3 Infrastructure

UNIT SPECIFICS

Through this unit we have discussed the following aspects:

- ***The present and future projection of various facets of Infrastructure development***
    - *Habitats - Megacities, Smart Cities, futuristic visions*
    - *Transportation - Roads, Railways & Metros, Tunnels (below ground, under water); Seaports, River ways and canals; Airfields and Airport, Futuristic systems*
    - *Energy generation - Hydro, Solar, Photovoltaic, Wind, Wave, Tidal, Geothermal, Thermal energy and New sources*
    - *Water resource management*
    - *Telecommunication - Towers, above-ground and underground cabling*
- ***Awareness of various Codes & Standards governing Infrastructure development***
    - *ISO Codes for infrastructure construction*
- ***Innovations and methodologies for ensuring Sustainability in Infrastructure***

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.

RATIONALE

This fundamental unit discusses the important facets of infrastructure for the better understanding of its practical aspects during practice of Civil engineering, in the context of Sustainable development and future trends. It further emphasizes the role of standards and codes, and highlights the innovations and methodologies the civil engineer can leverage to develop sustainable infrastructure.

UNIT OUTCOMES

List of outcomes of this unit is as follows:

U3-O1: Knowledge on the present and future projection of various facets of Infrastructure Development: Habitat, Transportation, Energy generation, Water provision and Telecommunication

U3-O2: Understanding/comprehension of various Codes & Standards governing Infrastructure development

U3-O3: Knowledge on innovations and methodologies for ensuring Sustainability in Infrastructure development

Unit-3 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**
U3-O1	3	3	3	-	3	2	1
U3-O2	1	1	1	2	1	1	3
U3-O3	2	1	2	1	2	3	2

The term 'infrastructure' can be traced to 1927 referring to the various systems, amenities and facilities of public works that enables the provision of services. For example, Transportation services is provided by the associated infrastructure of roads, rail lines, harbours, bridges, etc. and Irrigations and Water management service is provided via dams, canals, etc. Today, classified as 'hard' infrastructure, these physical systems support various other services such as, waste management, telecommunication, power generation.

Prud'homme (2004) enlisted the **common characteristics of infrastructure**, as follows:

(i) Infrastructure "*are capital goods*", i.e., it is a means to provide service and not consumed directly, requiring labour and other inputs for it to be useful.
(ii) It is "lumpy" and not incremental, i.e., it is of a limited capacity to handle demand and cannot meet growing demands. It also requires years for being built and and of being in use.
(iii) It is long lasting, having long term implications on maintenance and hence, financing.
(iv) It is space specific and immobile, having further implications on financial capital.
(v) Infrastructure and the service it renders is subject to market failures, decreasing costs, externalities, etc.
(vi) It is used by both, households and enterprises, as it increases welfare and productivity.

In contrast, 'soft' infrastructure refers to the institutions that maintain health, socio-cultural and economic standards of a society, such as, healthcare and financial facilities, law enforcement and education. Of these, some are 'critical' infrastructure, identified as per the priority of the Nation. For India, these are Power, Telecom, Aviation, Energy, Banking, Cybersecurity and Disaster Management.

Another classification of infrastructure is based on its direct or indirect impact on production. The types that are essential for either improving or impeding production and distribution, such as, power, irrigation, transport, communication, etc., are classified as 'Economic Infrastructure, while those that aid economic progress, such as, Education, Healthcare and Housing, are classified as 'Social Infrastructure'.

3.1. HABITATS

Together, these various facets of infrastructure respond to the physical characteristics of a region to support the use of resources and productivity by the inhabitants beyond the boundaries of their natural habitat, with the underlying motivation for socio-economic development. In the following Sections, the present and future projection of various these various facets are discussed.

European Nature Information System (EUNIS) defines a **habitat** as "*a place where plants or animals live normally, characterized primarily by its physical features – topography, plant or animal physiognomy, soil characteristics, climate, water quality, etc., and secondarily by the species of plants and animals that live there*". In 2004, EUNIS classified various habitats, such as, marine, coastal, inland surface water, grasslands, woodlands and forests, along with recognising habitats created out of human intervention, such as, cultivated agricultural, horticultural and domestic habitats, and constructed, industrial and other artificial habitats, such as cities.

3.1.1 Megacities

In 2018 "*World Urbanisation Prospects*" the UN identified very large cities with population of over 10million as '**Megacities**' and UN further enlisted 33 megacities of which half of these urban agglomerations are in India and China and 27 are in the developing regions of the world, termed as the 'global south'. Globally, this is projected to rise to 43 by 2030, and the number of cities with 1 to 5 million inhabitants is projected to grow to 597. The characteristics of a Megacity are; *size, rate of growth and complexity* in terms of administration and infrastructure (Wenzel et al., 2007), and are the economic drivers of the country.

