The Indian Forts – A Structural Engineering Marvel

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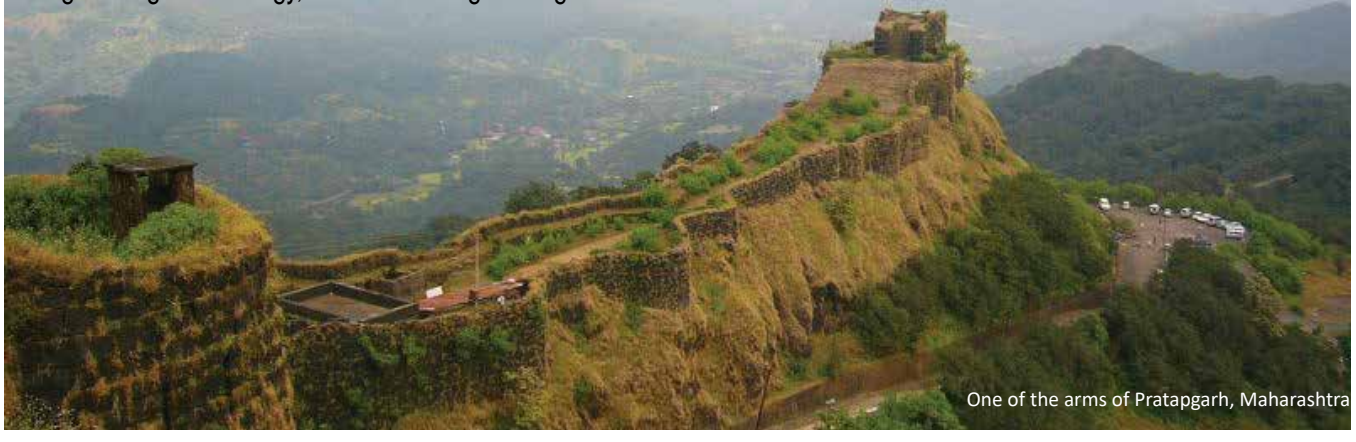
The Indian Fort
A Structural Engineering Marvel

Er. Vivek Abhyankar writes on the amazing architecture and planning, structural design, and performance, of many forts in India, along with their brief history, type, components, functioning, planning, and construction methodology. This article is particularly informative and useful to those who are working in the field of restoration of monumental structures, engineering archaeology, and ancient engineering.



One of the arms of Pratapgarh, Maharashtra

It is very difficult to encompass several aspects and dimensions of historic forts like 'Pratapgarh', 'Rajgarh', 'Raigarh', 'Sajjangarh', 'Sinddudurg' etc, especially from their structural perspective. Several kings and kingdoms that spread from Kashmir to Kanyakumari and Kabul till Arunachal, built forts for establishing secure empires. Several weapons, tools and techniques of wars were developed under the shelter of these forts. The construction of these forts took several years to complete due to non-availability of modern technology, materials, skilled workers, and attacks from enemies. There are more than 1000 forts in India and whatever was built has stood for centuries, facing the vagaries of weather.

From table 1, one can see the rich tradition of Indian empires, their glory and ability to construct and their refined sense of engineering. I have visited forts like Pratapgarh, Shaniwar Wada, Panhalaa, Sajjangarh, etc. The Daulatabad fort near Aurangabad is also a wonderful historic 'engineering monument'. The Mahim fort in Mumbai is on the verge of being ruined due to the crowd of visitors and lack of proper maintenance. What attracted my attention was Pratapgarh's ingenious features, including the complex geometry at its entrance.

Strategic location of forts

Forts were constructed at places which were difficult for foes to approach or attack; yet they are built at places with ample natural resources like a river, lake, fruit trees, natural caves etc, and closer to main cities, ports, and roads. Based on their geographical location, the forts are classified as below:

Forts on flat grounds: In these, security was ensured by armed forces, guards and deep trenches filled with water, thorny bushes, barren lands, animals and reptiles around the periphery. Many forts in Rajasthan are of this type.

