The Rich Heritage of Construction Engineering in India

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INTRODUCTION

1. Vāstu & Shilpa.

2. Vāstu is from *Vastu* that refers to materials or medium.
   Prthvi, Ap, Tejas, Vāyu, Ākāsha
   Earth, Water, Fire, Air, Space
3. Shilpa is artistic creation/replication of nature/divine concepts, by humans with the help of *Vāstu*. (Music, Dance, Painting, Architecture, Sculpting….fine arts were included in *Shilpa*)

3. Vāstu and Shilpa are the two faces of the same discipline.

4. Civil Engineering as different from Military Engg. is a colonial concept introduced by the British.

5. Construction Engg. is same as Civil Engg. This has well known sub-divisions …

Reconnaissance, Site Selection, Roads, Bridges, Water Resources, Building Materials, Foundation, Construction Practices, Residences, Schools, Temples, Offices & Civic Utilities…..

Architecture; Engineering; Indian Knowledge System

*Engineering as IKS → (Manufacturing, Construction)
Historically *Construction Engineering;* Metallurgical Engineering

*Is Architecture different from Civil Engineering? *YES, at present as a Colonial Legacy*

*Traditional Indian Point of View: Architecture and Civil Engineering are the two faces of the same coin. They are like: Theory & Practice. Like: Lakshana & Lakshya. Like: Shilpa & Vaastu. Like: Form & Content. Like: Project Planning & Field Work.

One can trace the origin of Technology also here as when artistic plans had to be constructed or produced in large numbers: Residences, Water Resources, Agriculture, Irrigation Structures, Civic Amenities, ……Textiles, Pottery, Ceramics, Household Utensils,…..

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The Heritage of Construction Engineering can be appreciated better if you keep in mind the above idealistic interplay between *Art and useful Construction* as Civil Engineering!

From the ancient environmental perspective, all human construction activity is to reproduce on urban/rural scale naturally existing balance among the five basic elements:
Prithvi, Ap, Tejas, Vāyu, Ākāsha *for the benefit of the society.*

The first two refer to Earth and Water: The Material; Vaastu
The other two refer to Lighting and Ventilation

The last is an esoteric concept of plans to be made of generic square patterns on Earth, following Sun's shadow: The Vaastu-mandala. Division of Space has to follow some principles. For example the central point/part is left open to sky.

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बुद्ध्याऽन्विष्य यथा न्यायं वृक्षशाखा गता यथा।
यथा कृतास्तु तैः शाखास्तस्माच्छालास्तु ता स्मृताः॥
एवम् प्रसिद्धाःशाखाभ्यः शालाश्चैव गृहाणिच।
तस्मात्ताश्च स्मृताः शालाः शालात्वं तासु तत्स्मृतम्॥ (Br.Pu. I.7.118-119)

The most basic construction was Shaala or Hall with a roof cover. Brahmanda Purana says that this was inspired by studying how trees branch out and provide shade and shelter.

Almost all traditional Indian structural forms have originated out of cane, wood, timber based architecture and geometry. Nearly same principles have been retained with mud, brick, stone, metal and lime-concrete. Innovation and growth of construction engg. Has been synonymous with new building materials.

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I will not talk about History; but present a few specific examples in a narrative style.

Any Ancient Tradition to be called a Knowledge System should have fairly developed Theory and Practice. We have both in good measure widely spread over in all parts of India. More than 50 Shilpa/Vaastuvidya theoretical texts in Sanskrit and regional languages starting from around 500-300 BC almost parallel with the cities: Pataliputra, Avanti, Kashi, Kanchi,… are available. This does not include unpublished palm leaf manuscripts.

For the *practice of engineered construction* the evidences are standing all over the subcontinent.

We know that all branches of Civil Engineering were practiced in the Harappan cities way back around 2500 BC. Town Planning, Roads, Water Supply, Sanitation, Residences,…. that remain important to this day.

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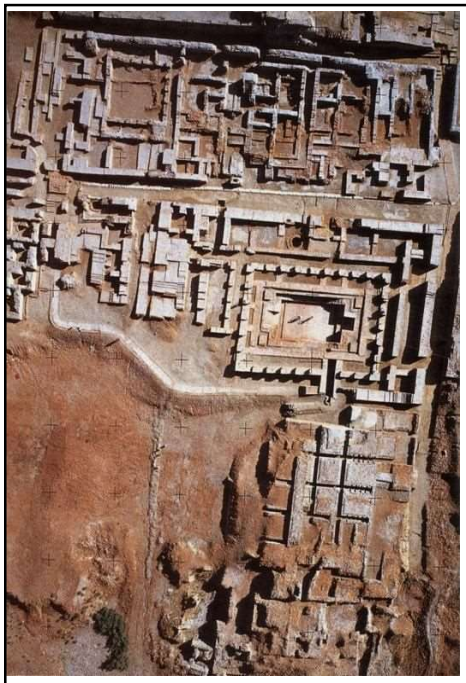

Aerial view of Mohenjo-Daro city

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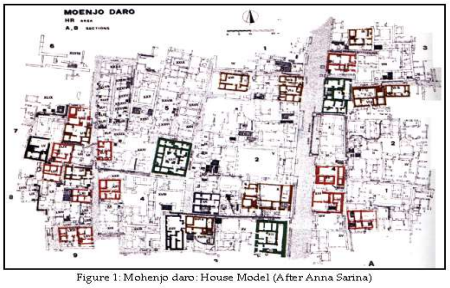

Figure 1: Mohenjo daro: House Model (After Anna Sarina)

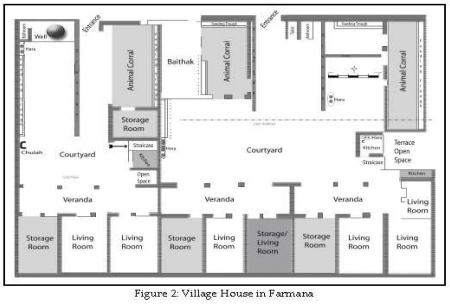

Figure 2: Village House in Farmana

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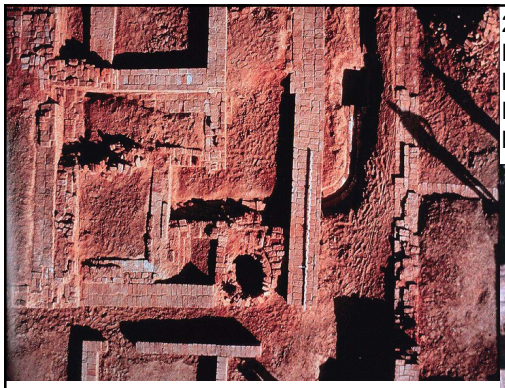
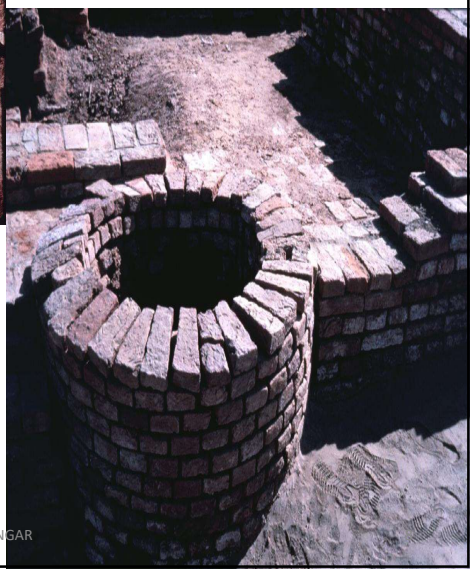
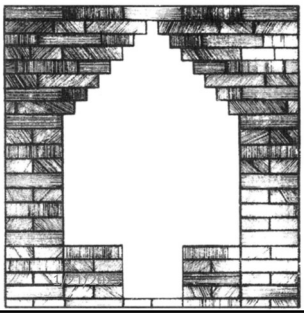
After Lahiri & Shinde



2450 BC
Mature Harappan period. 1 well per 3 houses! More than 700 wells in Mohenjodaro. Each house had its own bath and toilet. Population: 40-50,000.





Corbelled culvert for drainage. Surprisingly they did not use arches even though the wells were circular

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Water Supply and Sewage Disposal at Mohenjo-Daro
Author(s): M. Jansen
Source: *World Archaeology*, Vol. 21, No. 2, The Archaeology of Public Health, (Oct., 1989), pp. 177-192

The construction of the actual basin is a technical masterpiece which testifies to the high standard of Harappan engineering. The 1.35m thick innermost shell, forming the basin side walls and floor, was composed of specially manufactured, carefully uniform bricks pointing inwards and laid so precisely in stretcher bond with gypsum mortar that the joints were only a few millimeters wide. Sandwiched between this inner brick shell and an outer one 3cm thick was a 3cm thick insulation layer of bitumen which the second brick shell prevented from shrinking.