The urban population is projected to increase up to 28% worldwide, while rural population is projected to fall to 40% by 2030 (UN, 2018). Tokyo, Delhi and Shanghai that ranked 1st, 2nd , 3rd back in 2018 has already been overtaken by Shanghai, Chongqing, Beijing and Guangzhou, ranking Delhi at 5th today. This trend of fast-growing cities is widely noticeable in Africa as well, with Lagos in Nigeria being among the fastest growing, and other cities like Kinshasa in Democratic Republic of Congo and Dar Es Salaam in Tanzania.

Li, et al. (2019) analyses **four major problems of Megacities** from urban geography and ecology perspective, as follows;

- ***Land subsidence*** due to over exploitation of groundwater.
- ***Environmental problems*** such as, pollution, urban heat islands, urban air quality and haze, carbon emissions and dust storms, etc.
- ***Traffic congestions***, parking difficulty, public transport. This is closely related to the above problems of pollution, haze, etc.
- ***Energy consumption and production*** that is inefficient and unsustainable.

However, there is also the problem of declining of urban population. While large influx of population into urban boundaries is on rise, most of these cities also face high risk of population decline and loss of life due to geographical location, mostly coastlines, and consumption patterns are the vulnerable to at least one of the 6 types of natural disasters – cyclones, floods, droughts, earthquakes, landslides and volcanic eruptions. Some of the factors that contribute to the high risks of megacities in developing nations are; high population exposure due to housing concentration, complex and ageing infrastructure, lack of robustness of critical facilities and weakness of preparedness for response and relief (Wenzel et al., 2007). In addition, stagnating population has been associated with low fertility rates, particularly in Europe.

The mass movement of population from rural to urban has led to drastic changes in the constructed habitats and has put ever increasing demands and stress on infrastructure, limited resources and inequitable access, and deteriorating living conditions, leading to a large chunk of the population to be below poverty line and without social welfare. While cities today approximately occupy only 2% of the total land, it contributes towards 70% of the GDP and is responsible for 60% global energy consumption, 70% greenhouse gas emissions and 70% global waster generation. The enormous requirements of natural and human resources for energy, food, industrial production, services, construction, infrastructure, and maintenance, causes severe ecological impacts. In turn, development sprawl encroaches ecologically sensitive areas, such as, estuaries, coasts, riverbeds, which in turn require high developmental costs and maintenance more expensive. Other anthropogenic hazards, such as terrorism and war are also largely targeted towards megacities.

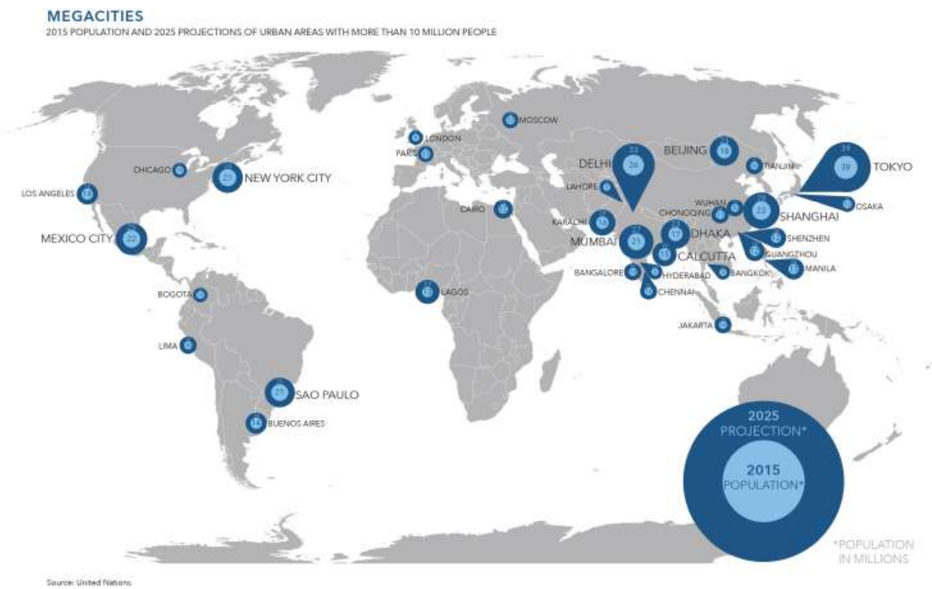

Fig. 3.1 : Megacities of the World (source : United Nations)

Krass (2007) noted **how megacities affect global changes**, enlisted below, and in turn, are affected by them. These changes maybe,

- ***Geo-ecological change:*** pollution, sea level rising, global warming, etc.
- ***Geo-economic change:*** globalisation, international labour division, urban markets, etc.
- ***Geo-social change:*** urban disease, social justice, migration, human security, etc.
- ***Geo-cultural change:*** urban ethnicity, social movements, global media, urban cultural diversity and hybridity; and
- ***Geo-political change:*** resource security, social stability, social justice, welfare, etc.

