abor-Suspension Bridges', *Royal Engineers Journal* XVI (1912) 217-218.

the river to the piece.

In western Himalaya, like in Kumaon, it could be a simple curved piece of wood with which a man would slide over to the other side with the help of his hands and feet (Figure 2, a & b), or a kind of "cradle" or "saddle" (Figure 2, c); on the Satlaj river, it was a half-hollowed piece of wood with several loops of ropes hung from it to serve as a seat for wayfarers [5] (Figure 2, d & e).

In eastern Himalaya, in Bhutan and along the borders of Burma, hoops or rings were used, hung upon the ropes or rattans which served to support the feet while the hands hauled on the ropes and slid the hoops along. In the Khamti Hills, a kind of basket in which a man might sit was hung on the canes by two loops and could be pulled across by men waiting at the other side of the stream.[6]

These two types of bridges were found all over the mountains from west to east. The first ones, when made with ropes, had an average length of 30 to 40m; with cane and bamboo, they could be between 70 and 100m long. The length of the second kind varied from 20-70m in Bhutan, and to 100m in western Himalaya.

The erection of these bridges demanded much ingenuity and boldness of the builders; they were temporary structures which had to be renovated in fair weather in order to remain sufficiently secure.[7]

c. *Iron chain suspension bridges*

In certain areas of the Indian side of the Himalaya, such as in Nepal and Bhutan, iron chain suspension bridges were also found, composed of several chains stretched parallel to each other and resting on either side on a pile of stones, sometimes topped, in Bhutan, by a kind of tower which served as a shelter or guard-room.[8] These bridges were not temporary structures; as the iron chains were of a good quality, they lasted for a very long period. The smiths of Bhutan, like those of Tibet, had mastered workmanship in iron.[9]

No change or improvement in the design of these suspension bridges has

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5 Forster, G. *Op. cit.*, I, 301; Drew, F. *Op. cit.*, 85 n; Traill, G.W. *Op. cit.*, 142-143; Baden Powell, B.H., *Op. cit.*, 234; Bellew, H.W. *Op. cit.*, 41-43; Gerard, A. *Op. cit.*, 33-34, 37; Vigne, G.T. *Op. cit.*, I 199.

6 Turner, S. *Op. cit.*, 54, 191; Wilcox R. *Op. cit.*, 42, 61.

7 Baden Powell, B.H. *Op. cit.*, 335; Hutton, Th. *Op. cit.*, 496; Wilson, A. *Op. cit.*, 183. These rope and cane bridges succeeded in linking human establishments that were separated from each other by deep river gorges; even in recent times they have been built on the same model in certain isolated valleys of the Himalayas: this is proof enough that they were well adapted to local conditions.

8 Cunningham, A. *Op. cit.*, 167; Traill, G. W. *Op. cit.*, 143; Turner, S. *Op. cit.*, 54-55, 59, 191; Pemberton, R. B. *Op. cit.*, 44-46.

9 White, J.C. *Sikim and Bhutan* (London 1909) 191. Not a single one of these bridges is now standing in Bhutan. Works of this kind are still built, but the iron chains are replaced by cables.

been noticed until the present century. Documents, dating from 1865 and 1868,[10] show rope bridges perfected by British engineers, which look stronger than the local structures of this type, but are built according to the same old principles .

The author of a *Punjab District Gazetteer*,[11] speaking of the Lahaul *jhulas*, writes in 1917: "the problem of substituting something more substantial for these birch-twig *jhulas* has often been considered, but there are certain engineering difficulties which make it probable that the locally made *jhulas* will remain".

In short these structures succeeded in linking human establishments that were separated from each other by deep river gorges.

It is only recently that the ropes and iron chains have been, in most cases, replaced with iron cables.

1.2 Wooden beam and cantilever bridges (Figure 3)

a. *Single-span cantilever bridges*

Wooden bridges were also very well adapted to local conditions. The simplest types often consisted of a wooden beam thrown across a river, but more elaborate and durable were the cantilever bridges whose two cantilever arms were built with timber superimposed from the sides. In the details these structures were quite elaborate. After two wooden and stone-work piers were erected, several tiers or rows of stout beams were built, each one slanting upwards and projecting a little distance over the stream, until they left an intervening space wide enough for beams to be laid across[12] (Figure 3, a). The best examples of these single-span cantilever bridges were found in Bhutan, where they were generally fortified and embellished with towers[13] (Figure 3, b).

The span of these bridges was on an average of 20m and did not go beyond 30 or 40m in any instance. When built with care, they could last for 30-40 years, like those in Kashmir or in Bhutan.[14]

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10 In J. C. Medley's book, *The Roorkee Treatise on Civil Engineering in India* (Roorkee 1877) 108-109, Plate XXII, will be found the description of an elaborate suspension bridge, built over the Chenab River, in Panjab, around about 1865. It was made of hemp, tarred and twisted into hard cable laid rope, supporting a light platform wide and strong enough for the passage of men and animals; the abutments were constructed of the ordinary native masonry of the hills. Also see *Professional Papers on Indian Engineering* V (1868) Plate 26, Kilar rope bridge.

11 *Punjab District Gazetteer* (Kangra District, Lahore 1918) 133.

12 For western Himalaya: Baden Powell, B.H. *Op. cit.*, 333; Cuningham, A. *Op. cit.*, 168; Vigne, G. T. *Op. cit.*, I, 201-202; Gerard, A. *Op. cit.*, 35, 221; Moorcroft W. *Op. cit.*, I, 166.

13 For eastern Himalaya: Hooker, J. D. *Op. cit.*, II, 43; Turner, S. *Op. cit.*, 132, 49 & pl. VIII, f.p. 132.

14 Vigne, G. T. *Op. cit.*, I, 201; *Imperial Gazetteer of India* VIII (London 1885) 65; Turner, S. *Op. cit.*, 133.

b. *Many-spanned cantilever bridges in Kashmir*

Many-spanned cantilever bridges were rare, except in Kashmir on the Jhelam river, where these structures have been much admired by travellers ever since Bernier's time. In the nineteenth century there were thirteen of them between Islamabad and Baramula. Their construction was ingenious.

A stake of wood forming a square compartment rested on a base of substantial stone. The logs were heaped crosswise in tiers usually to a height of 10m. The piles were united by long *deodar* trunks which stretched across from one to the other and were laid on the cantilever principle. This reduced the span, and huge trees were made to serve as girders to support the roadway[15] (Figure 3, c).

