

1

Impact of Civil Engineering : An Introduction

UNIT SPECIFICS

Through this unit we have discussed the following aspects:

- ***The past to look into the future:***
 - *Pre- industrial revolution*
 - *Agricultural revolution*
 - *first and second industrial revolutions*
 - *IT revolution*
- ***Major Civil Engineering breakthroughs and innovations - a Timeline***
- ***Sustainable Development - Present day world and future projections***
 - *The steady erosion in Sustainability and its global impact*
 - *Sustainable Development Goals (SDGs), its impact and possible causes*
- ***Evaluating future requirements for various resources***
 - *GIS and applications for monitoring systems*
 - *Human Development Index and Ecological Footprint*

Besides giving a large number of multiple-choice questions as well as questions of short and long answer types marked in two categories following lower and higher order of Bloom's taxonomy, a list of references and suggested readings are given in the unit so that one can go through them for practice.

There is a "Know More" section, which has been carefully designed so that the supplementary information provided in this part becomes beneficial for the users of the book. It is important to note that for getting more information on various topics of interest some QR codes have been provided which can be scanned for relevant supportive knowledge. This section mainly highlights applications of the subject matter for our day-to-day real life or/and industrial applications on variety of aspects, case study related to environmental, sustainability, social and ethical issues whichever applicable, and finally inquisitiveness and curiosity topics of the unit.

Unit 1 - Impact of Civil Engineering: An introduction

RATIONALE

This introductory unit on the historic and socio-economic drivers behind the emergence of Civil engineering and its profound impact on sustainable development sets stage for the chapters ahead.

UNIT OUTCOMES

List of outcomes of this unit is as follows:

U1-O1: Understanding/ comprehension of world history and socio-economic context

U1-O2: Knowledge on the major breakthroughs and innovations of the domain

U1-O3: Knowledge on Sustainable development, its Goals, Impact and Indicators

Unit-1 Outcomes	EXPECTED MAPPING WITH COURSE OUTCOMES						
	(1- Weak Correlation; 2- Medium correlation; 3- Strong Correlation)						
	CO-1	CO-2	CO-3	CO-4	CO-5	CO-6	CO-7
U1-O1	2	2	3	1	2	1	
U1-O2	3	1	2		2	1	
U1-O3	3	2	3		2	3	2

The distinct most character of a civilisation is the advent of organised social and physical infrastructures to improve the quality of civic life. Though formal recognition of this branch and degree first appeared in the early 18th century, the practice and profession of civil engineering has existed since the dawn of civilisation. It is the branch of engineering or professional discipline of; planning, designing, building/construction and maintenance of physical infrastructures and built environment, to serve the general public or civilians. Since the designed built environment is a testament to the cultural heritage of a civilization, and a reflection of the socio-cultural, scientific, and technological advancements of the time, Civil engineering plays a pivotal role in impacting the society and global population.

In the following Section, the historical events that transformed society and challenged the discipline of civil engineering to develop is discussed.

1.1 DAWN OF CIVIL ENGINEERING: A BRIEF HISTORY

1.1.1 Pre-Industrial Revolution

Early human history can be dated back to the Stone Age in the Palaeolithic period (2.5 million years ago – till 10,000 BCE) when early man followed nomadic ways of the hunter-gatherer, lived in caves and huts or *tepees* and had begun to develop rudimentary tools of stone and wood. But around 10,000 BCE, a shift in climate and discovery of farming led the Neolithic man to settle, mostly along riverbanks, with focus on production of food. This in turn, led to the need to build secure habitation, plan settlements, and land use, construct transport and irrigation systems, and design solutions towards water supply and sanitation, which can be identified as the first examples of civil engineering.