To combat these challenges, the '*New Urban Agenda'* was adopted during the UN Conference on Housing and Sustainable Urban Development (Habitat III) in 2016, that outlined the implementation of; Urban rules and regulation, Urban planning and design, and Municipal finance, with consideration of national urban policies to support sustainable development. In addition, megacities are greatly leaning on digital Information and Communication Technologies (ICT), to envision the ever-growing city through 3D modelling and visualisations, image and data fusion, Big Data, IoT and real-time Earth observations, becoming the backbone for 'digital cities of the future' or '**Smart cities**'. However, while megacities are heavily into employing 'Intelligent' strategies, but it may be argued that without addressing the elements of sustainability and noted improvement of quality of life, and only through employment of ICTs is inadequate. Presently, western megacities such as London, Paris and New York, are focusing on infrastructure for quality of life by ensuring; sustainable utilisation of land resources, improvement of design quality of buildings and urban spaces, balance between economic growth and environmental protection, improve air and water quality, climate change, etc. This gives an insight into what should the priority of developing nations such as India be to achieve SDG 11 – Sustainable Cities and Communities.

3.1.2 Smart Cities

SDG 11 aims for inclusive, safe, resilient, sustainable cities and 'smart city' planning is a proponent of the same, as it strives develop frameworks to technologically support all basic infrastructure and services required for its inhabitants towards becoming self-sufficient. Megacities and upcoming cities, with growing issues of sustainability are struggling to preserve natural and economic resources, lean on 'smart city' concepts however, the ***ground implementation is heavily dependent on the level of development, willingness to change and availability of resources*** (Bordoloi and Acharya, 2023).

'Smart' city is a broad concept with various sub-themes; urban and regional planning, economic development, environment and sustainability, ICT and technology. Integration of digital technology with improving urban areas and public spaces, reducing environmental impact, involvement of citizens in policymaking, and utilizing entrepreneurship and human capital for urban development; thereby making networks and services more efficient, flexible, and sustainable for the benefit of its residents is the key characteristic of a Smart city.

The **dimensions of Smart City** are smart - people, smart living, smart government, smart transportation, smart environment and smart economy. These are further expanded to include smart technology, smart infrastructure, smart water and waste, smart agriculture and smart security. In summary, the term 'smart' has three conceptual elements: Technology, including hardware and software infrastructures; People and their associated attributes of creativity, diversity and education; and Community, referring to institutions, governance and policy. And the four city technological brands included under 'Smart City' are 'Digital City', 'Intelligent City', 'Ubiquitous City' and 'Information City'. However, these must not be at the expense of social and environmental impact as 'quality of life' is the eventual goal of smart cities. Therefore, a term **'smart sustainability'** is often used to stress on the need to respect local or planetary limitations and to utilise resources without compromising the needs of future generation.

Thus, Smart City strategies help to create sustainable cities and communities by addressing social problems, optimising financial resources, and mitigating environmental consequences through conservation and controlled use of natural resources. **Key features of 'sustainable smart cities'** include *compactness, population density, sustainable transport, mixed land use, green areas, passive solar design and diversity*. However, there are still gaps between real world problems and available strategies and solutions.

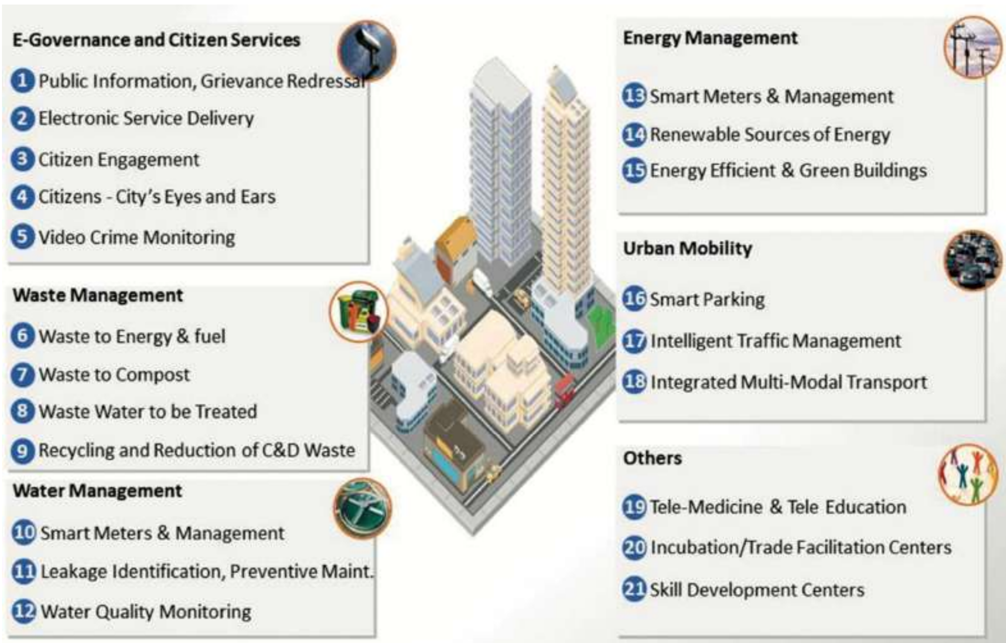

Fig. 3.2 : Illustrative List of Smart Solution, Mission Statement & Guidelines, MoUD, GoI (Jun 2015)