These cheap and picturesque bridges were remarkably effective. They were strong because *deodar* is one of the best timbers of India; they were also stable because their skeleton piles offered little resistance to the volume of water brought down at flood time and they could be repaired easily and quickly.[16]

Very little innovation took place in this respect. We know that a single-span bridge was perfected by British engineers over the Satlaj river in 1867,[17] but it was constructed on the same model as the traditional ones. In Kashmir, it is clear that the humble crafstmen who tried and tested empirical formulae proved themselves excellent engineers and bridge-builders, since it is only in the twentieth century that the ancient bridges of Srinagar have been replaced by modern constructions with lighter piles (in 1954, the last bridge of the old type could be seen in the city),[18] As regards single-span bridges, they are still to be found all along the Himalayas, where long and straight trees abound and furnish the necessary cantilevers.

Concluding remarks

Whether permanent or temporary, these constructions, made of rope, cane, iron chains or wood, dotted all the routes leading to the Tibetan plateau and were on the whole very well adapted to the filiform traffic found everywhere in the Himalaya.

As can be seen from the above examples, they were built with the same materials and on the same principles as the bridges of Tibet, South and West

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15 Baden Powell, B. H. *Op. cit.*, 335-336; Moorcroft, W. *Op. cit.*, II, 122-123; Bellew, H. W. *Op. cit.*, 55; Hugel, Ch. *Op. cit.*, 117; Bates, C. E., *A Gazetteer of Kashmir and the Adjacent Districts of Kishtwar, Jammu and Punch* (Calcutta 1873) 11.

16 Baden Powell, B.H. *Op. cit.*, 335; Bellew (*Op. cit.*, 56) reports that, during the time of the great flood of 1869, which swept away many houses, including his own, on the bank of the Jhelam river, the Srinagar bridges stood firm.

17 *Professional Papers on Indian Engineering* IV (1867) f. p. 82, wooden bridge of Vangtu.

18 Gervis, P. *This is Kashmir* (London 1954) 21 and f. p. 77.

China, described by Needham.[19]

This stability in traditional engineering is due mainly to the fact that, throughout the nineteenth century, there was no need in the mountains to build modern permanently bridged roads. The Himalayas did not have then the same strategic value as they have today and, for the colonial power, there was not much point in penetrating them, at least in a military and political sense.[20] Since existing practices were based on the accumulated experience of years, there was no demand for imported technology and therefore no confrontation between tradition and modernity.

The conditions were entirely different in the plains and plateaus of the Indian peninsula.

2. Bridges of the Indian Peninsula and European Engineering

There, because of the great average size of the rivers, the immense volume of water periodically brought down by them during floods and the erratic and unstable character of their channels, the construction of bigger bridges was necessary. But, due to the lack of accurate and valuable data, and the unawareness of many of the problems presented by water courses, relatively few masonry bridges were erected in the peninsula before the establishment of British power.

In western and southern India, the main works that we have noted were found at the entrance to old regional capitals or near places of pilgrimage; in the north, they were scattered over the great ancient highways, especially on the roads that radiate round Jaunpur in Uttar Pradesh and the pilgrim route from Bengal to Jagannath Puri in Orissa.

However, notwithstanding their limitations, the builders had a noteworthy engineering skill which deserves to be presented, as some of their achievements were adopted by British engineers.

2.1 Indigenous road bridge-building at the beginning of the nineteenth century

Two types of bridges were found: stone beam-bridges and brick or stone arch-bridges.

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19 Needham J. *Science and Civilisation in China* V:III (London 1971) 145-210. It would be interesting to know more about the connection that existed between the Himalaya and the Indian peninsula on one side, and between the Himalaya and the high plateaus of Central Asia on the other. This would allow us to raise the important question of the origins of the different techniques used in bridge-building and also the stages of their spread, in this part of the world.

20 The road from Sikkim to Lhasa via the Chumbi valley was built by British engineers in 1904, but the road from Raxaul to Kathmandu was only opened in 1956 and the road to Paro in Bhutan dates from 1962.

a. *Stone beam-bridges*

• *Bridges on columns*

In the Brahmaputra valley, especially in the Gauhati region, there existed gneiss or granite bridges made of solid masonry, built without lime or mortar. One of them was still in good condition in the middle of the nineteenth century: it had no arches, the superstructure being a platform, 42m long, with a slight curve, composed of stone slabs, resting on an understructure of pillars, divided by large solid buttresses; the component parts of the whole were assembled by means of iron pins.[21]

• *Corbel vaulting bridges*

In Orissa, at least fourteen corbelled bridges, built probably between the eleventh and fourteenth centuries, were noticed at the beginning of our period by European observers, and at least two of them are still used today for traffic.

They were built of sandstone and laterite on the horizontal corbel formula, in which the arches are formed by making each successive layer of masonry overlap the layer below, until the two piers come at the top to within a foot of each other; then, on the space between, a long narrow block of stone was laid as a sort of keystone. The best preserved, the Atharanala bridge near Puri, is 84m long, 5.4m wide and has 19 openings[22] (Figure 4).

It is interesting to note that these structures were built on the same principles as the khmer bridges made of laterite, erected in Cambodia by Jayavarman VII in the twelfth century, along the principal roadways, and varying in length from 6 to 49m;[23] but this early transfer of technology is outside the limits of our study.

• *Bridges built on massive piers of hewn stone*

Bridges resting on massive piers of hewn stone existed in the Dekkan. The most colossal is the aqueduct-bridge of Vijayanagar raised over the rocky bed of a branch of the Tungabhadra river: constructed like the other edifices in the ancient capital, with huge blocks of stone and enormous lintels, it consists of impressive piers. A few others like this have been found over watercourses in Tamilnadu.[24]

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21 Hannay, S.T. 'Brief Notice of the Sil Hako or Stone Bridge in Zillah Kamrup', *J.A.S.B.* X (1851) 291-294. An earthquake destroyed it almost completely at the beginning of this century (Bloch's report in *Annual Report of the A.S.I., Bengal Circle* (1903) 18-19).

22 Stirling, A. in *Asiatic Researches* XV (1825) 336-338; *List of Ancient Monuments of Bengal* 478-480, 488.

23 Boisselier, J. *Manuel d'archéologie d'Extrême Orient, 1ère partie, Asie du Sud-Est, t. I, Le Cambodge* (Paris 1966) 107 and pl. XVIII, 3.

24 Personal observations.

• *Bridges on square stone pillars*

In South India and the northern part of Srilanka, there were bridges built on square stone pillars founded on hard rock.

These structures consisted of square pillars of granite or gneiss cut from the rocks, placed upright in rows as long as the width of the bridge and secured at the bottom by being let into the solid rock. Above were placed stones, contiguous to each other and stretching from row to row.