Table 1: Showing Numbers of Major Forts per Indian State

(ref. https://en.wikipedia.org/wiki/List_of_forts_in_India)

	State	Number of Forts		State	Number of Forts
1.	Adhra Pradesh	28	16.	Kerala	14
2.	Arunachal Pradesh	07	17.	Madhya Pradesh	39
3.	Assam	05	18.	Maharashtra	250
4.	Bihar	07	19.	Manipur	02
5.	Chandigarh	02	20.	Odisha	05
6.	Chattisgarh	05	21.	Puducherry	01
7.	Dadra Nagar Haveli, Diu, Daman	04	22.	Punjab	18
8.	Delhi	12	23.	Rajasthan	105
9.	Goa	23	24.	Sikkim	01
10.	Gujarat	19	25.	Tamil Nadu	29
11.	Haryana	22	26.	Telangana	17
12.	Himachal Pradesh	10	27.	Uttar Pradesh	32
13.	J&K	07	28.	Uttarakhand	08
14.	Jharkhand	03	29.	West Bengal	08
15.	Karnataka	83		**Total Numbers =**	**766**

Areial view of Lohogarh Fort of Bharatpur

Closer view of Khandak seen around Lohogarh Fort of Bharatpur
Lohograph Fort, Bharatpur, Rajsthan

Note:- There are two forts with the same name 'Lohograh' – one in Pune. Maharashtra and second at Bharatpur, Rajasthan.

Forts on hills: Security was ensured due to lack of access to large guns, armoury, troops, trained soldiers and horses; but construction of these type of forts was most difficult and time consuming. Pratapgarh, Sajjangarh, Daulatabad fort, Rajgarh and many of the forts in western Maharashtra mountains are of this type.

Forts in water / sea: Security was ensured by deep sea water all around with waves and tidal variations. Janjira fort at Murud (a town in the Konkan region of western Maharashtra) falls in this category. These types were highly secured forts but scarcity of water was an issue sometimes.

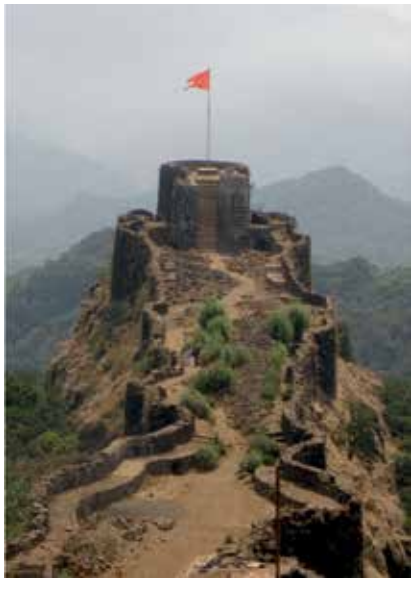
Forts in deserts, forests, marshy lands: These were very rare, difficult to construct and access, and not much preferred (except for a few in the deserts of north-western parts of India), and their security was ensured due to the harsh weather.

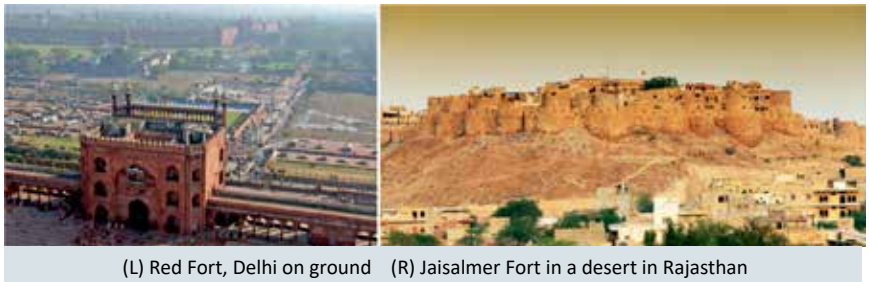
Palaces & City Forts: These types were mostly small in size and constructed for residential purposes and for the political affairs of kings in the heart of the cities. They were comparatively more approachable by foes. The Red Fort of Delhi, Shaniwar Wada of Pune are examples of this type.

The geometric shapes, height of walls and inner arrangements and services of the forts were chosen based on the above categories. For example, a fort in the sea had strong, tall walls, a perennial source and storage of sweet drinking water which was sufficient for the soldiers and their families living inside. Large wells and ponds to store rainwater are found in almost all the forts.

Geometric shapes of forts

Forts inside sea or water followed the good hydrology principles i.e. outer walls were curved / rounded and any sharp edges, corners, angles, projections etc. were avoided to honour the tranquil movement of water around the walls, as well as the raging sea waves. Whereas in city forts, decorative walls, corners, towers, and costly main doors in precious woods etc. were chosen.





(L) Red Fort, Delhi on ground (R) Jaisalmer Fort in a desert in Rajasthan

(L) Daulatabad Fort on a hill in Aurangabad (R) Janjira Fort in a sea in Murud
2 Types of Forts as per Geographical location

(Left) Narrow entrance to Main Gate (mid) Closer view of narrow passage (right) Metal cones fitted on entry door
Very narrow entrance towards the Main Gate of Pratapgarh

Walls of forts on hills naturally followed the profile of the mountain top. The front walls of the Panhala fort were made stronger using lead instead of regular mortar, since the enemies used shell missile bombs. In the biography of queen of Jhansi Rani Laxmibai, it is mentioned that the collapsed portion of walls due to canon attacks were rebuilt overnight - such was the commitment and dedication of the people.