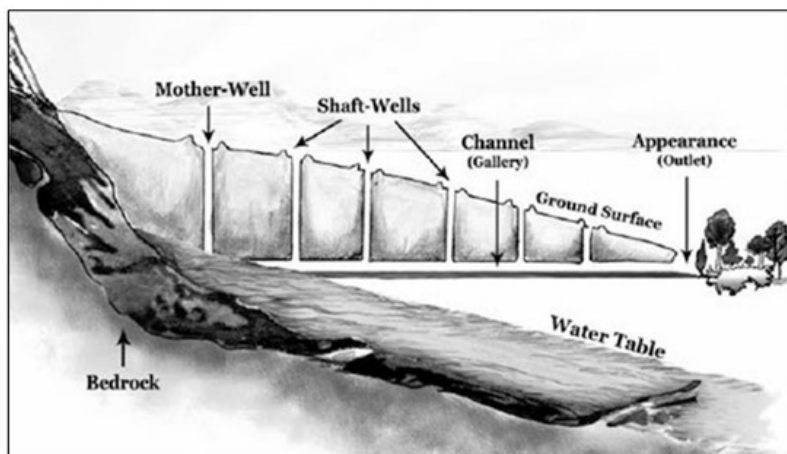


Fig. 1.1 Persian Qanat Profile (source: Manian, et al., 2022)

Unit 1 - Impact of Civil Engineering: An introduction

In the following era, known as Bronze age, the social organisation altered with kings and leaders emerging and early towns being established, leading to the migration of people for better wages and employments. Skills, tools, and techniques that were handed down from generation to generation of skilled artisans, stonemasons, and carpenters, in a small locale developed into expertise and artistry that led to the rise of planners, architects and engineers, tackling projects traversing regions and empires. Between 4000 and 2000 BC, the profession grew from being utilitarian to being a creative practice of achieving feats of grandeur as is exemplified in the intricate planning of urban housing, sanitation, and water systems in the Indus Valley civilisations; decadent pyramids and monuments of Egypt; *Qanats* in Persia and Mesopotamia; Stonehenge in UK and the Great Wall of China; where functionality and aesthetics paralleled each other. *This is discussed further, with detail in the next Unit.*

Most of the construction efforts were achieved by manual labour and non-mechanised tools, however, two major global occurrences, namely, the Agricultural Revolution and the Industrial Revolution, created a huge demand of infrastructure for, housing, transportation, sanitation, and water management, and eventually for environmental planning and construction management.

1.1.2 Agricultural Revolutions

The **First Agriculture Revolution**, also known as the Neolithic revolution, occurred in 10,000 BC and led to the organisation of modern man as a producer, rather than a hunter-gatherer. While the following millennia focussed on socio-economic development and in turn, creative feats of engineering and design, as discussed above; agriculture continued to be the primary occupation of the common folk. Across all the major civilisations that arose, from those in Indus Valley, Egypt, Mesopotamia, Greece, Rome, Mesoamerica, Europe, Arabia and eventually the new nations and colonies; innovations and developments centred on the methods, tools and techniques to support agriculture, through construction of water supply for irrigation and sanitation, granaries for food storage, tools and processes for production and preservation, etc.

However, by the mid- 17th century, an unprecedented growth in agricultural production from increase in labour and land productivity was observed in two nations, Britain and Netherlands. This was notably the **Second Agriculture Revolution**, and it spread across the other nations in Europe and their colonies in East Asia and North America over the next two centuries until the late 19th century. While the Dutch observed increase in the agricultural output per labourer, the British experienced the abundant outgrowth of output with respect to the population.

The strategic developments and innovations of the British Agriculture Revolution that shaped the era were; introduction of new crops, selective breeding and the method of crop rotation; improved design of the plough called the Dutch swing plough; and institution of land reforms, such as, land conversion, drainage and reclamation, increase in farm size, and enactment of Enclosure Act. Civil engineering played a significant role here, in the development of transportation infrastructure – roads, canals, railways, as well as social infrastructure, such as, development of national markets, supplemented with policies free of tariff, tolls and customs.

It is interesting to note that, while abundant food supply led to rampant increase in population, it eventually led to loss of labour force engaged in agriculture, leading to a need for new occupations. With time, though the inland production was countered with cheap imports of food supply, this revolutionary spike ensured a complacent food reserve that allowed a shift in the National priorities, from agriculture to industry. A new working class, seeking urban employment in the upcoming industries, emerged as a result and fuelled the onset of the Industrial Revolution.