In 1804, a bridge of this type, 420m long, was constructed at Srirangapatna on the northern branch of the Kaveri (in Karnataka) and called Wellesley bridge in honour of the governor general of the period.[25] At Sivasamudra, over the same river, in 1821 and 1832, were also built two bridges, one being 305m long, supported by 400 pillars[26] (Figure 5).

These bridges were erected according to ancient methods. At Sivasamudra, the builder, relying on the skill and judgement of the early engineers, even raised them on the ruins of ancient bridges of the same type, describing a sinuous line. The principles of construction were good and the best proof of the excellence of their form and structure is that some of them have withstood the violence of repeated floods for the last 160 years and are still in existence and in good condition. This type of structure is found even today in the extreme south of the peninsula, mainly on canals and rivulets in the Tambraparuni valley.[27]

b. Masonry arched bridges

Most of the arched bridges that have been surveyed, dating from the Mughal period, were of stone or brick; some were built with large dressed stones and excellent mortar; others were of inferior masonry; their shapes varied according to the nature of rivers and the features of the regional architecture. In Kashmir and Bengal, where rivers are navigable, they had humpbacked decks and approaches intended for the passage of boats. Elsewhere, we see bridges with smoothly graded decks; the height of their arches decreasing gently from the centre towards both sides. But generally we observe a marked preference for arches of equal height (Figure 6 & 7).

All of them, however, appear to constitute a massive dam of masonry or brickwork, perforated with pointed arched openings, and affording an open area for the passage of water, much less than the area of obstruction presented by the

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25 Buchanan, F. *A Journey from Madras through the Countries of Mysore, Canara and Malabar* I (London 1807) 61-62.

26 Ramaswami Mudeliar in *Journal of Literature and Science* I (Madras 1834) 83-84.

27 Personal observations.

piers, which is a great fault.[28]

However, if, in spite of their defects, most of these bridges, like the famous (and picturesque) Akbari bridge over the Gomati river à Jaunpur, built in 1564, 196m long,[29] have successfully resisted the floods of centuries, it is because an ingenious method, based on the sinking of brick wells, was used for foundations, an indigenous conception which has been "acknowledged as the standard resource in the system of hydraulic architecture of Upper India".

Use of wells as foundations (Figure 8)

Where hard substratum was available, bridges were laid on firm, rocky beds, but, in alluvial valleys, strong foundations were needed.

Piles would have been inefficient in shifting alluvium, for the people had no machines with which wooden pieces of a sufficient length could be driven; timber moreover could not be procured easily. On the other hand, bricks could be made at all places, and then the bridges were everywhere founded on small wells usually filled with lime and broken bricks and supporting a continuous masonry platform.[30] In 1801, a French officer, Legoux de Flaix, published a memoir in which he demonstrated that Indian bridges could have no better foundations[31] (Figure 8, a & b).

Early works by British engineers

Little detailed information is available as to the early British works. It is known however that, until the introduction of railways to India in 1853, road making was energetically carried out. The famous highway, "The Grand Trunk Road", from Calcutta to Peshawar, was started under the government of W. Bentick and permanently bridged throughout. In 1855, it was completed to Karnal (that is 1000 miles from Calcutta!). In the year 1840, work was commenced on a great trunk line of road designed to extend from Agra to Bombay. Then, it was decided to build the great Dekkan road, from Mirzapur to Bombay, and, in 1856, the bridging of this highway was initiated. By about 1870, nearly all the large undertakings had been completed.

European engineers, to a high degree unfamiliar with the characteristics of the great Indian rivers, constructed bridge structures (except in rocky places) with

28 For the arched bridges, see the table giving an informative and descriptive account of the works in my book *The Ancient Bridges of India* 26-49, where all the references will be found.

29 Even as late as the year 1871, 3m of water passed over the roadway carrying away all the shops that then existed on the piers (*Ibid.*, 39).

30 See Abbot F. *Practical Treatise on Permanent Bridges for Indian Rivers, with a description of the use of wells for foundations by Capt. Cautley P. T.* (Agra 1850) 64 pp., 4 pls.

31 An extract of this memoir can be found in Legoux de Flaix *Essai historique, géographique et politique sur l'Indoustan* (Paris 1807) t. I, 424-442, *Atlas*, pl. X.

the piers founded on cylindrical wells, or on perforated blocks of brickwork, sunk into the sand of the rivers, until a bed of clay was met with, in the manner peculiar to Upper India, which continued to be the most common method used for foundations.

The Palamcotta bridge constructed over the Tambraparuni river in 1843 had three consecutive piers built on rows of small wells sunk to a depth of ten feet (Figure 8, c). The largest of the road bridges, built between 1866 and 1873, over the Kanhan river, to the North of Nagpur, also had its piers designed so as to be founded on wells.[32]

Railways bridges

When the railways were introduced to India in 1853, the construction of great viaducts, bridges or culverts became necessary. The openings were then either arched over or spanned by beams or girders of wrought-iron or steel, sometimes of great stretch, supported on masonry and a line of intermediate piers, so disposed as to cover the entire waterway of the river.

As regards the foundations, the indigenous method was reduced to a remarkably developed art by British engineers. They were formed by sinking wells or cylinders of brickwork, either singly or in groups, on which the pier superstructures were built, or by sinking the entire pier of an elliptical or other form by means of well openings on chambers provided in the mass of the masonry.

The first example of those large iron works was the bridge over the Son River, in Bihar, 1,310m long, constructed between 1856 and 1862 and consisting of 28 decked spans with piers carried on brick wells, sunk to a depth of 10m beneath low water into a stiff bed of yellow clay.

The bridge over the Tonse river, to the east of Allahabad, in the Mirzapur district, had seven spans of latticed iron girders and the piers and abutments were constructed of brickwork also borne on groups of brick wells. In the same way, the Delhi Jamuna bridge consists of twelve deck spans carried on ten brick wells, disposed in two rows of four each.[33]

Prominent and important iron and steel railway bridges

Emphasis should here be given to the range of problems British engineers had to solve in connection with large bridge construction in India and their remarkable achievements in the last quarter of the nineteenth century. Our observations will be confined to a few fine examples of railway-bridge engineering.

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32 MacGeorge, G.W. *Op. cit.*, 95, 96-98.

33 *Ibid.*, 333-335, 336-337, 338.