In June 2015, the Govt. of India launched the '***Smart Cities Mission'*** to develop sustainable and inclusive cities, keeping in mind that by 2030, 40% of the Indian population will be in urban areas and will contribute towards 75% of the GDP. The Ministry of Housing and Urban Affairs (MoHUA) outlined the strategic components of a smart cities as; adequate water supply, assured electricity supply, sanitation and solid waste management, efficient public transportation and urban mobility, affordable housing, robust IT and digitalisation, e-governance and citizen participation, sustainable environment, safety and security of citizens, and health and education. The mission envisioned 100 cities across the country and strategized based on area-based development through retrofitting, redevelopment, greenfield development, and pan-city initiatives. There are several schemes, such as, Atal Mission for Rejuvenation and Urban Transformation (AMRUT), Swachch Bharat Mission, National Heritage city Development and Augmentation Yojana (HRIDAY), Digital India, Skill Development, Housing for All, etc., that offer complementarity to the Mission and convergence of these is promoted. Three tiers of monitoring, at national, state and city level is proposed, and while it is presently centrally funded, it requires state government and urban local bodies to contribute equal amounts for implementing the Smart City, approximately 100crore per city per year for 5 years. The total allocated investment stood at Rs.205,018 crore ($ 27.6 Billion) as of March 2021 and a recent Rs.16,000 crore has been allocated in Budget 2023. Presently, MoHUA reported that more than two-thirds of the total 7,804 projects have been completed.

3.1.3 Future vision of Habitats

Future habitats, while predominantly urbane and highly digitalised, will reflect the paradigm of Industry 5.0, with a shift from economic value to social value. This is exemplified by automation, robots and smart machines working alongside humans with resilience and sustainability as priority. The cities of the future, while 'intelligent', will lean strongly on tenets of Sustainability as the backbone for development and aim to create value through harmonising **five types of sustainable capital** from where goods and services are derived, namely, Natural Capital, Human Capital, Social Capital, Manufactured Capital and Financial Capital.

A large number of **futuristic city developments** underway all over the world are;

Amravati, capital city of Andhra Pradesh, India, designed by Foster + Partners, is under the Smart City Mission, is aimed to cover 217 sq.km. such that over 60% of the core area is occupied by greenery or water bodies.

Chengdu Future City, China, designed by OMA, will occupy 4.6sq.km. with focus on smart mobility network and a car-free masterplan.

New Administrative Capital in Cairo, Egypt, designed by SOM, will cover 700 sq.km. and will feature one of the world's largest urban parks.

Smart Forest City, Mexico, designed by Stefano Boeri Architectti, is intended to be a forested smart city near Cancun with plant covered homes and 7.5 million carbon absorbing plants and trees across its 557 hectares (5.57 sq. km).

Fig. 3.3: Future Projects - (*Top Left*) *Amaravati,* India, by Foster+Partners, (*Top Right*) *Chengdu Future City*, China, by OMA, (Bottom Left) *Maldives Floating City*, Maldives, by Waterstudio, (*Bottom Right*) *The Line*, KSA, by Neom

Several attempts to use advanced building and construction technology is also underway to **reclaim or rebuild presently vulnerable cities**, such as;

BiodiverCity, Malaysia, also designed by BIG, is a 1821 hectare (18.21 sq.km) development of three artificial islands built of the shore of Penang Islands, built using combination of bamboo, timber and concrete.

Maldives Floating City, Maldives, designed by Waterstudio, as a response to the rising sea level and the concern of the Maldives becoming uninhabitable by 2050, will be built on hexagonal structures that rise with the sea.

A prototype climate-resilient floating city is also being designed by BIG and tech company***, Oceanix, off the sea of Busan, South Korea***.

Further, state of the art, **breakthrough proposals** are also underway in unoccupied land stretches with the intention to design for the future population and a sustainable way of living, such as;

The Line, Saudi Arabia, which will house a 170km long, 500m tall, but 200m wide, linear city stretching to touch the sea, and is envisioned as a model for 'nature preservation and enhanced liveability'.

Telosa city, USA, designed by Bjarke Ingels and BIG on an unoccupied 150,000-acre (607.03 sq.km) site in the western desert.