The first half of the 20th century was rife with war and caused major setbacks in the developed countries. It is also at this time that several colonised nations sought their independence, further adding to the need for re-building and self-sufficiency.

The **Third Agriculture Revolution**, popularly known as the ‘**Green Revolution**’, transpired as a response to global hunger and poverty, dilapidated infrastructure, and scarce and contaminated natural resources by mid-20th century. New technologies and cutting-edge research in the areas of high-yield crops, hybridized seeds, genetically modified organisms (GMOs); use of chemical fertilizers and pesticides; methods of controlled irrigation and mechanized cultivation; characterise this era.

MS Swaminathan, agronomist and parliamentarian, lovingly called the ‘*Wheat man of India*’ invited Norman Borlaug, the ‘Father of the Green Revolution’, at the brink of a famine in 1961, and initiated collaboration with the Ford Foundation to import newly developed variants of wheat and later rice. Punjab became the birthplace of the **Indian Green Revolution** or ‘**Harit Kranti**’ and the Government of India facilitated programs to support farmers in the use of agrochemicals and irrigation. Late Prime Minister Shri Lal Bahadur Shastri, gave the slogan ‘*Jai Jawan Jai Kisan*’. Today, India is the world’s largest rice exporter.



Fig.1.2 : ‘*Harit Kranti*’ - The Indian Green Revolution

Presently, several strategies and contributions of the 'Green revolution' is being questioned, despite the fact that it addressed world hunger, poverty, and reconversion of land for agriculture. The decrease in food security and increase in production of export crops, has been unwarranted results of the same. However, while a rehauling of perspectives is underway to ensure long-term sustainability, some of the fundamental innovations and engineering contributions of this time set the tone for the future.

1.1.3 Industrial Revolution

While the North American colony was the primary producer of cotton, India was compelled to cultivate indigo on large-scale, despite several revolts by farmers. These two crops propelled the production of indigo-dyed cotton fabric, which in turn, thrust the need to improve the existing hand production to machines and mills, leading to the evolution of the design of cotton mill - from *Spinning Jenny* (1764) to the *Power Loom* (1787), to meet growing demands and establish a monopoly in international trade. This marks the **First Industrial Revolution**, spanning approximately 100 years from 1760 – 1850, characterised by mechanisation, fuelled by abundant coal supply and the optimisation of the design of steam engine by James Watt in 1765. new profession in engineering – mechanical engineering, was born, and several machine and production line innovations were developed.

Studies and experiments looking into the phenomena of electricity, by Benjamin Franklin, James Watt and Alessandro Volta, eventually gave rise to the **Second Industrial Revolution** between 1850 – 1917 with electrical energy as a new source of power that enabled mass production. However, by the mid-19th century, the working conditions in the factories across Europe worsened and there was worker unrest leading to The Great Reform Movements, thereby slowing the industries. By early 20th century, World wars and demand of independence by colonies, further led to the slowing of Europe as a forerunner in industry, and USA emerged as the promised contender.

The span between 1877-1917, termed as the '**Gilded Age**' of America by satirical author, Mark Twain, is characterised by massive economic growth, fuelled by development in the areas of manufacturing, railroads, telecommunication, automotive, product and industrial design, in the newly united federate, post-civil war. A centralised government and growing bureaucracy looked at expanding their jurisdiction and focussed on public services, through building of extensive rails and roads, telecommunication infrastructure, '**mass production**' industries and support facilities for public health and sanitation. A new connected world gave a global overview to markets, businesses, politics, and the invention of the lightbulb by Edison allowed prolonged working hours, furthering the industrialisation agenda.

The role of engineers, sanitarians and public health scientists grew in importance, while new domains of **product design and industrial design** came into being. Some of the common products that are used till date, came into conception during this era, such as, the foot-powered sewing machine, patented by Isaac Singer in 1851; the electric iron, invented by Henry Seeley in 1882; the first drum washing machine, patented by James King in 1851; and the first

mechanical, hand-cranked, dishwashing device made of wood, was registered in 1850 by Joel Houghton.