Bathing and toilet facilities

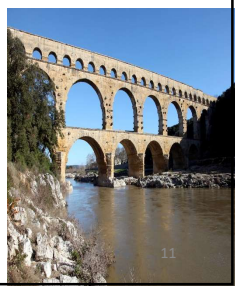
The level of technical accomplishment and sheer frequency of the bathing platforms in Mohenjo-Daro make them unique in the ancient world. Even in Mesopotamia, where the use of a standard-sized brick as the smallest building construction element can be paralleled in the Harappa Culture, such bathing facilities were practically unknown.

Sewage system

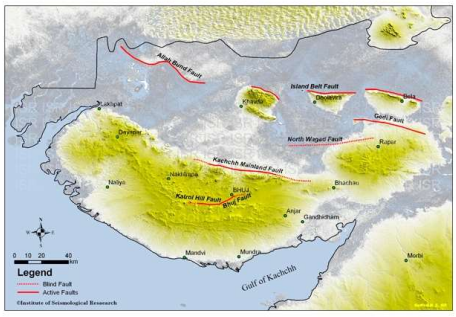
An astonishing feat of civil engineering achieved by this culture over 4,000 years ago is the network of effluent drains built of brick masonry along the streets of Mohenjo-Daro. The drains mostly ran along past the houses on one side of the normally unpaved streets, some 50 or 60cm below the surface. U-shape in cross-section, the sides and bottom of the drains were built of bricks set in clay mortar while various coverings could be used for the open top. These covers, whether loose bricks, flagstones or wooden boards, could be removed for cleaning as required.

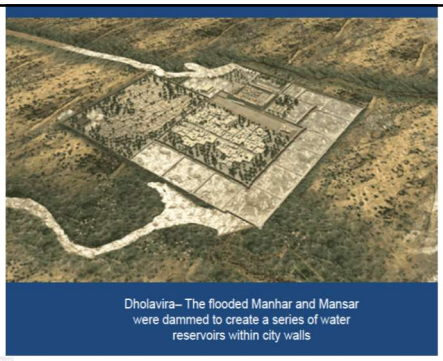
THESE ARE HERITAGE SITES & CITIES, MANY STILL AWAITING EXCAVATION; SHINING EXAMPLES OF WHAT MODERN ENGINEERS CAN STILL LEARN FROM HISTORY

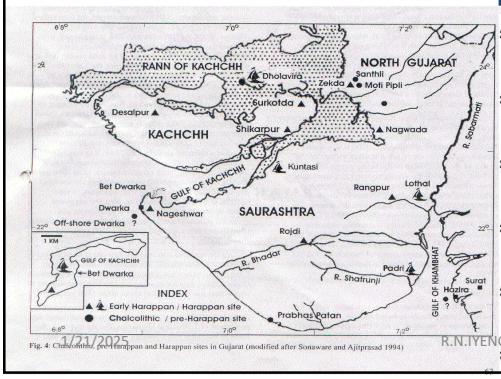
the inner-urban water supply and effluent disposal systems stand out as major achievements of the mature Harappans. Here, for the first time in the history of mankind, such waterworks were developed to a perfection which was to remain unsurpassed until the coming of the Romans and the flowering of civil engineering and architecture in classical antiquity, more than 2,000 years later.

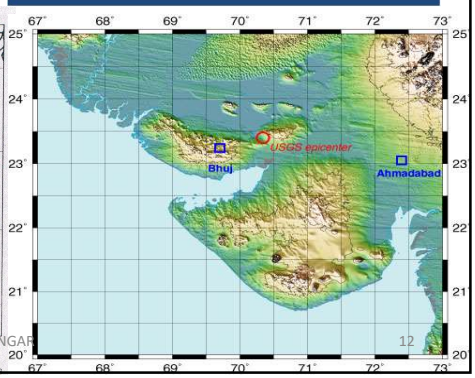


Roman Aqueduct 20 BC




Dholavira– The flooded Manhar and Mansar were dammed to create a series of water reservoirs within city walls





COLLAPSE OF BRONZE AGE CIVILIZATIONS ?

Why and How did the Indus-Sarasvati River Civilization suffer a Great Disaster ?

Civil Engineers have to address natural disasters and damages to habitat. Minor disturbances may just cause some damage that a resilient community can withstand. If the disaster is of catastrophic proportions, extensive reduction in population, panic, migration and sharp changes in cultural discourse are the results. Drying up of Sarasvati (whatever might be the reason) appears to have been a disaster of serious consequences.

From modern studies we know that NW-India including Gujarat, Rajasthan is prone for earthquake damage. Severe loss of habitat for prolonged period can cause discontinuity in construction practices.

BRICKS BURNT & DRIED.

GEOMETRY CONCERNING BRICKS IN VEDIC LITERATURE

KNOWLEDGE OF THE SO CALLED PYTHAGOREAN RELATION OF RIGHT ANGLE TRIANGLES TO PRODUCE RIGHT ANGLES IN CONSTRUCTION DESCRIBED IN VEDIC TEXTS

THIS LITERATURE BELONGS TO ~4000-500 BC IN ORAL FORM.

AS FIXED WRITTEN TEXTS AFTER 500 BC

SHRINKAGE OF BRICKS SPECIFIED IN THE VEDIC LITERATURE CALLED SHULBA SUTRA

BRICKS OF VARIOUS SHAPES: RECTANGLE, SQUARE, TRIANGLE, WEDGE.

9.1. The decrease (in shape) suffered by the bricks due to drying and burning is made good by further addition so as to restore the original shape.

9.2. The decrease is always by one-thirtieth part of the original; hence the same is to be added to have the original shape.

9.3. A brick of 150 (sq.) *aṅgulas* decrease by 6 (sq.) *aṅgulas;* the area of the brick other than this is deformed (or not natural).

Vedic Altar built out of burnt bricks. 50'x40'x5'(approx). Himalayas Purola, Uttarakhand. 1 cent BC.

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KAUTILYA'S ARTHASHASTRA (~400 BC)

RAINFALL MEASUREMENTS. DESCRIPTION OF THE MEASURING VESSEL. QUANTITY OF RAINFALL.

FIRE SAFETY REGULATIONS IN THE CITY AND ITS ENFORCEMENT

Penalty for not following fire safety regulations could range from one week to one month salary of a palace official.

CITY OF PATALIPUTRA

~500 BC

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Primary Construction Material was Timber. Hence Fire Safety Regulations were also stringent.

Kindling of fire shall be prohibited during the two middlemost parts of day-time divided into four equal parts during the summer. A fine of 1/8th of a *pana* shall be imposed for kindling fire at such a time.

Masters of houses may carry on cooking operations outside their houses.

(If a house-owner is not found to have ready with him) five water-pots (*pancha ghatínám*), a *kumbha*, a *dróna*, a ladder, an axe, a winnowing basket, a hook (such as is used to drive an elephant), pincers, (*kachagráhini*), and a leather bag (*driti*), he shall be fined ¼th of a *pana*.

They shall also remove thatched roofs. Those who work by fire (blacksmiths) shall all together live in a single locality.

Each houseowner shall ever be present (at night) at the door of his own house.

Kautilya's Arthashastra

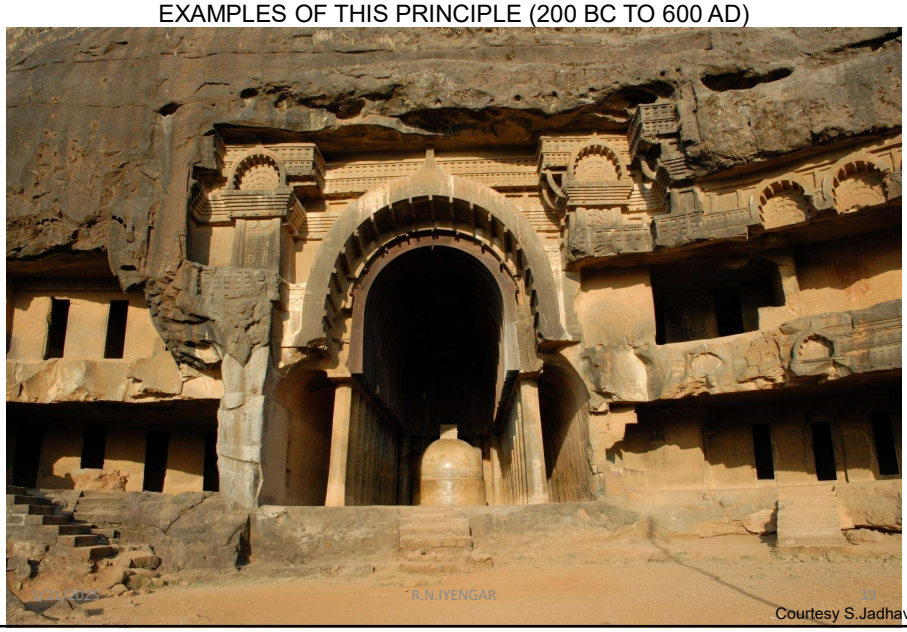
Vessels filled with water shall be kept in thousands in a row without confusion not only in big streets and at places where four roads meet but also in front of the royal buildings (*rajaprigraheshu*).

Any house-owner who does not run to give his help in extinguishing the fire of whatever is burning shall be fined 12 *panas*; and a renter (*avakrayi*, *i.e.*, one who has occupied a house for rent) not running to extinguish fire shall be fined 6 *panas*.