Most of the forts have a curved profile of the walls instead of straight due to their inherent stiffness and stability of the curved forms (form-resistant structures).

Entrances of Forts

The main entrance of forts used to largely dictate the safety of the entire fort. Enemies would attack the main entrance with elephants or with large wooden logs. To protect the main entrance, curvy access ways were used and secret windows at top of the entrance walls from where the soldiers and guards used to throw down stones, water, hot oil or shoot arrows.

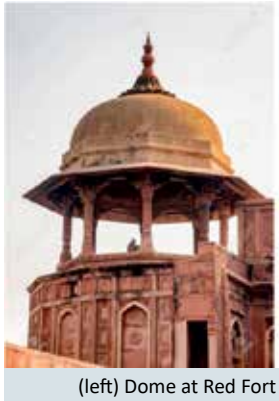
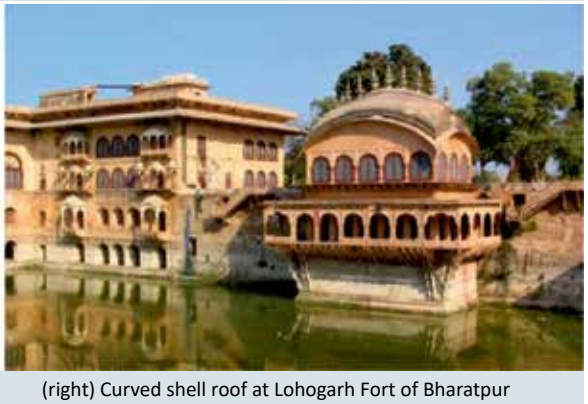
Often the main entrance door used to be fitted with large metallic cone shaped projections which would cause injury to the elephants and attackers. Each main door contained a small access door for a single person to enter, with a peephole or a slit window.

Construction materials, methodology, structural forms

Stones of different types (basalt, granite, marble, sandstone etc) were the popular construction materials used in forts because of their robustness, sturdiness, easy availability, abundance, and affordability. Timber and metals (iron mainly) were used for selective applications like beams, large cantilever projections, floors, doors, windows, hinges, and metal rings in walls to tie horses and other animals. Lime was used as a binding material in masonry. In some selective forts, use of lead was observed as a binding material in a few walls. For masonry works, white and red sandstone is found to be popularly used

(Left) Hidden entrance of Sinhagarh Fort (mid) Inaccessible entrance of Harihar Fort, Igatpuri (Right) Oblique / angular entrance at Lohogad Fort, Pune


(left) Beam-Column grid work in Fatepur Sikri (right) Three decorative arches, Panhala Fort

(left) Dome at Red Fort (right) Curved shell roof at Lohogarh Fort of Bharatpur


Decorative corbels to support beams / cantilever projections / balconies / chajja / porches

Various Structural Forms used in forts

in forts of Rajasthan and Delhi; marble and other coloured stones were used for decorative purpose on walls and floors; basalt stone is widely seen in forts in the west coast region; copper and metallic alloys are seen very rarely. Unlike Scandinavian wood, the wood in tropical countries has lesser density hence lesser life; but Indian forts and palaces used the best quality wood (like Saag, Daar etc) after seasoning timber for several years in water to make it anti-fungal and termite resistant. The Shaniwar Wada fort once had a wonderful timber palace inside, but it was burnt during a fire.

The construction methodology of any fort, largely depended on its geographic location, availability of natural resources (material & workers), urgency of construction, and importance of services inside the fort, stability of the kingdom, and the budget/funds. A majority of the forts in the Maratha empire were constructed in the shortest duration of 5 to 6 years; but there are also several examples where construction went on for a few decades, due to internal changes in the kingdom, scarcity of resources, enemy attacks etc.

In those days (almost 500 years ago) there were no modern surveying instruments, analysis and design software programs, design codes, drawing software, advance construction equipment, or drones, yet coordination was done, and longevity of performance was assured. This would be impossible without a great vision and in-depth understanding of construction works on hill tops, inside deep seas, in valleys etc.

- For construction of forts on hill, dressed stones were towed on horses, donkeys, bulls and even men. Then a dedicated team of expert masons would build a wall under the instruction of the lead supervisor. In rare cases, a chain pulley was used.
- For construction of forts on land, soil ramps were constructed and the top roof (shikhar, gopuram or Kalasha), was placed by elephants and men.
- For forts in water, hundreds of small ships were deployed first to reclaim the land with boulders and pebbles to form a raised land above the high tide level. Then the materials were towed to this artificial island during high tides. The tidal variations, strong waves, and stormy winds were major hurdles in the construction.