Another key area of innovation continued to be **telecommunication**. Graham Bell invented the telephone in 1876 and founded the AT&T company. While Edison invented the phonograph - a sound recorder, in 1877 and the kinetoscope - a peephole video player, in 1892.

Transportation remained a focus and a remarkable innovation that took place at that time was the design of the 'Quadricycle' by Henry Ford in 1896, that featured four bicycle wheels powered by a four-horsepower, internal combustion engine fuelled by petroleum and not steam. This led to the establishment of the Ford Motor Co. in 1903, which became the America's largest car manufacturer, housing a moving assembly line (*refer Fig. 3*) that made the Ford model T, a household name. That same year, the Wright brothers took first flight in the powered airplane, the 1903 Wright Flyer.



Fig. 1.3 : Assembly Line at Ford Motor Co. (source : www.corporate.ford.com)

*The use of **new source of power – electricity and petroleum**; new materials– iron, steel, glass, rubber; new techniques and design of engineered systems – turbines, engines, motors, conveyors, etc.; new technology, such as, Babbage's Analytical Engine or the first computer, led to mass-production, eased transportation and improved computation and telecommunication. Unfortunately, the early 20th century saw the onset of two World Wars, during which, while great scientific and engineering progress was made, catastrophic societal and environmental damage was onslaught.*

1.1.4 Digital Revolution and Industry 4.0

An era of rebuilding began around 1947, which is noted as the Third Industrial Revolution or Digital Revolution, characterised by the adoption of digital technologies, many of which had its precursors developed during the World Wars. It is also at this crucial time in history when India received her independence and was faced with many challenges, and took time to catch up to the state of the art.

The early years of the '*Information Age*' saw several firsts. In 1943, the ENIAC (Electronic Numerical Integrator And Computer) was developed; In 1947, the first working transistor was designed at Bell Labs, and later the MOSFET or MOS transistor was developed. In parallel, at Fairchild Semiconductor; the first monolithic integrated circuit chip was developed in 1959, alongside research and development in the area to improve the MOS chips, paving the way for the first microprocessor, Intel 4004. This technology also led to the development of image sensors for future digital cameras. In the 1960s and 70s, early CAD (Computer aided Drawing) software were sprouting, with Sutherland's SKETCHPAD, popularly nicknamed, 'Robot Draftsman' and Hanratty's Automated Drafting And Machining (ADAM).

1969 saw the breakthrough invention of the 'internet', when a message over the first wide-area network, ARPANET, was sent to public. This further led to development of inter-networking protocols, and with the introduction of the first home computer in 1970, a proliferation of digital technology and information sharing became the new way of life. Apart from utilitarian needs of digital record keeping, computation and automation, computers also led to a thriving video gaming industry that excelled in the development of first game consoles, game graphics and arcade games. Over the next decade, industrial robots, CGI in film and animation, electronic music and signages, were widely incorporated and eventually, the first mobile phone by Motorola in 1983 and the first digital camera in 1988 came into being.

The internet arrived in India in 1989, through the development of our indigenous network commissioned by the Department of Electronics (DoE), modelled on the ARPANET, named ERNET (Education and Research Network) and as a start, it connected IISc Bangalore, 5 IITs, NCSDCT (National Centre for Software Development and Computing Techniques) and DoE. Hardware and computers were already being imported by 1981 and India was already exporting software. In 1984, C-DoT (Centre for Development of Telematics) was established under the leadership of Sam Pitroda to design digital exchanges, but later expanded to develop software applications. In 1993, satellite link became operational in Bangalore Software Technology Park, and by 1998, VSNL launched Internet services that enabled companies operating from these parks to engage international clients. The Information Technology India market accounts for 9.3% of India's GDP and 56% of the global outsourcing market (IBEF, 2022) and all six Indian brands feature among the top 10 fastest-growing IT Services brands over the course of 2020-2022.