Whoever carelessly sets fire (to a house) shall be fined 54 *panas*; but he who intentionally sets fire (to a house) shall be thrown into fire.

Whoever throws dirt in the street shall be punished with a fine of 1/8th of a *pana*; whoever causes mire or water to collect in the street shall be fined ¼th of a *pana*; whoever commits the above offences in the king's road (*rájamárga*) shall be punished with double the above fines.

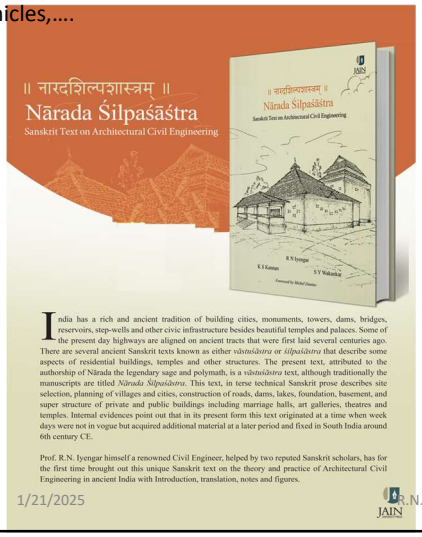
MANY SHILPA BOOKS DISCUSS BUILDING MATERIALS AND DURABILITY OF CONSTRUCTION. THEY ALL SAY THAT JOINTS SHOULD BE AVOIDED FOR MAXIMUM DURABILITY. CAVE TEMPLES AND MONASTERIES ARE EXCELLENT EXAMPLES OF THIS PRINCIPLE (200 BC TO 600 AD)



Courtesy S.Jadhav

Undavalli caves, Mangalagiri

Famous Texts: Vishvakarma Prakasha, Mayamatam, Kashyapa Shilpa, Samarangana sutradhara, Manasara, Manushyalaya Candrika, Shilparatna, …..
More than twenty texts can be listed as published. Many more like Vrddha-Gargasamhita, are in manuscript form yet to be published. Naradashilpa (500-600 AD) was one such manuscript that I edited and got published. This is a unique prose text that describes planning, construction methods, foundation, classification, safety, interior planning, public buildings, palaces, vehicles,….



CONTENTS

The text is divided into 3 broad sections called *Prakaranas*, each section divided into lessons.

I. General, Roads, Water Resources, Town Planning. (L.1-L.58)
II. Residences, Palaces, Furniture, Law Courts, Art Gallery, Theatre. (L.59-L.71)
III. Temple, Iconography, Paraphernalia. (L.72-L.83)

12. Foundation

49. ॥ भूमिलंबः ॥

This type of classification is the forerunner of present day Importance Factors prescribed in Standard Building Codes used by designers.

1. Towers, city and fort doors and gateways are the *most-superior* (*uttamottama-vāstuka*) The foundation for such structures built in pairs will be 20-32 *PS* in dimension.
2. Palaces, pavilions, exterior halls and fort walls are *superior (uttama-vāstu)* and have foundation of 16-20 *sūtra*.
3. Mansions, front halls of houses, ponds, and wells are *medium-superior (madhyamottama*) structures. These require 10-12 *sūtra* basements.
4. Medium structures (*madhyavāstu*) are residences and houses needing single basement of 8-10 *sūtra* measure.
5. Elephant and horse stables and interior rooms are *inferior* structures (*adhama-vāstu*) requiring 6-8 *sūtra* of basement.
6. Village houses, partitioned halls, unimportant shelters, platforms, pilasters in outer walls are *most-inferior (adhamādhama-vāstu)*. For such structures, 2-5 *sūtras* wide basements are sufficient.
7. All other wall constructions are minor (*kṣudra-vāstu*) structures. For these, 1-2 *sūtra* is needed with the width of the basement being 1-3 *sūtra*.

All the technical persons involved with the work get together to decide how deep the foundation trench has to be dug. The deepest place is stabilized with layers of bricks in lime concrete (*sudhā-cikkaṇakeṣṭi-jālam*).

Gaja-paadaka

The ground is further strengthened using elephant-foot rammers. The place is covered with stone slabs or with laterite blocks (*durgeṣṭikā*) and skillfully combined, over a period of time, with the construction in the foundation trench.

CITY TEMPLE COMPLEXES: SRIRANGAM, TIRUVANAIKKAVAL!

ANY ONE VISITING THE BRHADISVARA TEMPLE OR

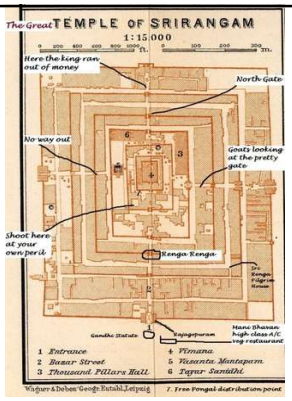
THE KONARAKA TEMPLE WOULD WONDER HOW SUCH GIGANTIC STRUCTURES WERE BUILT IN 10th -13th CENT.

WHAT SKILLS & PRINCIPLES OF ENGINEERING THEY EMBED?

HOW DID THEY FIRST ENVISION?

DID THEY MAKE DRAWINGS, MODELS, TRIAL & ERROR EXPERIMENTS?

HOW DID THEY HAUL SUCH HEAVY STONES HORIZONATALLY & VERTICALLY?



KONARKA TEMPLE: MASTERPIECE OF ENGINEERING NOT JUST ARCHITECTURE
A CHALLENGE FOR THE NATION TO PRESERVE THIS HERITAGE STRUCTURE.

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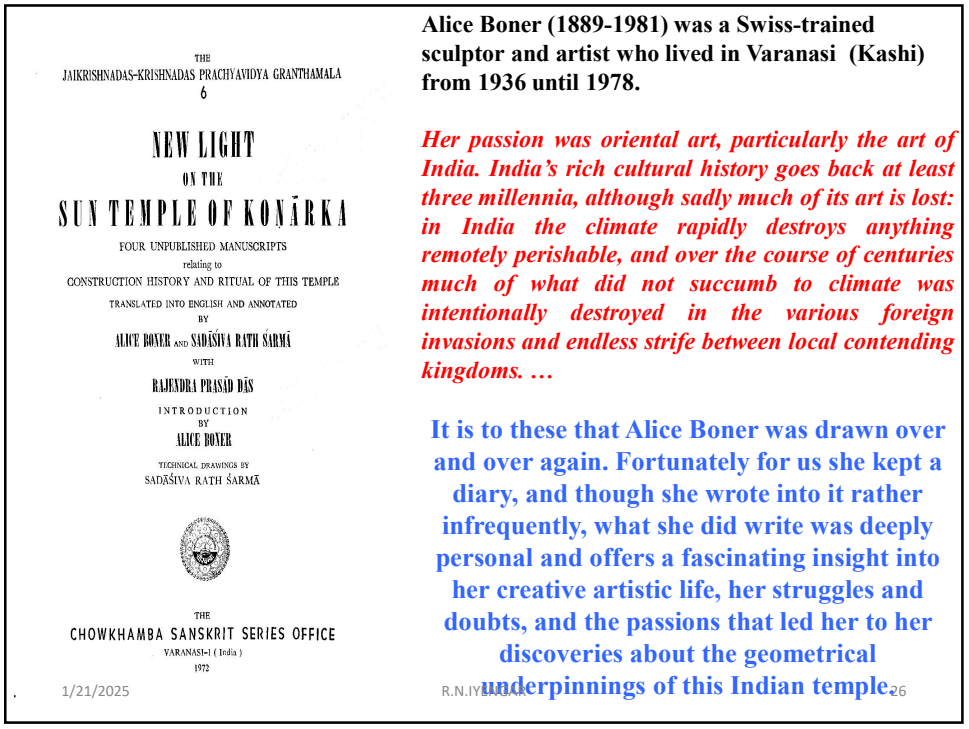
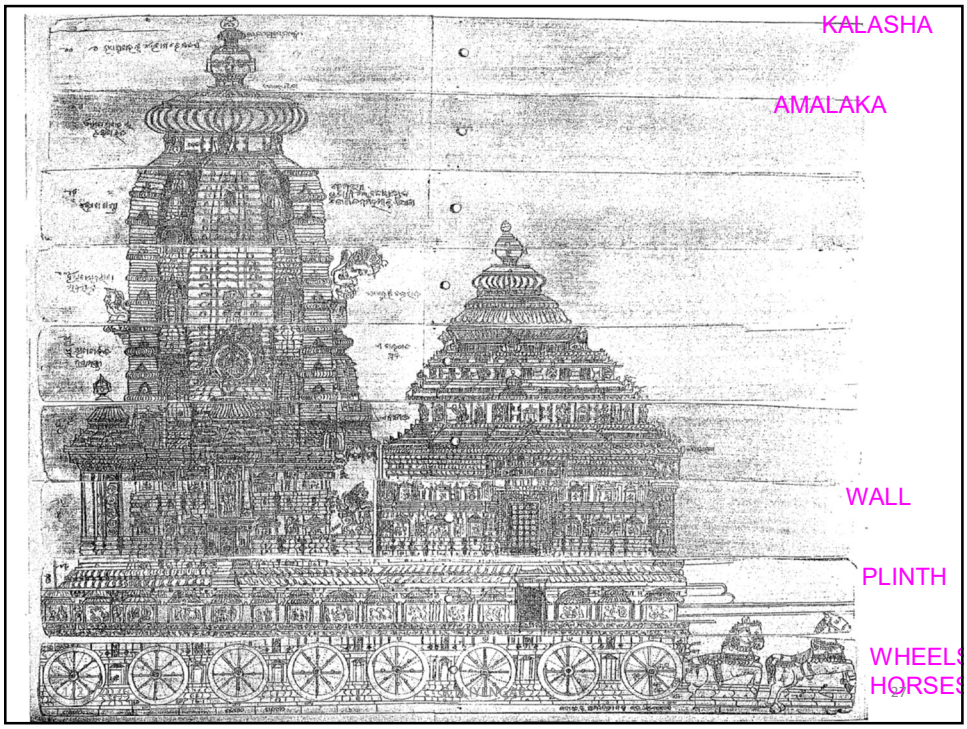


Alice Boner (1889-1981) was a Swiss-trained sculptor and artist who lived in Varanasi (Kashi) from 1936 until 1978.