Over the Hoogly tidal channel, at Calcutta, the famous Jubilee Bridge, opened in 1887, is a noteworthy engineering work, constructed for a double railway line. Its superstructure consists of three sections of steel girders, curved in bow form above, with two piers supporting the central cantilevers; each one being enclosed by a wrought-iron caissson; the length of the bridge proper is 364m.

The magnificent bridge over the Indus at Attock in Panjab on a section of the North-western Railway running from Lahore to Peshawar, opened in 1883, was designed to meet peculiar and unusual conditions (abnormal floods, earthquakes). An open wrought-iron framework was employed, because it is a more elastic material than stone or brick for the piers. It consists of three spans with piers formed or columns connected by horizontal and diagonal cross-bracings, and steel girders; its total length is 496m.

The Lansdowne Bridge (so named after the then viceroy of India) over the Indus at Sukkur, completed in 1889, was for a period of time the largest in the world as regards magnitude of clear rigid span. It consists of single cantilevers, one on each side of the channel, each cantilever virtually composed of a gigantic shear legs, or guyed crane, used to support the bridge platform. The total weight of steelwork in the huge main span is 3316 tons![34] At that time, these structures compared favourably with similar constructions in any part of the world.

Conclusion

To conclude, it can be said that these works of exceptional magnitude and importance may be truly designated as stupendous, and Kipling's tribute to the engineering genius of the Englishmen is "technologically" justified. But we should not overlook the fact that there existed in the Indian subcontinent hydraulic techniques which served their purpose so well that they were adopted by European engineers.

Most of the ancient bridges of Upper India, in the Mughal period, were founded on brick wells sunk into the sandy beds of rivers and, during the greater part of the nineteenth century, there was in this respect no fundamental innovation, as the most usual system followed by British builders was an adaptation of the old native conception.

European experts, recognising its suitability, have highly improved and developed this practice and have introduced numerous mechanical contrivances for rapidly sinking the cylinders to great depths; but nevertheless, *the principle was entirely derived from indigenous sources.*

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34 *Ibid.*, 338-346, 382-389, 389-395.

It is therefore manifest that, at least in the domain of bridge-building, the East and West interaction in the subcontinent proved beneficent, since it resulted in both acceptance and improvement of Indian skill by European technology.

Figure 1: Types of V and U-section suspension bridges, adapted from photos: (a) over the Kishanganga River at Rampur, Kashmir, (b) over the Chenab River, Jammu, (c) over the Tista River, Sikkim, (d) tubular bridge of the Abors, Assam.

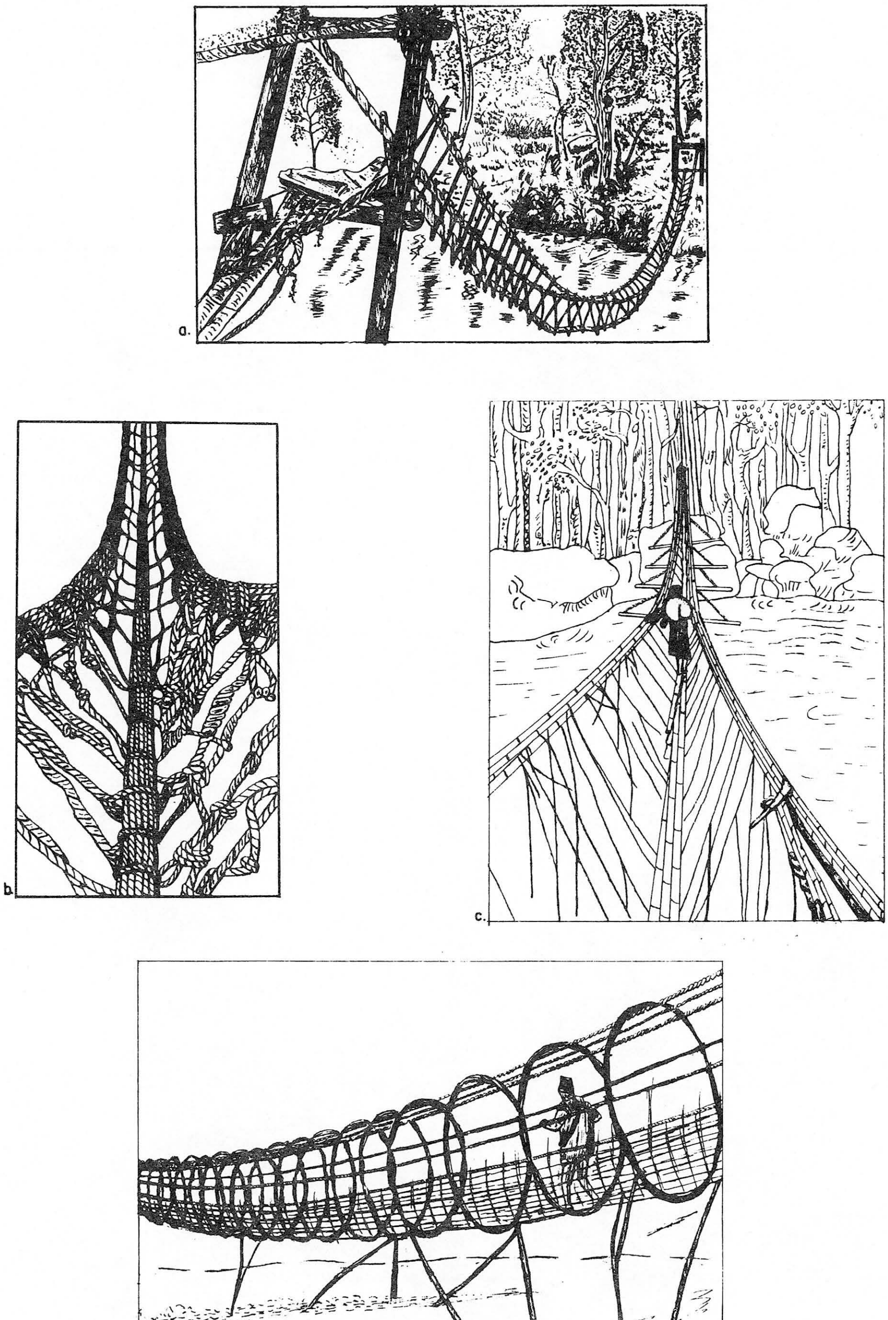


Figure 2: Types of cableways, adapted from photos: (a), (b), (c) over the Kali River, Uttar Pradesh, (d), (e) over the Satlaj, Himachal Pradesh.