While digitisation remains integral to our present day lives, a new technological advancement is on the horizon, termed as **Industry 4.0 or the 4th Industrial Revolution**,

characterised by artificial intelligence, advanced robotics, internet of things (IoT), cloud computing and cyber-physical systems (CPS). 'i4.0', coined in 2015, leverages interconnectivity and big data to facilitate quick and decentralised decision-making and allows to cater to customised solutions for individual needs, in contrast to 'mass -produced' solutions, and imbibes increased automation, improved communication, Machine-to-machine as well as Human-Computer Interactions, and self-monitoring and autonomy.

Several i4.0 technologies, such as, Building Information Modelling (BIM) with cloud technologies, additive manufacturing or 3D printing, AR/VR (Augmented and Virtual Reality), drones and unmanned aerial vehicles, etc. is widely being used in the Architectural design, Engineering and Construction (AEC) domain today.

1.2 MAJOR BREAKTHROUGHS AND INNOVATIONS

From early man's tools to present technology of using drones, unmanned vehicles, and cloud computing; the major breakthroughs and innovations that moulded what civil engineering is today is as follows:

Tools, the first breakthrough that enabled construction, were developed from available natural materials, dating back to the Neolithic age. Stone axe with wooden handle, bone hammer, stone adze, celt, flake tools, sickle, drills and even, sledge, have been discovered from that era. Ancient tenements and structures were primarily built of raw natural resources that were abundant in the region, such as, rocks and stones, timber and bamboo, mud, and clay, etc.

Bricks, were a major innovation and till date, is the integral building-block of most structures. Sun-baked mud bricks or '*adobe*', cemented by lime mortar, was extensively used in Indus Valley and Egypt. Later, kiln-fired, and glazed bricks were developed in Mesopotamia. Large rocks were also chiselled and faced into massive bricks. This in turn, led to innovations in new tools, such as, ramp, lever, lathe; and techniques, such as, butterfly interlocking, method of drilling stone, enamelling; led to development of complex and tall structures, such as, pitched-brick vaults, and pyramids.

Cranes, pulleys, and jibs to raise construction materials to great heights, employing metal cramps to join large stone blocks, and development of early 'construction drawings', to build mega-structures, such as, groin vaults, arch bridges and the early multi-storied buildings were some of the contributions of the Greek.

Road design and construction, as we know it today, was first formidably developed by Romans and the first known roadway, the **Appian Way** or the '*Queen of the roads*', was constructed in 312BCE, connecting Rome with its allies in Capua. The design comprised of digging shallow trenches with retaining walls on either side, filled with layers of; levelled earth and mortar or sand topped with rocks, crushed rocks or gravel cemented with mortar and surfaced with blocks of cut rocks, arranged pebbles, iron ore or hardened lava.

Unit 1 - Impact of Civil Engineering: An introduction

Roman cement, developed by adding volcanic ash, called *pozzolana*, in lime mortar to make it harden under water, is one of the major breakthroughs in the history of civil engineering and construction. This further led to the development of Roman concrete, where concrete made of rubble and mortar was filled inside stone or brick formwork, which was later replaced with the use of removable wooden shuttering; this technique allowed building of arches, barrel vaults and domes over large spans.

Romans also introduced, the use of lead or '*plumbum*' for pipes and roof covering, thus being the origin of the word plumbing; and centralised heating achieved through raising the floor above a wood or coal fire exhaust. They also made use of glass for windows and in mosaics.

Iron reinforcement dates back to the time of the ancient times when cramps and bolts were in use to either hold together stone blocks or timber members in trusses. Later in the 15th century, the same were used by Brunelleschi in the design of the dome, where two layers of domes met at the top in an open stone compression ring and iron cramps held together tie rings running horizontally between ribs. The design was improved in cupola of St. Peter's Basilica, where three continuous iron chains held the dome in tension.