Her passion was oriental art, particularly the art of India. India's rich cultural history goes back at least three millennia, although sadly much of its art is lost: in India the climate rapidly destroys anything remotely perishable, and over the course of centuries much of what did not succumb to climate was intentionally destroyed in the various foreign invasions and endless strife between local contending kingdoms. …

It is to these that Alice Boner was drawn over and over again. Fortunately for us she kept a diary, and though she wrote into it rather infrequently, what she did write was deeply personal and offers a fascinating insight into her creative artistic life, her struggles and doubts, and the passions that led her to her discoveries about the geometrical underpinnings of this Indian temple.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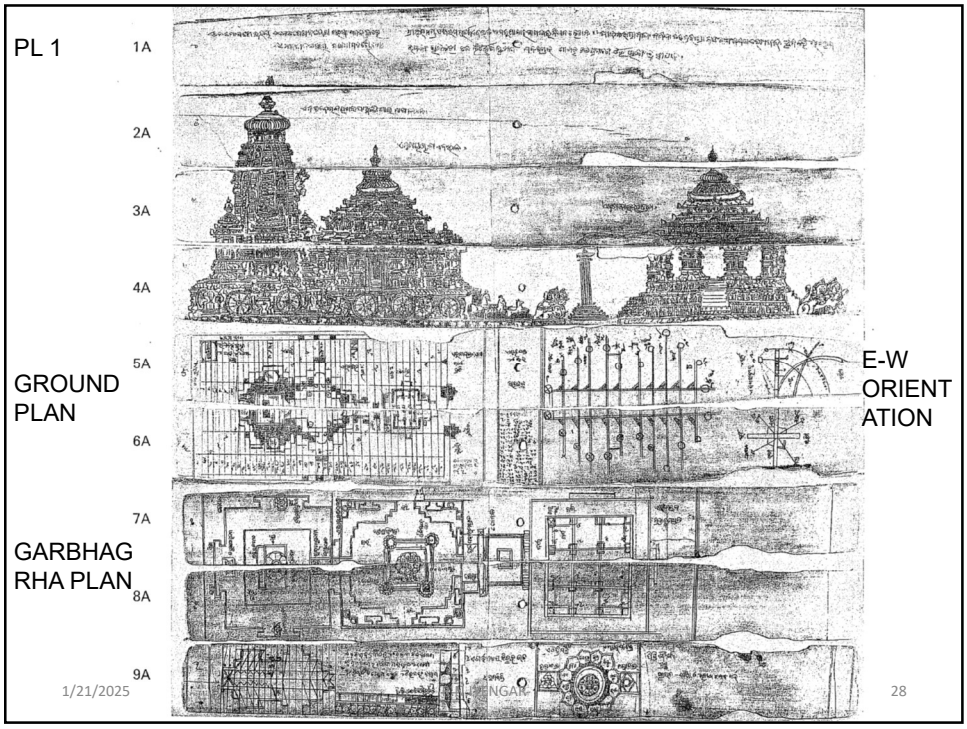
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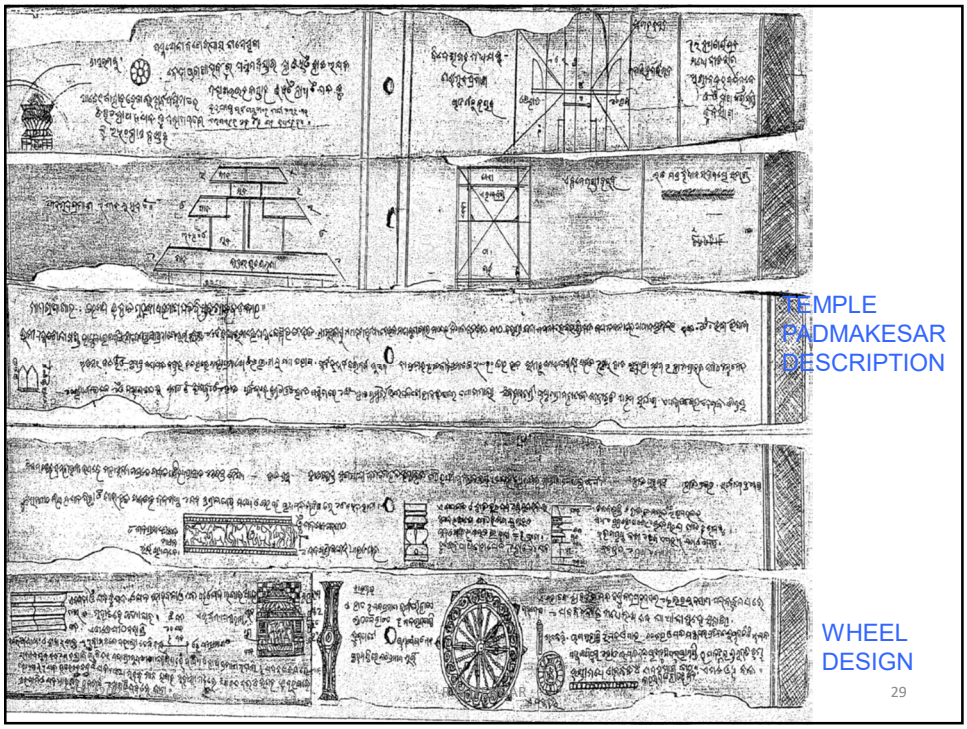

TEMPLE PADMAKESAR DESCRIPTION

WHEEL DESIGN

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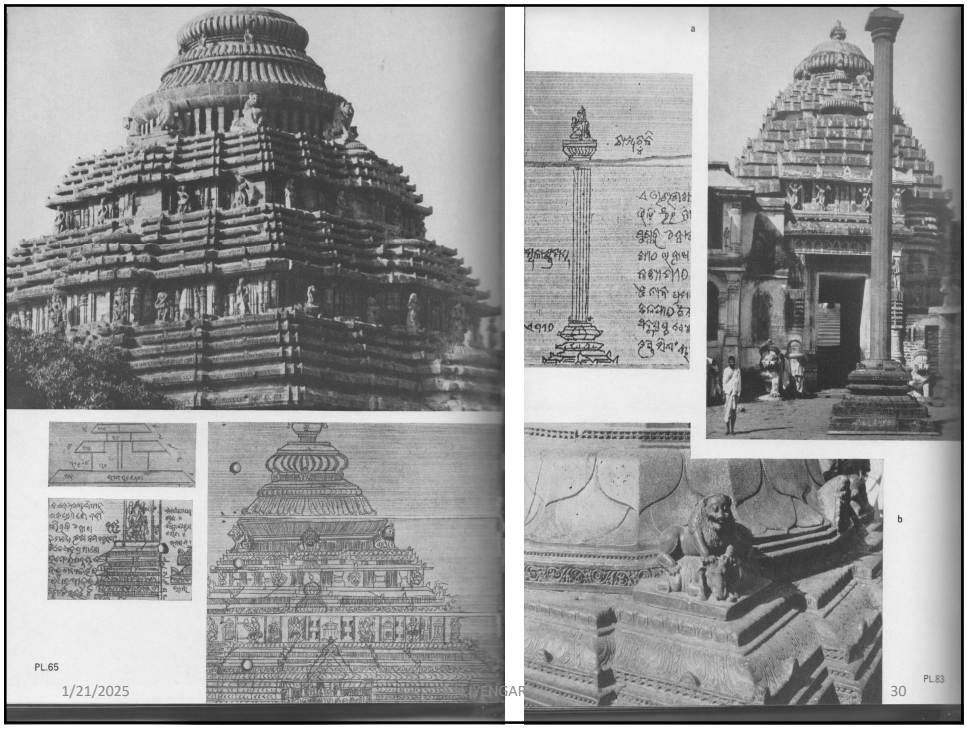