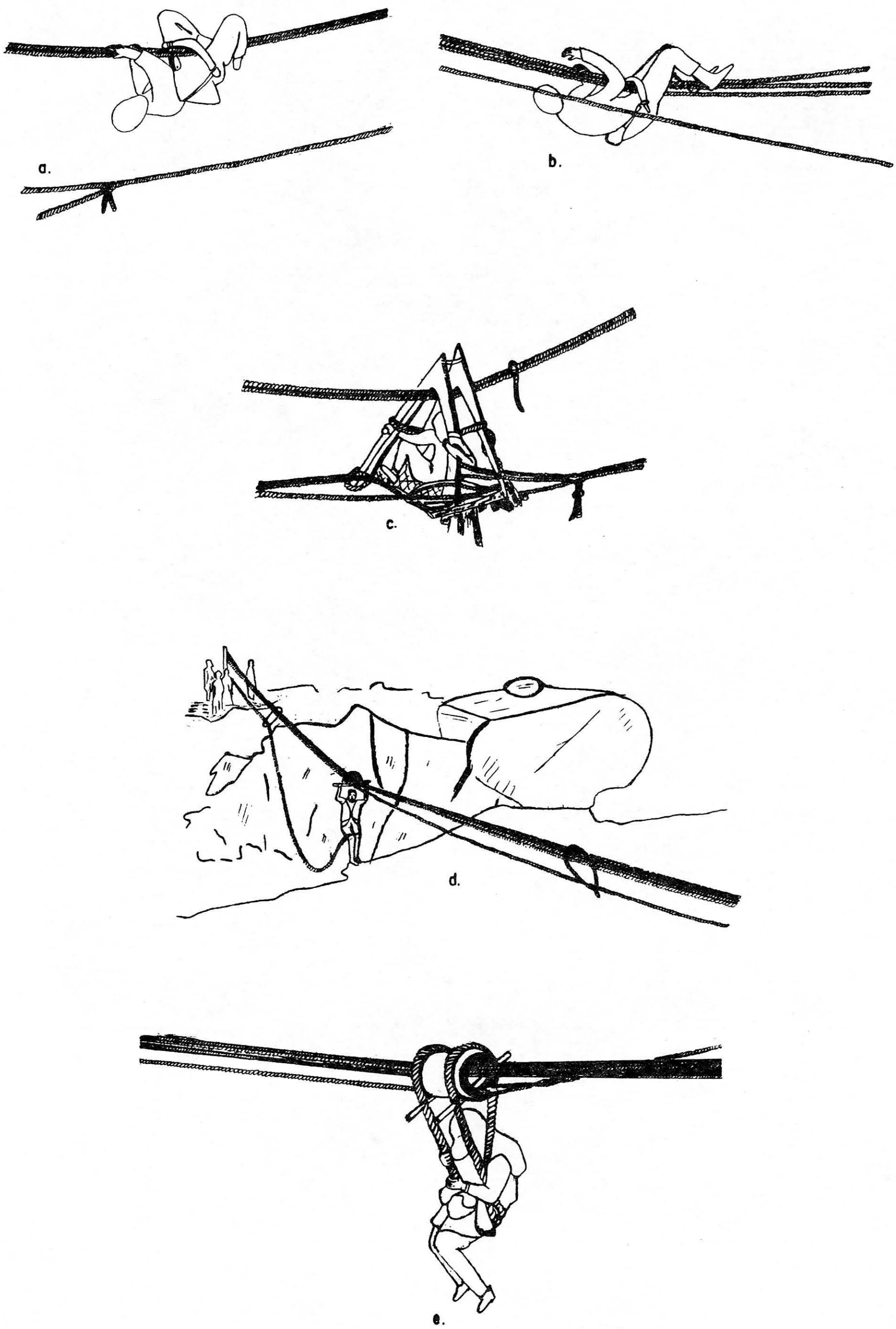
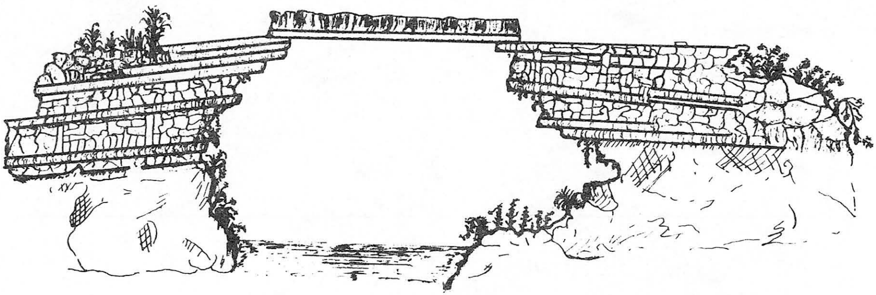
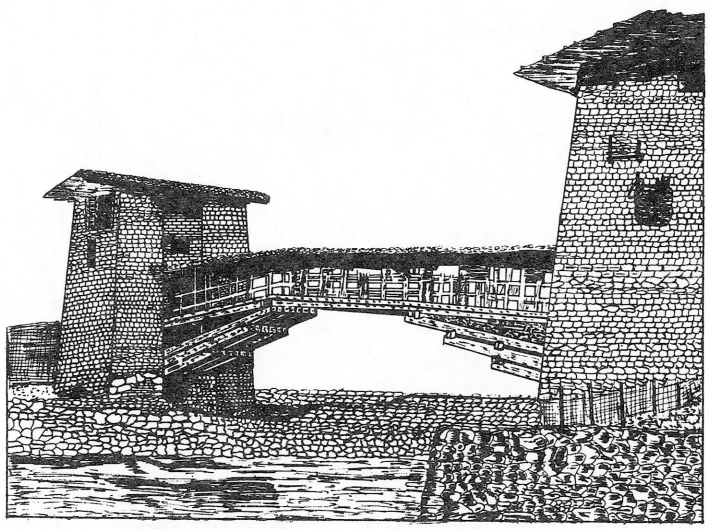


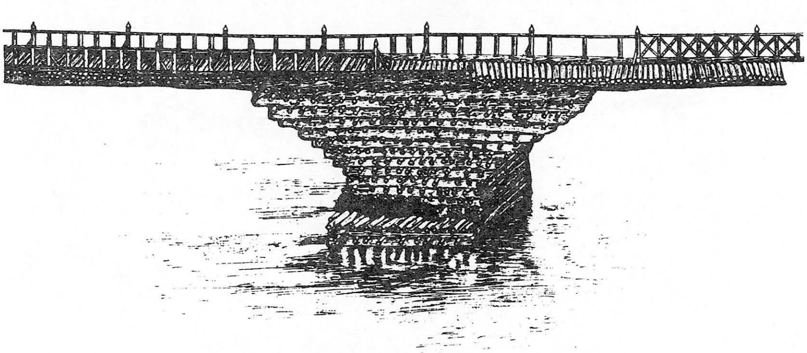
Figure 3: Types of wooden bridges, adapted from photos: (a) single-span cantilever bridge over the Jamuna River, Uttar Pradesh; (b) same type of bridge over the Pochu River, Bhutan, (c) wooden pier of a many-spanned cantilever bridge at Srinagar, Kashmir.



a.



b.



c.