Pile driver, a tool to drive 'piles' or vertical, pole-like, structural members of deep foundation, driven deep into the ground where the soil is loose, to support piers, bridges, cofferdams, etc., was invented in 1500.

First railway line has been referred to in 1515, having wooden rails and a hemp haulage rope through a treadwheel operated by manual power. Several funiculars have been spotted across Europe, however, the world's oldest operational railway - the Middleton Railway, was built in 1758 in Leeds, UK.

Drafting and surveying tools like, the line gauge, plumb line, the carpenter's square, the spirit level, and the drafting compass were developed in the 17th century.

Structural iron was introduced as a building material with the availability of iron, soon replacing wood and charcoal. Iron ore was smelt with the use of coke on a mass scale in 1702. Christopher Wren used iron hangers to suspend floor beams at Hampton Court Palace, and iron rods to repair Salisbury Cathedral and strengthen the dome of St Paul's Cathedral, and iron columns in the House of Commons. Cast-iron was used for the bridge at Coalbrookdale in 1776, while wrought iron was used for the roof structure of the Louvre, Paris. Later in the 19th century, the first two exhibitions of The **Great Exhibition of the Works of Industry of All Nations**, or the *Exposition Universelle*, namely, the Crystal Palace in Hyde Park, London, and the Eiffel Tower, Paris, were also exemplars of iron structures.

Modern road design developed in the 18th century, with method improvements and new technique proposals by Tresaguet, Metcalf, Telford, and McAdam. The present design is an adoption, named the '*Tar McAdam Road*', patented in 1901.



Fig. 1.4 : Ancient building materials and techniques - (Top Left) Egyptian Hieroglyph showing building construction with brick; (Top Middle) Roman Cement, (Top Right) Lead 'plumbum' Pipes, (Bottom Left) Sun-dried Mud bricks of Mesopotamia ; (Bottom Right) Roman Road

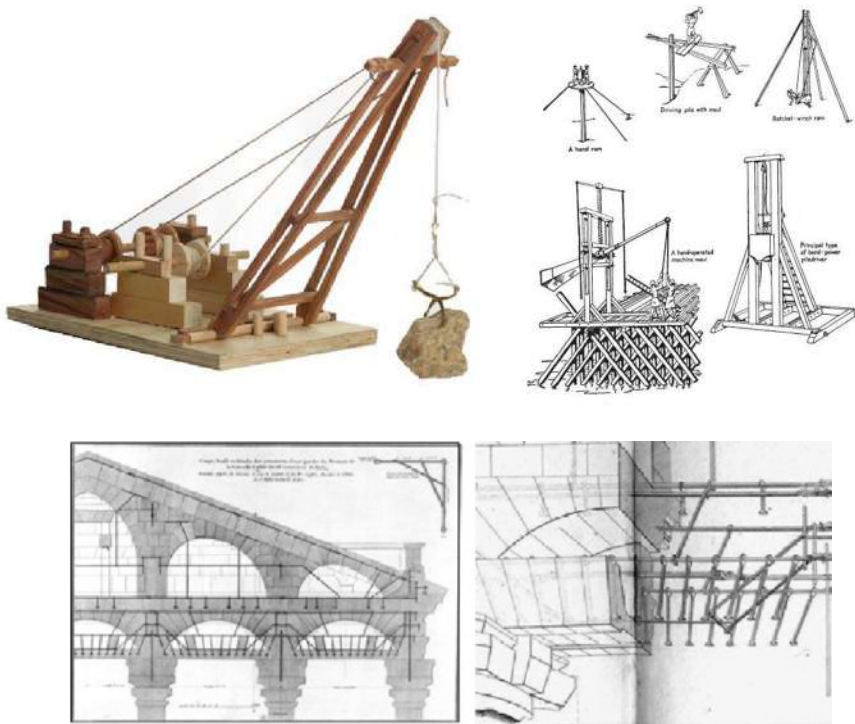


Fig. 1.5 : Ancient construction tools and techniques - (Top Left) Greek crane, (Top Right) Designs of Pile Driver, (Bottom) Rondelet's drawing of reinforcement iron bars (Blasi and Iori, 2008)

Unit 1 - Impact of Civil Engineering: An introduction

First iron chain suspension bridge in the Western world was the Jacob's Creek Bridge (1801), Westmoreland County, Pennsylvania, designed by inventor James. However, Union Bridge (1820) is the oldest operational chain suspension bridge.