PL.65

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BAYA CAKADĀ

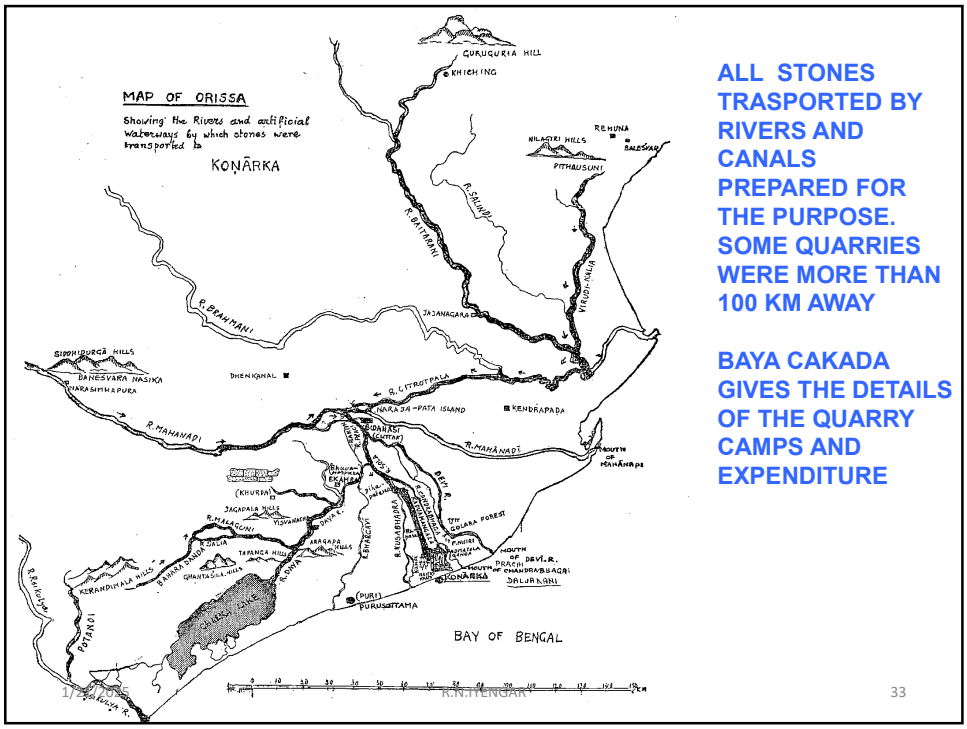
6. Nārāyaṇa Mahāpātra, Mukunda Mahāpātra and Dharma Mahāpātra with 14 other sculptors were given for two Navagraha stones, a contract of :	230 māḍha
7. For work on the wall upto the bandhanā of the jagamohana, 203 śilpīs received :	25 māḍha
8. For making the stone-berm (pahaṇḍa) on both sides (north and south ?) forty pathuriās received :	120 māḍha
9. On the fifth day of Tulā of the victorious, prosperous reign of this aṅka,* all wall-work was finished, except the niches (upper parts of niśā-temples). 214 posts of the scaffolding were left and the rest removed. Labour charges to 4 pāiṭāḷas :	1 bharaṇa
For a religious food-offering on opening and removing the scaffolding (mauḷā-pūjā) :	24 gauṇi cu
10. 240 Regaḍākuṇḍā** stones arrived on the canal from Narasiṁhapura Fort. Carrying charges :	1 bharaṇa 70 gauṇi
11. On the 24th day of Tulā the images were set up in the niches. Nārāyaṇa Mahāpātra received salary (see Leaf X, 17 note) (Pl. 40–45) :	53 māḍha
Sadāśiva Sāntarā Mahāpātra Sūtradhara received :	50 māḍha
Gadādhara Mahāpātra :	50 māḍha
Sūtradhara for setting up the images*** :	1 māḍha
12. Dharma Mahāpātra, Nidhi Mahāpātra and Lakhaṇa Mahāpātra with 12 pāiṭāḷas took the Navagraha stone and placed it near the pillars :	32 gauṇi
13. The carpenter Nidhi Mahāpātra supplied two thick planks of bandhana wood 18 hasta long. Labour charges :	4 gauṇi
14. Carrying and placing four wooden rollers of 3 hasta length, labour charges for 3 people :	2 gauṇi
15. These were placed on the eastern nandāvarta. The two planks were placed upon them on the pīṭha, leaving the necessary gap (khāndi) in the middle. On these the (Navagraha) stone was placed. Labour charges :	23 gauṇi

SITE BOOK MAINTAINED BY THE RECORD KEEPER OF THE TEMPLE IN THE LAST 6 YEARS OF CONSTRUCTION.

A HERITAGE BY ITSLEF UNPARALLELED IN HISTORY

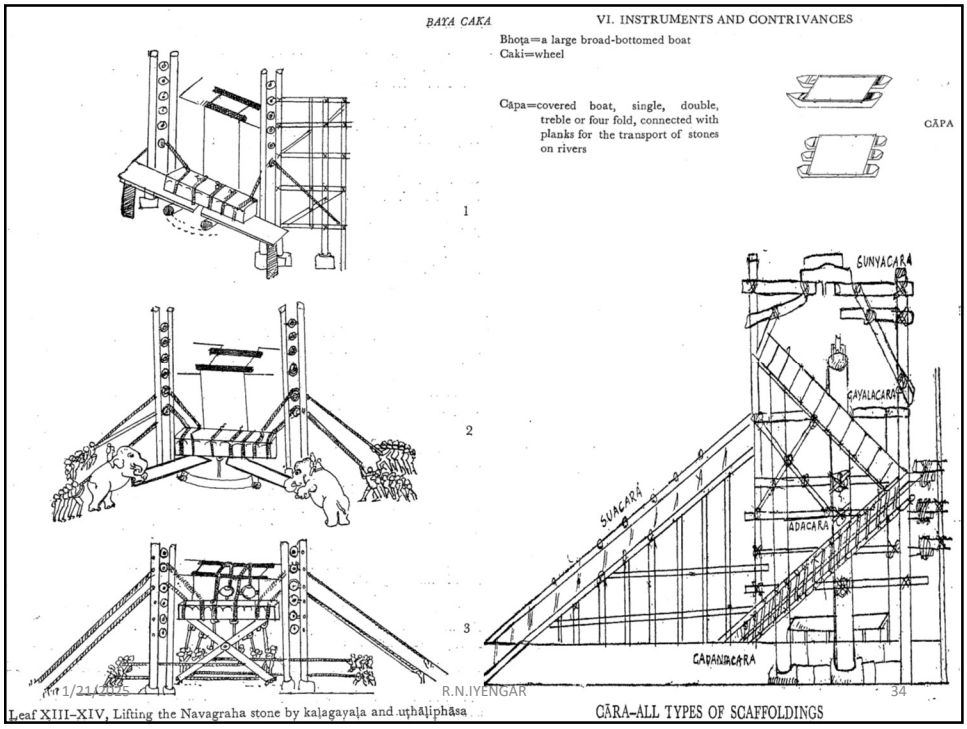
BAYA CAKADĀ

The team which had stayed in Kerāṇḍimāḷa for 7 months and 14 days in the 11th aṅka, under the leadership of Kerāṇḍimāḷa Subudhi, for the maintenance of their camp :	70 māḍha 4 bharaṇa 17 gauṇi rice
For clothing :	13 māḍha
Sulphur powder (bāruda) for explosives to blast stones :	7 māḍha
Stone-blasters :	7 māḍha
30 stone-cutters :	13 māḍha
324 people carried and loaded the stones on 70 cāpas. The Cāpadaḷāi (chief boatman) of Ṛṣikulyā river brought the boats to the Dayā river through the Bāhāradaṇḍā canal, to the Saḷiā and Malāguṇī river. He received :	70 māḍha
22 bharaṇa paddy for this group was supplied from the Bhīma Nagara Daṇḍapāṭa (stores).	
7. The group which had gone to Arāgaḍa and the barren hill of Jagadaḷapura under the leadership of Daḷabeherā of Tikarapaḍā and the Lenkā of Jagadaḷapura, stayed there four months and 13 days in the 11th aṅka. For the maintenance of their camp :	30 māḍha 3 bharaṇa 7 gauṇi
Powder for stone blasting :	43 māḍha
The stone blasters :	11 māḍha
The stone-cutters :	20 māḍha
230 people who carried and loaded the stones* on the cāpas, and the boatmen of 31 cāpas who transported the stones upstream on the Dayā and then to the Sola river, received :	130 māḍha
64 bharaṇa rice were supplied to them from the Tarāboi in Khileśvarī Daṇḍapāṭa. This (consignment) was for the team of Gadei Mahāraṇā.	
8. From the Arāgaḍa Hills 1307 large slabs of Regaḍākuṇḍā stones were quarried under the supervision of Vīra Bhaṭṭa and Nidhi Mahāraṇā. They stayed 3 months and 10 days of the 11th aṅka at the Tarāboi camp.	70 māḍha