Design of green buildings, use of eco building materials, incorporation of natural environment and urban open, green spaces, apart from the 'smart' services and their allied infrastructure would be characteristics of cities of the future. In addition, there is a hope that the citizens of the future will be more conscientious as a society and continue to strive towards the SDGs collectively. This brings us back full circle to the early '**social indicator movement'** of the 1960s where the important linkages between infrastructure and quality of life (Terleckyj, 1975) was captured in order to systematically assess existing possibilities for social change, by mapping the infrastructure against attributes of human habitat, i.e., Health, Safety, Recreation and Aesthetics, Economic opportunity and Leisure. Aschauer (1989) reflects that, *the general public desires cleaner environment, safer urban streets, increased mobility and economic opportunity for the disadvantaged, and an economy well equipped to compete internationally*; and empirically establishes the importance of infrastructure development and investments towards improved quality of life and economic performance.

3.2 TRANSPORTATION

The global economy functions through trade and commerce, and transportation service sector is the most essential aid. It not only supports the supply chain through timely movement of raw materials and resources, but also enables eventual distribution of finished goods, in turn assuring economic competitiveness and growth. It is also the mode of travel for people for employment and education opportunities, healthcare, leisure, or social networking, etc. But while this was greatly hampered in the pandemic era, with millions with home bound. The times are also exemplar of the heights of exploitation of transportation infrastructure and logistics, becoming one of the most critical infrastructure sectors along with Energy, Water and Telecommunication. And today's new normal is quick and easy, door-to-door delivery, demanding development of further land, water, underground, air, as well as futuristic modes of transport infrastructure.

3.2.1 Land Transport Infrastructure

Land transport can be broadly categorised into roads, railways and metros; a 'way' for travel. The word 'way' as per Britannica, stems from the Latin '*veho'* which means, "*I carry"*, derived from the *Sanskrit* word, '***vah'*** meaning to "*carry, go or move*".

Roads

The generic word 'road' used to encompass all land vehicular ways is derived from the Old English word '*rad'*, which means "*to ride*". However, the term highway predates it, back to the elevated Romans roads which created a mound in the centre and ditches on the side, upon compacted layers of soil and gravel. It is used to refer to major roadways that connect several rural and urban space and is characterised by various controlled points of entry and exits for traffic. While 'streets' has its origin in Latin '*strata'* meaning paved, and is till date used to refer to all small rural scale roads.

Road networks follow a system of hierarchy in their capacity and capabilities. Most roads world over are conventional, undivided two-way; however, there are divided roads such as; expressways, having minor at-grade intersections; freeways, having no at-grade intersections, collectively called motorways in the UK. Functionally roads are classified as: Highways - the major roads between regions; Arterial roads – that carry through traffic from adjacent areas and are major roads within a region; Collector, distributor and feeder roads – that carry only through traffic from a certain area perimeter; and local streets – that do not carry through traffic but only serve adjacent properties.

The earliest records of animal trodden paths used by man have been dated back to 6000 BCE, with evidence on first constructed road dating 4000BCE at Ur, present day Iran. Oldest existing paved road, made of layers of sandstone bound by clay-gypsum mortar with two rows of basalt slabs in the centre for use by foot, while the dipping edges were for animals, was built by the Minoans on the island of Crete. It was about 50km long at an elevation of 1300metres, from Gortyna to Knossos. The earliest long-distance road, traversing 2500 kms, between Susa in the Persian Gulf to the Mediterranean ports of Smyrna (Izmir) and Ephesus, was first used around 3500 BCE but came into organised use aroud 1200 BCE under the Assyrians. The Egyptians around 2600 BCE built roads to haul limestone blocks for pyramids and to connect towns and temples. Routes from Thebes and Coptos on central Nile ran towards the Red Sea and from Memphis (Cairo) towards Asia Minor. By 1500 BCE, a trading network across eastern and central Europe called **the 'amber routes'** grew for trading various materials such as, amber from northern Europe, salt from Austria, freestone from Belgium, lead and tin from England, flint from Denmark,etc. and connected Hamburg, Cologne, Frankfurt to Passau and Venice. In 334 BCE, Romans championed road making building nearly 85,295 kms, radially connecting Rome to its several provinces, with 29 great military roads (*viae militares*). **The Appian Way** was the most famous one, constructed in 312 BCE and at a distance of almost 660km from the capital, along the Mediterranean coast. In addition, the Romans also had two classes of public transport – the express service and freight service. China too had an extensive road system by the 7th century CE across 40,000km, development of which began under the Emperor Shinhuangdiin 220BCE. In India, under the Mauryan Empire around the 4th century BCE, had quality roads across its empire which stretched from Indus River in the Northwest to the Bramhaputra in the East, from Himalayas in the North to the Vindhyas in the South. Their **Great Royal Road** ran through Taxila or Takshashila, in modern day Afghanistan, across Punjab and Prayagrai, until the mouth of the Ganga River. The famed **'Silk route', the longest road of the time** that linked the Mediterranean with China, is said to have existed partially around 300 BCE and by 100 BCE it was pivotal to trade. However, the following centuries saw neglect of road systems without strong dynasties and leaderships, and wasn't until 8th century that road revival became a priority. In 9th century that the Moors of Cordoba, Spain developed an extensive street network. The following 11th and 12th century witnessed revival of cities and roads, mostly in western Europe, and by 15th century, well maintained infrastructure was ubiquitous. Meanwhile, in South America, the Inca empire (1000 – 1450 CE) extended the '*Qhapaq Nan'* or royal road from Ecuador, Peru until Chile, with two parallel systems – one along the coast and another along the Andes. Eventually, by 18th century, the modern masters of road building – Treaguest, Telford, Mc Adam, Mitchell, appeared in England and France.