Structural forms like small length beams, cantilevers, beam column grid work, plates (walls & roof slabs), conical shells (for shikhar / gopuram), short columns, curved walls etc. are observed in these forts. Most of these forms were ‘compression’ and ‘flexure’ type due to wide use of stone. In some of the flexural forms metallic strips were seen to act as reinforcement. The ‘arch’ is commonly seen in several forts because of its inherent stiffness of this compression form. Spherical domes and shells were found in forts under Islamic kingdoms. Modern forms like suspended roofs, stretched membranes, trusses etc. were not available (except for use in short life tents with cotton fabrics) due to non-availability of high tensile engineered vinylic fabric materials. Still, it is astonishing to see the use of spherical domes without advanced FEM analysis etc, and this refined sense of material and structural behaviour is what distinguishes these forts.

Complex Inner access ways and steps of Lohogarh (Pune) like a puzzle / Bhool-Bhulayya

Layout of rooms and other facilities

The layout of a fort used to be an important aspect for its longevity, security, utility and overall completeness. Most of the forts have strong outer walls in stone with a wide walkway at top for security guards and weapons to place and tiny window openings in the top parapet. Usually, the outer face had a deep sleep ground leading to a valley or a gorge (in hilltop forts) or deep water-field trenches (in case of forts on ground). These features made the forts intact and difficult to conquer. Most of the forts have one main entrance and three sub exits in other three directions located in complex cliffs, forests or valleys. So, access from these exits was practically impossible.

The inner walls were placed with several doors. Often a narrow way connecting from the entrance to the inner core used to be undulating and wavy for security reasons. Most of the forts had a raised platform in stone inside the main entrance door for old people, women, and children to rest before going inside the fort.

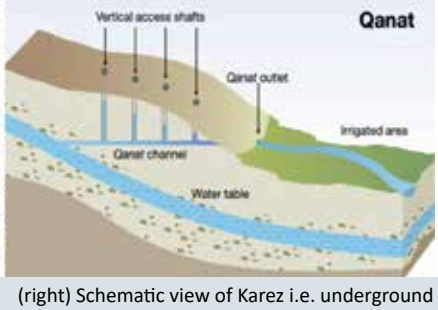
After crossing the inner walls, one would reach the inner core containing houses, temples, tombs, king's palace, other palaces, fountains, ponds, bath spaces, drains, lakes, wells, inner roads, marketplaces, storerooms for food grains and weapons, horse-shelters, trees, observation towers, etc.

Water, food & drainage management (karez system)

Storage of adequate quantity of food and drinking water was extremely important (especially during war). Often, manmade ponds/trenches were dug up in stone to store rainwater. For storage of food grain, jumbo size watertight rooms were built in thick stone walls. In terms of livelihood, most of the forts were like a small independent township, where in war like situation people could reside for several months or a year without going outside. In fact, such independence of the fort was a key selection parameter. The 'Karez' type underground water transportation tunnel system was used in a couple of forts; this system originated in Persia, and later spread all over the world.

Another aspect is effective drainage and sewage disposal: a few of the states of western coast of India experience good rainfall every year; hence forts here either had large slopes or level differences and adequate spacing between two structures and a few also have open or underground drains made in stone. Disposal of sewage was never a problem because of the simple lifestyle and the bio-degradable wastes generated.

(left) Karez Tunnel in Bidar Fort, Karnataka



(right) Schematic view of Karez i.e. underground irrigation tunnel system

(Left) Pond on Jaipur Fort

(right) Ambarkhana (food grain store room) at Panhala fort, Kolhapur

Water and food storage facilities of various forts

(Left) Underground drain in Red Fort, Delhi

(right) Open drain, Lothal Gujarat

Drains at couple of forts


(Left) Canon on Daulatabad Fort, Aurangabad (right) Kalal Bangdi Top (Canon), Jangira Fort, Murud Security Weapons on forts in History

Security & secret tunnels / rooms

Security was the main reason why forts were built and made so robust. Various guns and cannons found in Indian forts depict their history. The cannons were made from molten metals poured into sand / clay moulds, and packed with explosives, which would shoot out like missiles projecting on the opposite side to fall on the enemy camps. Hence, positioning the cannon in the correct direction and angle was extremely important, as seen in the cannons fixed on the terrace windows of the Jangira fort. It is surprising how the soldiers without formal knowledge of physics or mathematics or engineering, could decide the trajectory / missile projection path!