ALL STONES TRASPORTED BY RIVERS AND CANALS PREPARED FOR THE PURPOSE. SOME QUARRIES WERE MORE THAN 100 KM AWAY

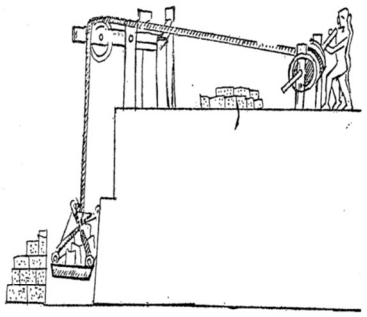
BAYA CAKADA GIVES THE DETAILS OF THE QUARRY CAMPS AND EXPENDITURE



Leaf XIII–XIV, Lifting the Navagraha stone by kalagayala and uṭhāliphāsa

CĀRA–ALL TYPES OF SCAFFOLDINGS

Jhapaka=kind of pulley-crane with rope basket worked by a winding wheel, for lowering stones into the foundations

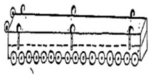


JHAPAKA

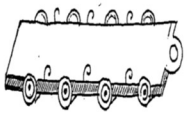
Olhāla=ring-like heavy stone with a wooden axle hung on ropes as counter-weight, when lifting large stone-weights

OLHĀḶA

Kaḷaśagaḍi or śagaḍa=thick plank on wheels for transporting heavy stones

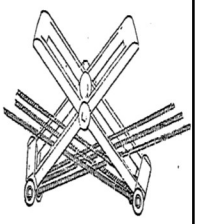


KALASAG



KALASAGAḌI

Uṭhāḷiphāsa=two metal-frames hinged together in the centre in the likeness of a reading stand on small wheels which were pulled from opposite directions for supporting or raising big weights, serving the purpose of a jack.



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BAYA CAKAḌĀ

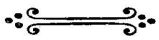
20. Having performed this work truthfully and conscientiously (with Satya and Dharma) I have now been appointed Deputy Supervisor (Sāna Parichā) of the Sun-God (temple).

21. In the beginning during six years and three months the preparatory work was in the charge of the Chief Supervisor of the Puruṣottama kṣetra. Therefore I have no knowledge about it.

LEAF LXX

1. On Friday, the 4th day of Phālguṇa kṛṣṇa pakṣa in the 18th aṅka, Sāla era 665 (1258 A.D.) of the victorious prosperous reign of Virašrī Gajapati Gauḍeśvara Navakoṭi Karṇāṭa Kalavargeśvara Pratāpī Viravara Mahārāja Laṅgulā Narasiṁhadeva, Taḍau Vidyādhara Paṭṭanāyaka, the keeper of accounts made over his accounts and gave his signature, this flower :

2. This sign is the signature of the Superintendent Bhaṭṭa Nārāyaṇa Bhramarabara Sāmanta of Kīlā Bayāḷisabāṭi, who received it.



3. This sword is the signature of Bāuribandhu Daḷabeherā of Gaḍarupāsa Bārabhāga (12 parts or villages)

4. This circle is the signature of Śyāma Paṭṭanāyaka of the village Gaḍabeṇṭapura, the keeper of stores and accounts on the work-site and Officer-in-charge of the Royal Camp-Treasury (Śrīkaraṇa Padmakeśara Khaḷā Bhaṇḍārabaya karaṇa).

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WE KNOW THE NAMES OF THE CHIEF ARCHITECT, SITE ENGINEER, SCULPTORS, CARPENTERS, THE MUSLIM WORKER WHO CAST THE IRON BEAMS.

THE FAILURES, DEATHS, RESIGNATIONS, INTERNAL DISSENSIONS.

SCULPTORS FROM MADURAI SENT BY THE FATHER-IN-LAW OF THE KING NARASIMHA VERMAN

WATER

Narada Shilpa

5. **Roads, Water Resources**

8. ॥ मार्गलक्षणम् ॥
9. ॥ जलाशयतटाकलक्षणम् ॥
10. ॥ प्रणालीसेतुनिर्माणम् ॥

Fig.3 Check Dam with sluice and walkway

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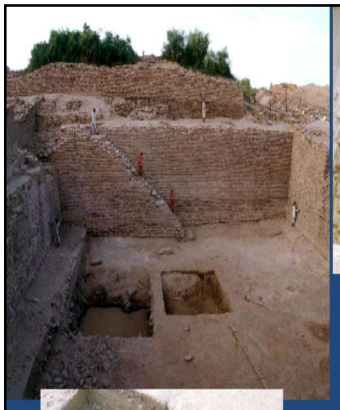
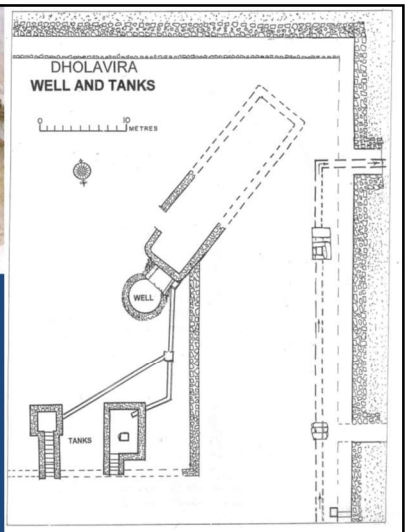


Rock-cut step well in the eastern reservoir

Dholavira– Eastern Reservoir-Located to the east of Castle



MOST REMARKABLE HYDRAULIC ENGINEERING IN THE BRONZE AGE ! THE WELL WITHIN THE TOWN WAS CONNECTED TO THE RESERVOIR OUTSIDE.

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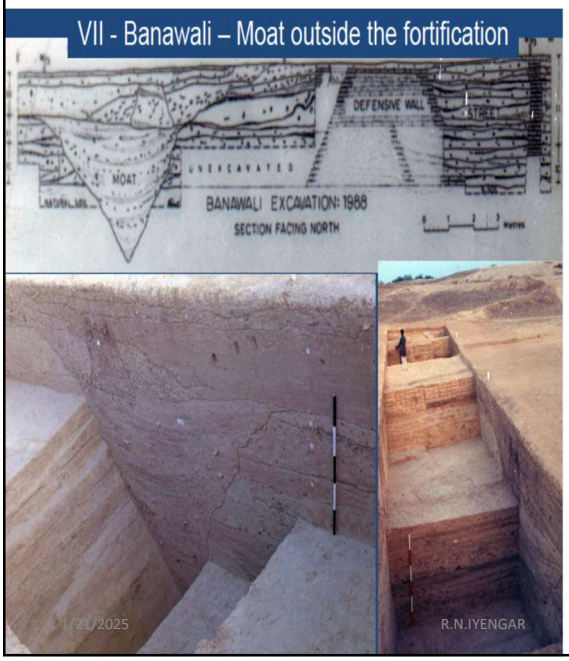
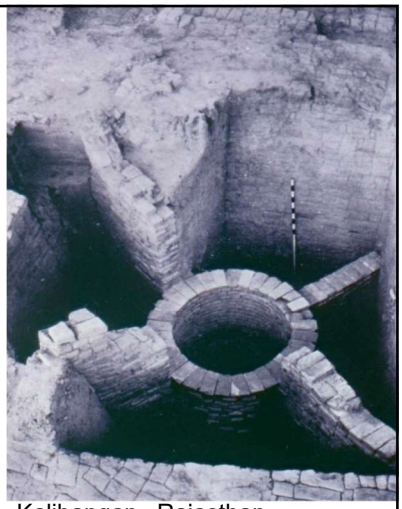
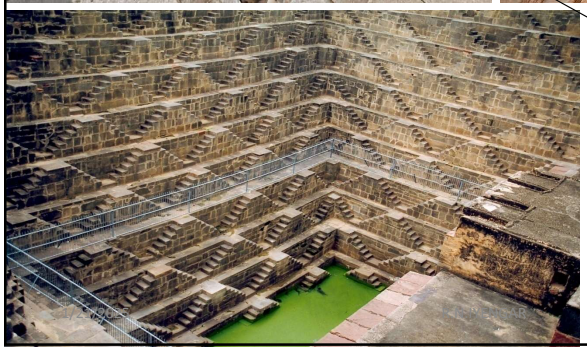
BANAWALI, HARYANA





Kalibangan , Rajasthan
Radial Stiffeners for a well.

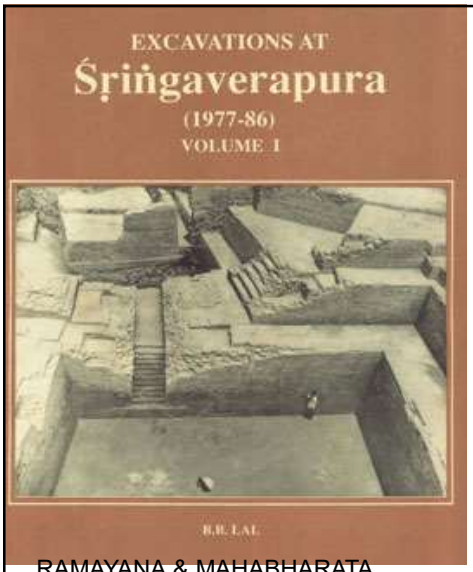
FIRST TIME MANKIND ACHIEVED VERTICAL TRANSPORT OF WATER WAS IN THIS PART OF GREATER INDIA WHERE ISVC FLOWERED.