Figure 4: Stone beam bridge (corbel vaulting), over the Madhupur Stream, at Puri, Orissa (plan by Stirling, 1825).

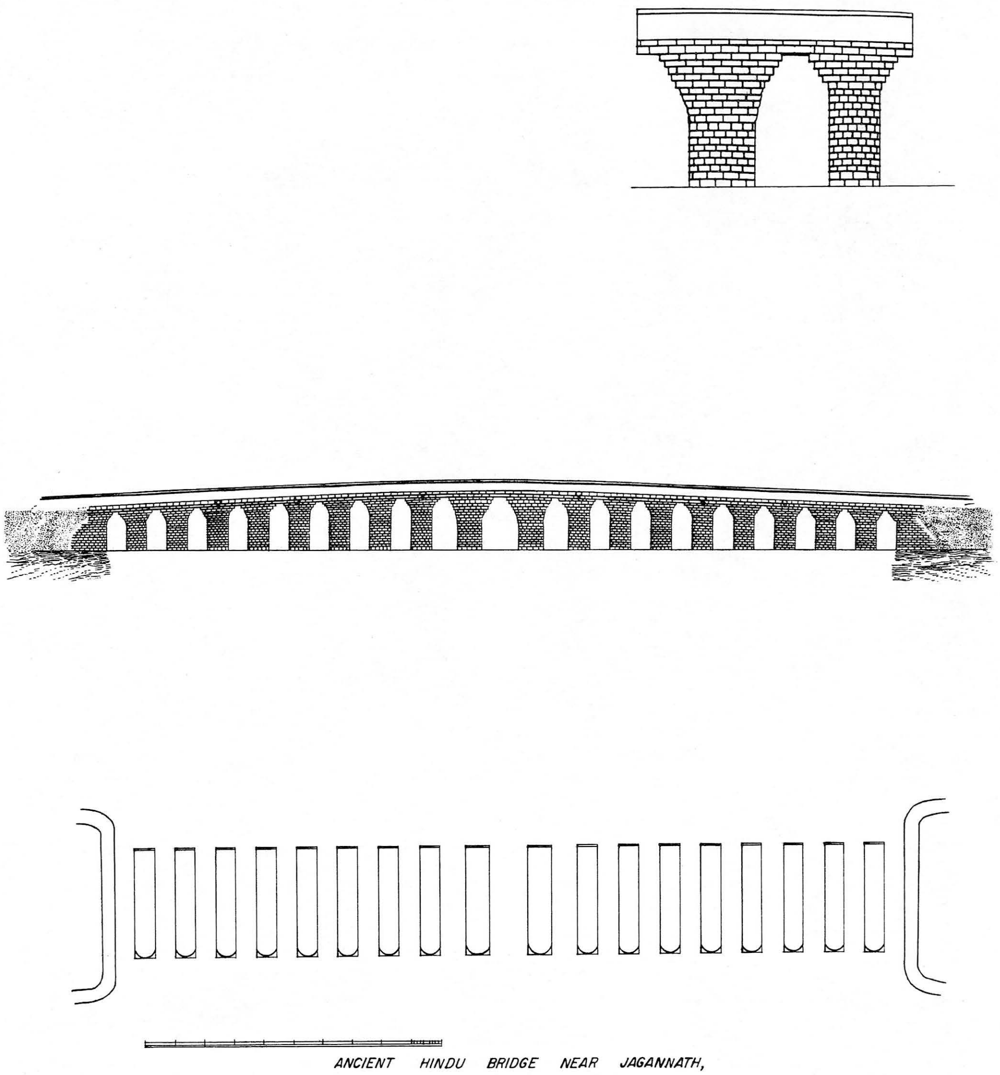


Figure 5: Stone beam bridges on square stone pillars, over the Kaveri River, at Sivasamudram, Karnataka (plans by R. Mudeliar, 1830).