Road design is an exceedingly important aspect of national and regional planning, especially in the context of urban connectivity and the population, commerce, industry and transportation needs of the community. Estimating traffic on a route as well as conducting civil surveys to establish the site conditions are integral to successful road system planning and design. To design a road, three-dimensional road alignment of the cross-sectional profiles along the terrain on which it is laid is of utmost importance. For quality and uniformity, **standards and codes** are established for different types of roads. It helps with guidelines on, number of traffic lanes as per traffic volume and speed, width of lanes, carriageways and shoulders, and specifications on roadside barriers. Other integral elements of road system design include design of pavements and drainage. Safety and serviceability of the roads are also critical aspects to be considered and financing and maintenance are key determinants. Jurisdiction of the section of the road and its onus, also plays an important role in case of any legality and taking responsibility. In India, roads are under the aegis of Ministry of Road Transport and Highways. Some of the **salient features reported** in the review 2022, note the major push in the following areas;

- Highway development
- Connectivity
- Logistics development
- Online citizens service
- Under Bharat series, regularisation of registration mark
- Retro fitment of CNG and LPG kits allowed in BS VI
- Bharat N-CAP safety rating introduced
- Compensation of victims increased
- Green fuel and vehicles
- Construction of '*amrit sarovar*' along National Highway
- NHAI InvIT bonds enlisted on BSE and NSE, and
- Manthan conference held in Bengaluru to discuss issues in road, transport and logistics.

Railways and Metros

In earlier chapters, we have discussed the oncoming of railways. The role civil engineer is pivotal for railway transport infrastructure, and encompasses surveying for a new line, construction and maintenance of the line, ensuring longevity, safety and reliability of the structure. In addition, the civil engineer also has to design bridges over rivers, station buildings and allied facilities, such as, office rooms, parcel offices, goods sheds, restrooms, wating lounges, as well as, loco sheds, pump houses, water and drainage lines, etc.

Railways evolved from **'tramways'** which were originally of stone slabs, timber and baulks, laid in flush with the road surface for horse carriages, and later, reinforced with iron straps or plates. Further on, these were improved, and tracks were designed, having angle irons with a vertical leg, later replaced by cast iron beams, which further evolved into rail sections on which the locomotive's wheels align. The wheels transfer the load of the locomotive on to the two rails of the track, kept at specific distance, i.e., gauge, and is placed on perpendicular sleepers equitably distanced on a bed of ballast. There are ballast-less, and continuous longitudinally-supported tracks as well, the latter being very uneconomical. Earlier, rails were of 'I' or dumb-bell sections; but this further developed into a 'T'-section, laid inverted and popularly termed as the 'Flat-footed' rails. Other rail profiles are Bullhead rail, Grooved rail, Bridge rail (inverted U-shape) and Barlow (inverted V-shape) rails. There are two common types of gauge - Broad gauge (1676 mm) that supports the speed of 100-160 Km/h, and Metre gauge (1000 mm) having a maximum permitted speed of 75Km/h. Another type is Narrow gauge, such as those of the Darjeeling Himalayan Railway or the Toy train which has achieved the UNESCO World Heritage status. Sleepers maybe made of wood, cast iron, steel, concrete. The rails are fastened on to the sleepers with dog spikes, and the ends are connected by fish plates or fish bolts, and can be switched to direct the trains. Other types of fastening are - round spikes and screw spikes, different types of bearing plates, tie bars, etc. The rail line is either placed on an embankment, or in a cutting where a pit is dug and the centre is raised to house the track, as it cannot be laid directly on ground. The railway track comprises of rails, sleepers, fastenings and ballast, and may also be called **'permanent way'**.

The **first steam locomotive** to carry passengers, designed by engineer, George Stephenson, began operations between Stockton and Darlington in 1825. The first railway proposal in India under the British rule was made in 1832, and the **first train transport named 'Red hill'** plied in 1987 carrying freight of granite for road -building. India's inaugural passenger train operated by the Great Indian Peninsular Railway, having three steam locomotives named '*Sahib, Sindh and Sultan',* ran between Bori Bunder (Bombay) and Thane, for a distance of 34kms, in 1853, and first passenger train ran between Howrah and Hoogly in West Bengal in 1854. Today, the Indian Railways is Asia's largest network and among the world's largest. It is about 108,706 track Kms and runs around 11000 trains daily, off which 7000 are passenger trains carrying around 13 million passengers every day.