RANI KI VAV, PATAN, GUJARATH

STEPPED WELLS, GHATS, TANKS ARE SEEN ALL OVER INDIA. SPIRIT OF PUBLIC BATHING IN SPECIAL PLACES IMBIBED FROM IVC TIMES!

STEP WELL CHAND BAORI, RAJASTHAN



RAMAYANA & MAHABHARATA SITES EXCAVATED BY B.B. LAL

CULTURAL LAYERS BELONGING TO ABOUT 1500-1000 BC UNEARTHED. NO CITY CULTURE YET FOUND IN THIS PERIOD

At Sringaverapura near Allahabad in Uttar Pradesh, India, there exists an extraordinary example of hydraulic engineering dating back to the end of the 1st century BC.

It comprises three percolation-cum-storage tanks, fed by an 11 m wide and 5 m deep canal that used to skim the floodwaters off the monsoon-swollen Ganga.

Water from the canal first entered a silting chamber where the dirt settled. This clean water was then directed to the first brick-lined tank then on to another Tank through a stepped inlet (which cleaned the water further). This tank constituted the primary source of water supply. Next, the water passed to a circular Tank, which had an elaborate staircase. A waste weir, consisting of seven spill channels, a crest, and a final exit, ensured that the excess water flowed back into the Ganga.

Atharnal bridge, Madhupur, (Puri Entrance) Orissa, 12th Cent.

Bukka's Aqueduct Vijayanagar, Hampi Karnataka, 14th-15th Cent.

TANK AND ANICUT IRRIGATION SYSTEMS: AN ENGINEERING ANALYSIS

CHITRA KRISHNAN
Department of Applied Mechanics

Submitted
in fulfillment of the requirements for the degree of
DOCTOR OF PHILOSOPHY

to the

INDIAN INSTITUTE OF TECHNOLOGY, DELHI
HAUZ KHAS, NEW DELHI – 110016
INDIA
JUNE 2003

Name	District	Bund height	Capacity / (Circumference)	
Cummum	Guntoor	31 m (102 ft)	-	(12.9k m)
Madag-Masur	Dharwad	30.5m (100 ft)	-	-
Moti talab	Mysore	24.4m (80 ft)	22.2 Mm^3	-
Shantisagara	Shimoga	18.3 m (60 ft)	-	(64.4k m)
Viranum	South Arcot	6.1 m (20 ft)	76.45 Mm^3	-

LARGE DAM > 15 M (REF: ICOLD)

STORAGE > 1-3 Mm^3

Sir Arthur T Cotton (1803-1899), doyen of colonial engineers in the 19th century commented.
(Lectures-Irrigation works in India)

'When I first arrived in India (1821), the contempt with which the natives justly spoke of us on account of neglect of material improvements was very striking ; they used to say we were a kind of civilized savages, wonderfully expert about fighting, but so inferior to their 'great men' that we would not even keep in repair the works they had constructed, much less even imitate them in extending the system…'

……

"With our western and unbounded means we should not think ourselves bound to follow the natives, who had not a thousandth part of our advantages…." (Cotton, 1874)

R.H Sankey, Chief Engineer of Mysore in the 1860s also noted that

"in Mysore there were 37,000 of these reservoirs, the larges of which had a surface of 14 square miles. In the madras presidency there were about 42,000. Such a vast system or anything comparable to it did not exist in any other part of the world"
(Proc. Inst. Civil Engrs.1896)

The expertise of colonial engineers on the problems of Indian dams & anicuts was limited!

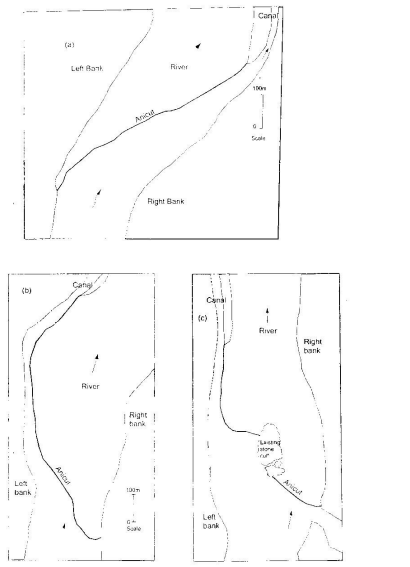


Figure 2.18 Plan views of three traditional anicuts, each with single canal (*Source: (a) & (b) were surveyed by author in 2001 and (c) was gathered from the PWD Tambraparni Division, Tirunelveli.*)

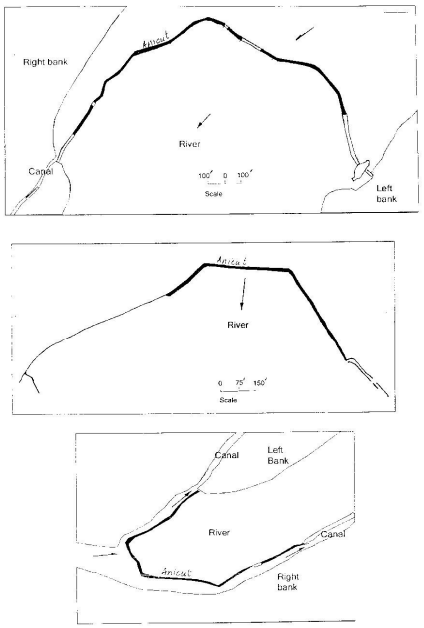


Figure 2.19 Plan views of three horseshoe shaped traditional anicuts (*Source: (a) was gathered from the Engg. Research Station, Mysore. (b) from (Anon, 1958) & (c) from (Gomathinayakan 2000)*)

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"…..nearly all (native) weirs were designed in curves or a series of curves in greater of less imitation of the forms assumed when water crossed a natural shoal or hard in the bed of a channel.

On the other hand madras engineer officers for the most part rejected this theory, and adopted straight, level and perpendicular outlines in their constructions.

One of the advantages possessed by the native system was, that the curved surfaces of the crest of the weir allowed the water to pass over more easily; while the central depression,

Or depressions, insured a greater degree of uniformity and permanence in the deep-water channels into which the broad beds of sandy rivers with small falls were apt to be divided.

Another advantage possessed was, that owing to the greater velocity at the depressed portions of the weir, the sand and silt brought down from the up-country were passed over the weir instead of being allowed to accumulate in the bed of the river on the upstream side." (Godsman Proc. I.C.E, Vol 35,1873)

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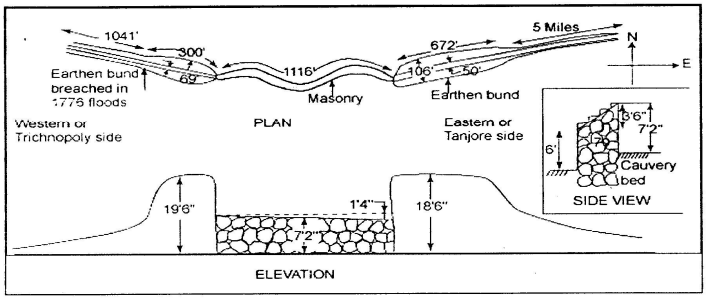

Figure 2.10 Plan and Elevation of Kallanai based on the 1777 description (not to scale)

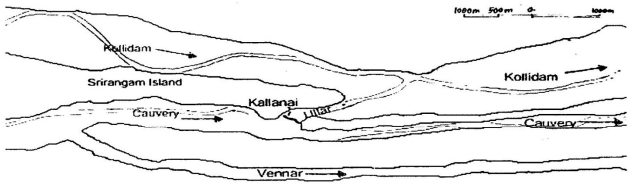

Figure 2.5 Map of the river reach around Kallanai originally (i.e. prior to 1800) *(Modified from a current Survey of India toposheet)*

600,000 acres of land irrigated by the Kaveri branch prior to 1800 AD.

Special features of the 1116 ft anicut mentioned in the record from 1777

*It was curved making three waves from one end to the other.

**Its crest was not level but sloping; 1.3 ft higher at the western end than the eastern end.

***It had a descent from the front to the rear of 3ft and ½ inch which makes in some parts a regular and smooth slope and in other irregularly by 3 or 4 steps.

****Between the stones where they are not jointed is rammed a mixture of pebble-stones or rather round gravel and chunam, and overall is spread about ¾ inch think of a very fine and smooth chunam to prevent the water from making the smallest impression…" *this plaster probably needed to be replaced every five years.*

*****Further the front was ragged and uneven which however, was said to be an advantage as it "threw up a bed of sand in perpetual suspension for its defence.*

Raja of Thanjavur complained to the court of Directors of the East Indian company on 21st Oct 1776.

"….. this year the cavery flowed to an extraordinary height and broke down the bank near Kelior which separates it from the coleroon. If it is not repaired the country can produce no crop as the water of that river which fertilizes the soil would then run into the coleroom and by that channel fall useless into the sea. When any part of the bank is demolished we always dug earth in the Trichnopoly country for the repair of it but the Navab will not allow of this at present though it has been customary to do so for upwards of hundred years."