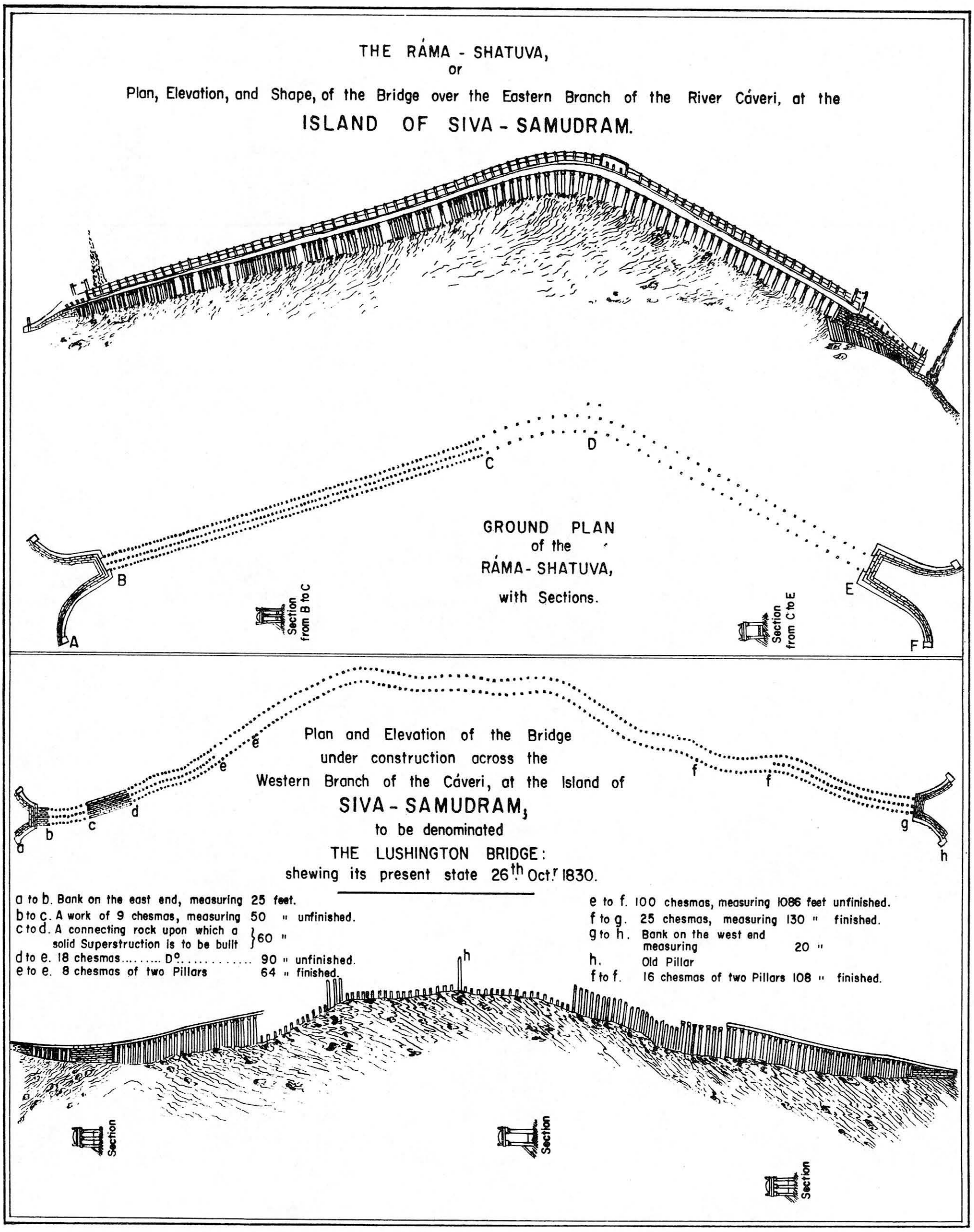


Figure 6: Types of arch bridges, adapted from photos: (a) the Mughal arch, (b) over a stream, at Hadaf, Bihar, (c) over the Gomati River, at Jaunpur, Uttar Pradesh, (d) over a canal, at Srinagar, Kashmir, (e) over the Non River, Uttar Pradesh, (f) at the entrance of Bharatpur Fort, Rajasthan.

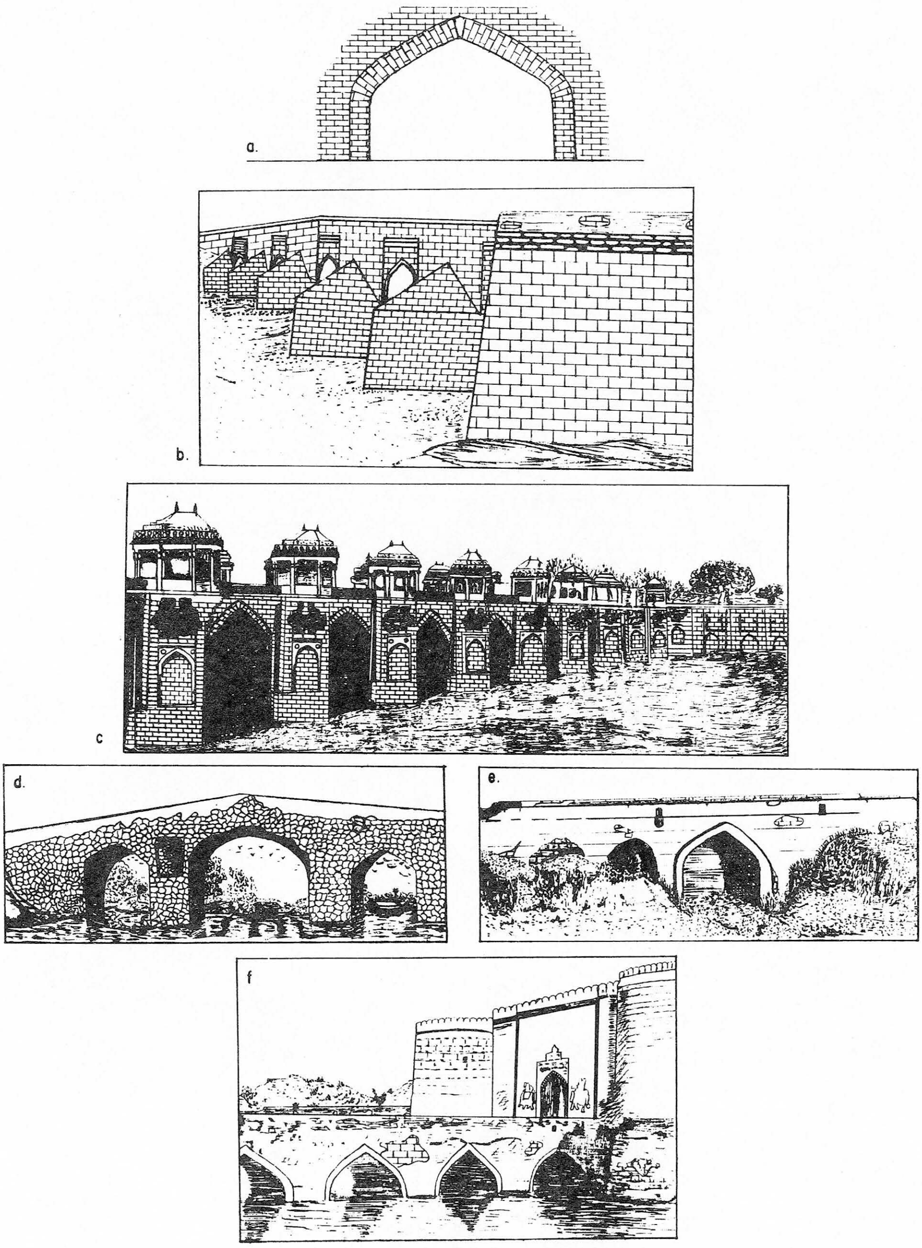


Figure 7: Map of the indigenous stone and brick bridges in India.