In 1984, South Asia's first subway line began operations in Kolkata after 23 years since the commencement of underground construction. Delhi, too, had a urban rapid transit proposal back in 1969 but the construction began in October 1998. Today, the Delhi Metro is a benchmark, not only as the largest and busiest metro system, but also due to its state-of-the-art design and construction. The network consists of 10 colour coded lines, covering the National Capital region and its satellite cities of Ghaziabad, Faridabad, Noida and Gurgaon. It is a mix of broad and standard-gauge and has underground, at-grade (at road level) and elevated sections. **DMRC (Delhi Metro Rail Corporation)**, a company with equity from Government of India and Government of Delhi, under leadership of E.Sreedharan, has been certified by U.N. as the first rail-based system in the world to get carbon credits for reducing greenhouse gas emissions and carbon emissions. Mumbai also boasts of the first of its kind, Mumbai Monorail, that was completed in 2014 and is presently witnessing the development of the sixth longest operational metro network in India.

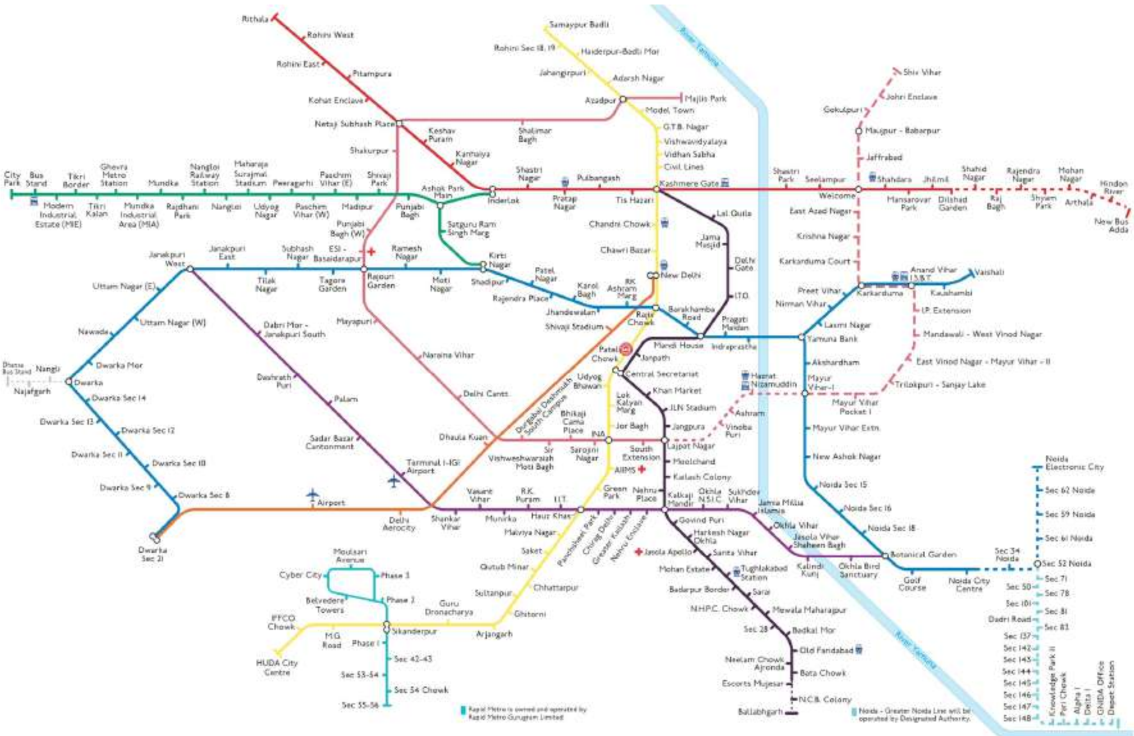

Fig. 3.4 : Delhi Metro Map (source : India Tourism, 2022-23)

Tunnels : Below ground or under water

Tunnels are under ground or under water, enclosed passages constructed by digging through rock, soil and earth, for movement of vehicles. With the massive excavation needed, the integrity of the passage is subject to the loading and pressure of the surrounding earth and/or water, construction of tunnels is highly specialised. There are various methods of tunnel construction on land, such as, *Cut and cover method* where a trench is cut and covered by some support;, *Bored method* where boring machines are used; *Clay kicking* method common from the time of World War I, where clayey soil is literally kicked to create a tunnel; *Shaft method* is used for reaching great depths from the ground level and pre-cast shaft structures with concrete walls are lined and connected; *Pipe jacking method* where pipes are driven underground using hydraulic jacks, usually under existing infrastructures like roads, railways, etc.; and *Box jacking method* where boxes instead of pipes are driven in. For underwater tunnel construction usually calls for immersing tubes or boring tunnels through rock.