Kallanai was the boundary between the unfriendly domains of Thanjavur and Tiruchirapalli ! Land east of Kallanai belonged to the Raja of Thanjavur, while the land west of it belonged to the Navab of Arcot. In the October 1776 flood the masonry sustained damage at the western end. three layers of stone swept away to a great distance . The British took over in 1801,….

AND MEDDLED WITH THIS HERITAGE STRUCTURE WHICH HAD SERVED WELL FOR 1500 YEARS !

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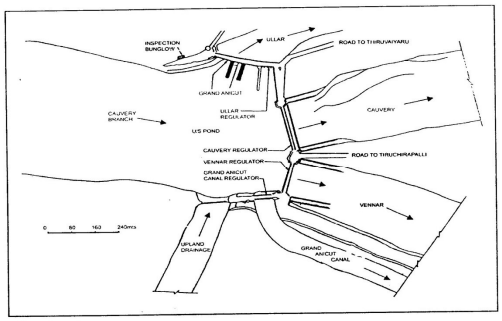

Figure 2.9 The Grand Anicut Complex at present *(Source: Mohanakrishnan, 1990)*

KALLANAI IS A MIXED HERITAGE STRUCTURE OF THE COLONIAL PAST !

GRAFTED ENGINEERING HERITAGE HAS POTENTIAL TO BECOME A MILL AROUND OUR NECK. SOME OF OUR CURRENT STRUCTURES MAY NOT BE LIKED BY FUTURE GENERATIONS ALSO!

HIGH TIME CIVIL ENGINEERS EXHIBIT OUT-OF-BOX THINKING AS OUR ANCIENTS DID INSTEAD OF BLINDLY TEACHING & FOLLOWING BRITISH PRACTICES

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The Method of Making the Best Mortar at Madrass in East India: Described in a Letter from the Honourable Isaac Pyke, Esq; Governor of St. Helena, to Edmund Halley, L. L. D. Reg. Astr. Vice-President R. S. and by Him Communicated to the Royal Society

Author(s): Isaac Pyke and Edmund Halley
Source: *Philosophical Transactions (1683-1775)*, Vol. 37, (1731 - 1732), pp. 231-235
Published by: The Royal Society

Edmund Halley:
Astronomer . 1656-1742

Isaac Pyke: Governor General of St. Helena. 1714-1719; 1732-1738

TAKE fifteen Buſhels of freſh Pit-Sand, well ſifted; add thereto fifteen Buſhels of Stone-Lime: Let it be moiſtened or ſlack'd with Water in the common manner, and ſo laid two or three Days together.

Then diſſolve 20 ℔ of *Jaggery*, which is courſe Sugar (or thick Molaſſes) in Water, and ſprinkling this Liquor over the Mortar, beat it up together till all be well mixed and incorporated, and then let it lie by in a Heap.

Then boil a Peck of *Gramm* (which is a Sort of Grain like a *Tare*, or between that and a *Pea*) to a Jelly, and ſtrain it off through a courſe Canvaſs, and preſerve the Liquor that comes from it.

Take alſo a Peck of *Myrabolans*, and boil them likewiſe to a Jelly, preſerving that Water alſo as the other; and if you have a Veſſel large enough, you may put theſe three Waters together; that is, the *Jaggery*-Water, the *Gram*-Water, and the *Mirabolan*. The *Indians* uſually put a ſmall Quantity of fine Lime therein, to keep their Labourers from drinking of it.

The Mortar beat up, and when too dry, ſprinkled with this Liquor, proves extraordinary good for laying Brick or Stone therewith; keeping ſome of the Li-

H h quor

quor always at Hand for the Workman to wet his Bricks therewith; and if this Liquor prove too thick, dilute it with freſh Water.

Obſerve alſo, that the Mortar here is not only to be well beaten and mixed together, but alſo laid very well, and every Brick, or Piece of Brick, flufhed in with the Mortar, and every Cranny filled up, yet not in thick Joints, like the common *Engliſh* Mortar; and alſo over every Courſe of Bricks, ſome to be throwed on very thin: And where the Work hath ſtood, though but for a Breakfaſt or a Dining-time, before you begin again wet it well with this Liquor with a Ladle, and then lay on your freſh Mortar; for this Mortar, notwithſtanding its being thus wetted, dries much ſooner than one not uſed to it would conceive, but eſpecially in hot Weather.

For ſome very ſtrong Work, the ſame Mortar above is improved as follows:

Tow in old English = Jute/ Hemp/ textile fibre

Take courſe Tow and twiſt it looſely into Bands as thick as a Man's Finger (in *England* Ox-Hair is uſed inſtead of this Tow) then cut it into Pieces of about an Inch long, and untwiſt it ſo as to lie looſe; then ſtrew it lightly over the other Mortar, which is at the ſame time to be kept turning over, and ſo this Stuff to be beat into it, keeping Labourers continually beating in a Trough, and mixing it till it be well incorporated with all the Parts of the Mortar. And whereas it will be ſubject to dry very faſt, it muſt be frequently ſoftned with ſome of the aforeſaid Liquor of *Jaggery*, *Gram*, and *Myrabolans*, and ſome freſh Water; and when it is ſo moiſtened, and beat, it will mix well, and with this they build (though it be not uſual to build common Houſe-Walls thus) when the Work

is intended to be very ſtrong; as for Inſtance, *Madraſs* Church Steeple, that was building when I was laſt there; and alſo for ſome Ornaments, as Columns, good arched Work, or Imagery ſet up in Gardens, it is thus made.

Having your Mortar thus prepared, as is before deſcribed, you muſt ſeparate ſome of it, and to every half Buſhel, you are to take the White of five or ſix Eggs, and four Ounces of *Ghee* (or ordinary unſalted Butter) and a Pint of Butter-Milk, beaten all well together: Mix a little of your Mortar with this, until all your *Ghee*, Whites of Eggs, and Butter-Milk be ſoaked up; then ſoften the reſt well with plain freſh Water, and ſo mix all together, and let it be ground, a Trowel full at a time, on a Stone with a Stone-Roller, in the ſame manner that Chocolate is uſually made, or ground in *England*; and let it ſtand by in a Trough for Uſe. And when you uſe it, in caſe it be too dry, moiſten it with ſome Water, or the before mentioned Liquor. This is the ſecond Coat of Plaiſtering.

Second coat

Note, When your firſt Coat of Plaiſtering is laid on, let it be well rubbed on with a hardening Trowel, or with a ſmooth Brick, and ſtrewed with a gritty Sand, moiſtened, as Occaſion requires, with Water, or the before-mentioned Liquor, and then well hardened

Pyke refers to the steeple that was under construction when he visited

St. Mary's Church located at Fort St George, is the oldest Anglican church East of Suez and also the oldest British building in India. 1670-1680

Inſtead of *Aloes*, either *Turpentine*, or the Bark and Branches of the *Sloe*-Tree. Though *Turpentine* be not ſo ſtrong, yet, if uſed in greater Quantity, may ſerve to the ſame Purpoſe.

But there is a Sort of *Aloes Hepatica*, often very cheap. Inſtead of *Mirabolans*, ſome Juice of **Aloes*; alſo inſtead of *Jaggery*, courſe Sugar, or *Molaſſes*, will do; inſtead of *Toddy*, which is a Sort of *Palm*-Wine, the Liquor from the *Birch*-Tree comes near to it.

Note, That in *China*, and ſome other Parts, they temper their Mortar with Blood of any Sorts of Cattle; but the Ingredients before mentioned are ſaid to be as binding, and do full as well, and does not make the Mortar of ſo dark a Colour as Blood will do.

The Plaiſtering above deſcribed, is thought in *India* vaſtly to exceed any Sort of *Stucco*-Work, or Plaiſter of *Paris*; and I have ſeen a Room done with this Sort of Terraſs-Mortar that has fully come up to the beſt Sort of Wainſcot-Work, in Smoothneſs and in Beauty. I am,

SIR,

Your moſt Obedient Servant,

ISAAC PYKE.

This was most likely a technology transfer. How this was used or influenced British builders is not known. But we are told that Portland Cement was discovered in England.

Joseph Aspdin, a British stonemason, discovered Portland cement in 1824. He patented the process of heating limestone and clay to create a hydraulic cement that hardens when mixed with water

OUR CURRICULUM & TRAINING STRESSES MORE ON DESIGN LESSER EXTENT CONSTRUCTION.

SAFETY & PRESERVATION OF MONUMENTS AGAINST WIND, RAIN, EARTHQUAKES, FIRE IS EQUALLY THE RESPONSIBILITY OF CIVIL ENGINEERS.

CIVIL ENGINEERING HERITAGE SHOULD NOT BE LIMITED TO BUILDINGS, TEMPLES, PALACES.
ANCIENT TOWNS, WATER RESOURCE STRUCTURES, DAMS, WELLS, GHATS ARE EQUALLY IMPORTANT.

OUR CIVIL ENGINEERING HERITAGE
STARTING FROM THE INDUS-SARASVATI VALLEY PERIOD TO MODERN TIMES IS A SHINING EXAMPLE OF THE CIVILIZATION DIMENSION OF INDIAN KNOWLEDGE SYSTEM

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THANK YOU