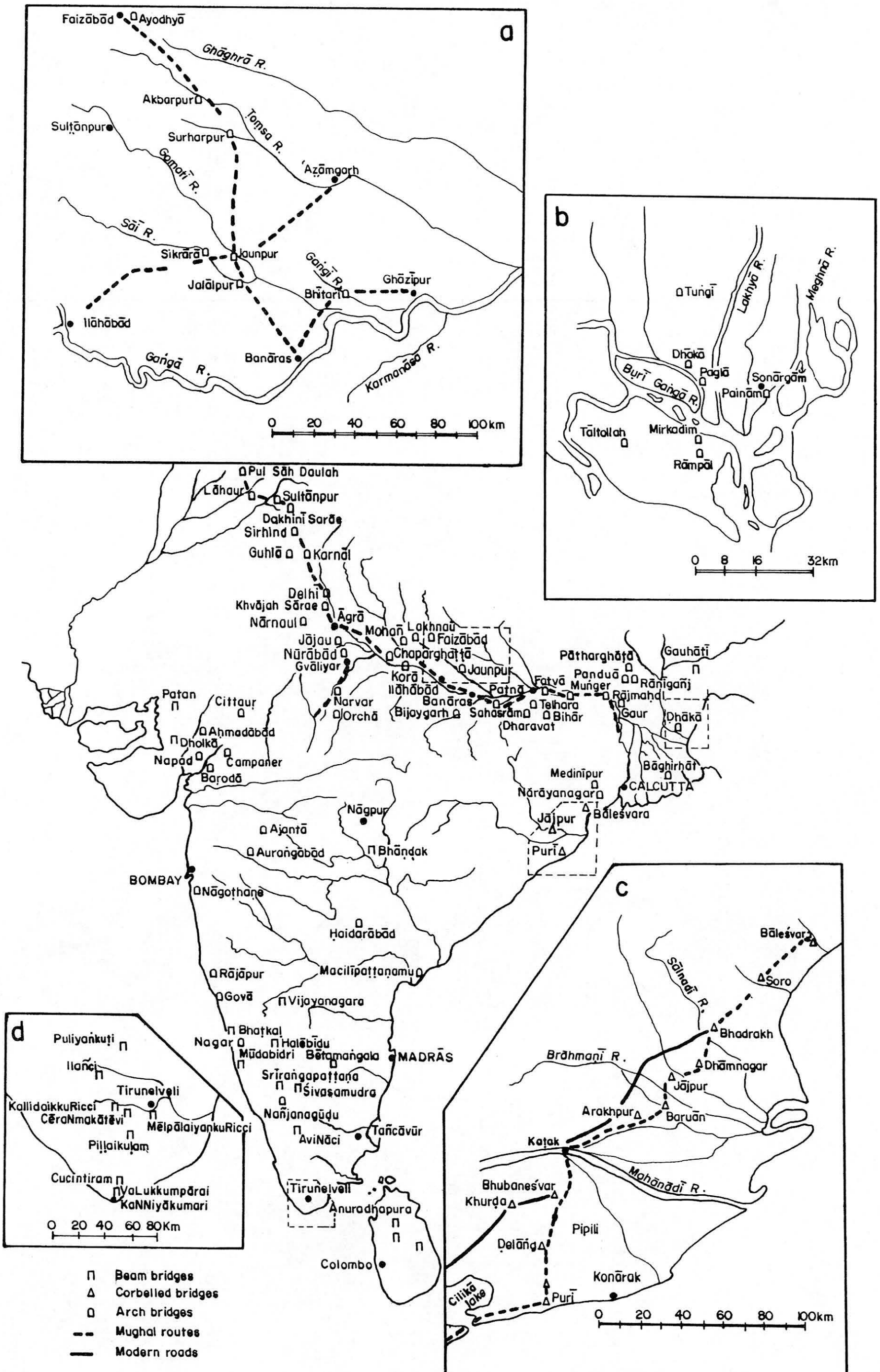
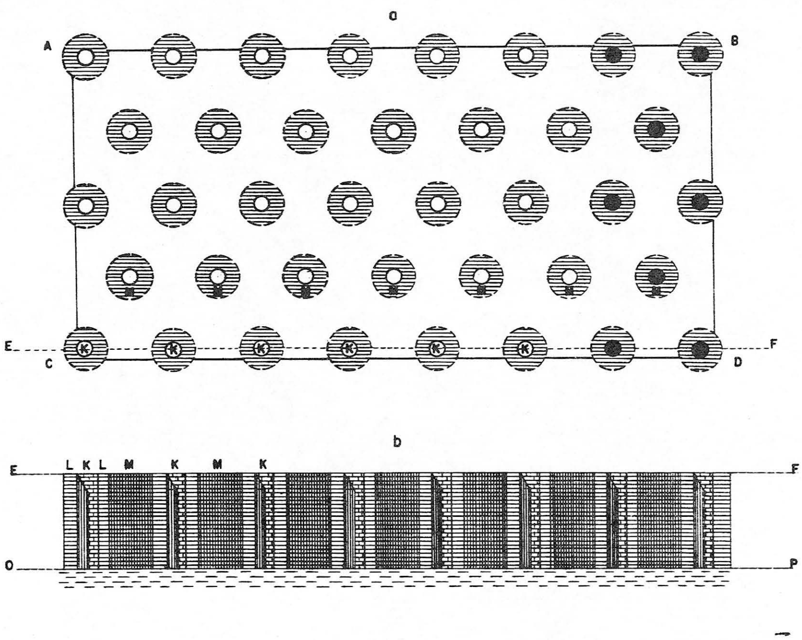
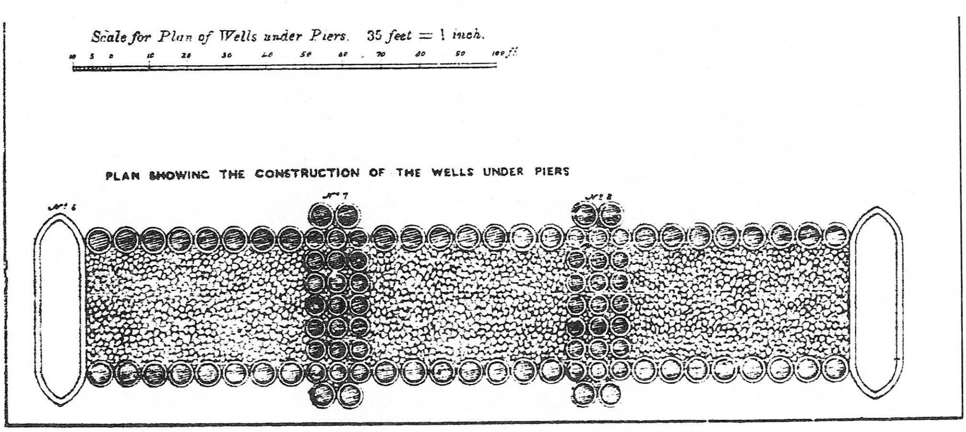


Figure 8: Use of wells in foundations: (a) and (b) rows of wells below the pier of a bridge (plan and longitudinal section by Legoux de Flaix, 1807), (c) plan showing the construction of the wells under the piers of the Palamcotta Bridge, over the Tambraparuni River, 1843 (plan published by J. C. Medley).





c.