Another security technique during extreme events was evacuation of families through secret underground tunnels dug in the forts. Some had half dug tunnels which were used to hide during bombing by the enemies. The engineering, planning, design, construction, and maintenance of these tunnels is still unknown. A few of the forts on hills have well-built ramps for access and stone wall fences.

Life & Age of Indian Forts

The Kanfra Fort near Dharamshala is known as India's oldest dated fort, said to be built around 3,500 years ago by Maharaja Susharma Chandra, a descendant of the Katoch family. Several forts of Maharashtra were built during and before Chatrapati Shivaji Maharaj (i.e. 400 years or more old). In modern design codes we design concrete structures for hundred years using high-strength materials, advanced software programs to accurately assess the stresses and strains in various parts, complex loads and load cases, maintenance etc. yet we are unable to preserve these structures till 100 years, as most of them start showing signs of dilapidation, cracks, vibrations etc. after just 25 to 30 years. Hence, the long life of the Indian forts is indeed astonishing. Their long life also points to the pitfalls in the construction sector today, the corruption, awarding of the L1 bidder contract etc.

Artistic Views & Messages

Forts which were built in the northern states took several decades to complete and were constructed in very artistic and lavish ways.


(left) Artistic Mural on wall in Mehrangarh Fort (right) Decorative Bath Tub, Red Fort, Delhi


(left) Colourful decorative floor Junagarh fort, Bikaner, Rajasthan

(right) Decorative walls and floor, Agra Fort


(left) Colourful glass doors of Meherangarh Fort

(right) Decorate entrance of Amer Fort, Jaipur, Rajasthan

Artistic views in a few Forts

Shilalekh (messages carved in stone) at Raigarh Fort, Maharashtra

(Left) Dover Castle – England's largest castle, built in 11th century

(right) Caerphilly Castle, Great Britain, 13th century

Ankara Castle, Turkey Yr. 1073

St. Basil's cathedral, Russia Yr. 1561

Expert masons and craftsmen were employed to undertake these decorative carvings in marble and precious stones, which were fitted into grooves (without epoxy, glue, resins, or other adhesives), yet they have lasted for hundreds of years.

Messages and poems were also engraved on stones. Today, engineers and masons know how to easily carve messages in dense stones like marble, but carving messages in basalt rocks or sandstone is a challenge.

Castles & Forts in Foreign Countries

Castles and forts found all over the world are equally good and represent the heritage, culture, and history of their country. Many are more than 200 years old and are well maintained, and also exhibit the sound understanding of the principles of engineering construction.

Signs of Dilapidation

The average age of Indian forts could be around thousand years (although the youngest is about 500 years old). Considering the vagaries of weather and the attacks by enemies that they have over the years, they have started showing signs of aging or dilapidation. Unlike modern structures (which are sleek, and iron reinforced) the forts are massive (bulky) and free from corrosive irons. Hence, the phenomenon which we see in modern structures (carbonation, corrosion, cracks, vibrations etc. due to lesser durability and stiffness) are not seen in these ancient structures. A fact that must be remembered is that 'the density of consumption / usage of natural material (stone and timber mainly) per cubic meter space is much higher in ancient structures as compared to

(left) Major cracked wall of Balalrpur Fort, Nagpur (right) Ruined buildings of the fort, Adilabad Fort, Delhi

(left) Frigile structure of Narvar Fort, Shivpuri (right) Vegetation growth due to lack of maintenance, Narvar fort

(left) Debris from one of the forts in Hyderabad (right) Collapse portion of Holkonda fort, Hyderabad

Heaps of garbage & graffiti on Fort Walls

the modern era structures'. Thus, logically spoken, modern structures are closer to preservation of natural resources (stone, timber, fuel etc); but due to the tremendous population demand, the overall natural resources are depleting year after year. This is a modern age disparity, a dilemma, a paradox and an irony!

Considering the national and cultural heritage, and the sentimental value attached to forts, proper and regular maintenance must be done by the government, and initiate firm plans for their audit, repair and maintenances. The civil engineering fraternity must also come forward and launch a 'Save the Forts' campaign!

References

- Indian Temples a Structural Engineering Marvel – paper by Vivek Abhyankar on SEFI website
- Several lectures, speeches, books of Shiv-Shahir Shri Babasaheb Purandare
- Forts of India book by Amrit Verma, publisher
- Maharashtratil Forts – book by Dr D. G. Deshpande
- Maharashtra Desha book by Uddhav Thackeray (CM Maharashtra)
- Havai Mulukhgiri book by Uddhav Thackeray (CM Maharashtra).
- Ikshwaku Wanshaj Raam – book by Amish Tripathi

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