The **first wire-cable suspension bridge** was the Spider Bridge at Falls of Schuylkill (1816),

Portland cement was patented in 1824 by Joseph Aspdin and its modern common version was developed by his son, William, in the 1840's.

The **first** advertised **prefabricated home** was the "Manning Portable Cottage" conceived in 1830 by London carpenter H. John Manning. Shortly after in 1845, Isambard Brunel designed the prefabricated wood and canvas, Renkioi Hospital, for assemblage on site at the Crimean War.

The **first systematic national building standard** was established with the London Building Act of 1844, and by 1855, Metropolitan Board of Works was set up. Meanwhile in the USA, the City of Baltimore passed its first building code in 1891 and by 1908 a formal building code was rafted and adopted.

Reinforced concrete was invented in 1849 by Joseph Monier and the first reinforced concrete bridge was built by the inventor-engineer.

Building of the **Panama Canal** between **1905-14**, was a feat of civil engineering as it was the biggest earth dam in the world and created the largest man-made lake, by deepening of the Pacific and Atlantic **canal** entrances, widening and deepening the Gatun Lake navigational channel. It remains one of the busiest shipping lanes in the world.

Mass production of Steel, was enabled by the Bessemer process, introduced in 1855. However, the move to steel as an important material date back to 1740, with the development of the crucible steel technique by English inventor, Benjamin Huntsman, who also established a steelworks at Sheffield, England. This was further supported with the use of steam engines to operate heavy machinery and the invention of steel roller for steel production by Henry Cort in 1783.

Along with **mass-production of Glass** and the urge to explore non-traditional design and construction in mid- 19th century, **the first skyscrapers**, namely, the Empire State Building, Rockefeller Center and Chrysler Building, in New York were conceived. The Empire State Building was constructed in only 13 months, towering to a height of 443 meters and 102 stories, it was the tallest building of its time in 1931.

Prestressed concrete invented by Freyssinet in 1928 and further applied it to develop precast segmental construction.



Fig. 1.6 : Panama Canal (*Top*) A Cross Section Canal, (*Bottom*) Picture

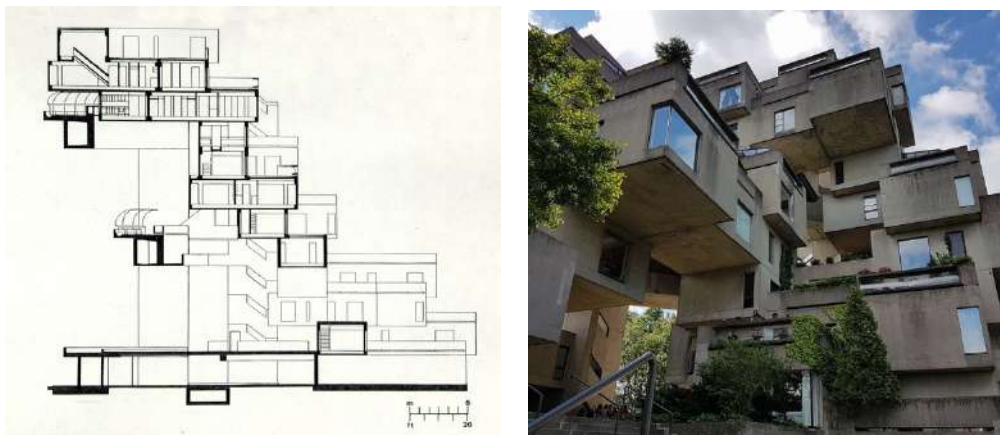


Fig. 1.7 : Modular construction - Habitat 67, Montreal (*Left*) Section drawing, (*Right*) Photograph