The **world's longest road tunnel** is the *Lærdalstunnelen*, of 24.5 Km linking Aurland and Lærdal, and offering a ferry free connection built in 2000, followed by the Yamate tunnel in Tokyo, Japan measuring 18.2Km built in 2015 and the Zhongnanshan in Shaanxi, China measuring 18.04Km built in 2017. The Eisenhower Road tunnel in Colarado is one of the **world's highest tunnels** at a height of 3,401m above sea level, on the Rocky Mountains.

The **world's longest and deepest train tunnel** is the Gotthard Base Tunnel in Switzerland, running 57 Km in length and at a depth of 2300m under the Swiss Alps, significantly reduced train travel time connecting Zurich to Milan. Previously this distinction was held by the Seikan railway tunnel, spanning the Tsugaru strait connecting Honshu and Hokkaido, running 53 Kms at 140m depth. Another phenomenal feat is the Channel tunnel across the English Channel between England and France, spanning 50Km, having two rail and one service tunnel for passenger and freight.

A piece of modern engineering is the **SMART** (Stormwater Management and Road Tunnel) Tunnel in Kuala Lumpur, Malaysia, designed keeping in mind the flash flood situation that the city faces and operates in three ways : as a road tunnel when there is no flood, the upper level operates for traffic while the lower channel allows water diversion when there are medium floods; and closes for traffic but allows floodwater to flow through via a holding pond, bypass tunnels and a storage reservoir during heavy floods.

3.2.2 Water Transport Infrastructure

Seaports

Ancient Greeks heavily relied on sea travel as land travel was difficult. Greece is a series of archipelagos and peninsulas, surrounded by the Ionian, Mediterranean, and Aegean Sea, which they traversed by trireme ships. Beyond travel, they instituted maritime trade and frequented the ports of Canopus before Alexandria in Egypt and Messina in Sicily from Athens. Ostia Antica and Portus were later set up in Rome, and Swahili kingdoms of East Africa were described to have vibrant trade ports. Trade flourished amidst the Arabs, Greeks, Romans, Egyptians, Africans and Chinese. The south-western coastal ports of Muziris and Calicut, or Kozhikode, in present day Kerala, are accounted in ancient texts and is to have played a crucial role in the spice trade. The latter gained prominence after the arrival of Vasco da Gama. The port of ***Lothal***, the southernmost city of the Indus civilisation, at the edge of the Arabian Sea in present day Gujrat and is believed to be **the world's oldest dock**, dating back to 2200 BCE. Another important port in Gujrat, at the mouth of the river Narmada is Bharuch. East of the Indian subcontinent, Chittagong in present day Bangladesh, has been found referred in Ptolemy's map, dating back to 2nd century. And the south-eastern ports of Tuticorin (Thoothukudi), Arikemedu at modern day Pondicherry and Poompuhar, all in Tamil Nadu were bustling ports. In the far east, ancient seaports were Guangzhou in China during the Qin Dynasty and Osaka in Japan during the Edo period.

Civil engineering plays a crucial role in the design of water transportation and construction of ports and harbours. Ports are locations where ships and vessels can dock and allow movement of people and goods and are either on a coasts or shores, while harbours are constructed for the safe keeping of the vessels. Other infrastructures that have nuanced variations but support sea travel are; quay or wharf, pier, jetty , berth and dock, and all together form a network of waterway infrastructure for overseas transportation.

Inland waterways and canals

The beginning of rails marked the demise of canals and inland waterways, which used to be the preferred mode of transportation. All ancient civilisations settled around rivers, such as, the Indus civilisation along Indus River, Mesopotamia between the Tigris-Euphrates, Memphis (Egypt) along the Nile. Several prominent European capital cities, such as London, Paris and Amsterdam all are also along rivers. Apart from being a source of water for consumption and irrigation, riverways and inland waterways became the mode of trade and travel. Several other cities, such as, Giethoorn in Netherlands, Birmingham in England, Burges in Belgium, Hamburg in Germany, Stockholm in Sweden, are all traversed with network of canals with most prominent being **Venice**, Italy, which has **150 canals** including the *Grand Canal*. These were built by lining the dugout pits by closely spaced alder wood which is waterproof, to make the lagoon fit for habitation. While most of these canals are 1.5-2m deep, the *Canale della Giudecca* that separates the main part of Venice from the island of Giudecca, is about 12-17m deep.

Two of the most ambitious canal projects that are engineering feats are; the **Suez canal**, also referred to as *Qanat al Suway* (length of 193Km with branches, depth of 20m and width of 205m) across the Isthumus of Suez in Egypt which connects the Guld of Suez and the Mediterranean, thereby allowing a quicker path between the Pacific and Indian Oceans, and the **Panama canal** (length of 82Km with branches, depth of 12m and width of 150m) which connects the Pacific and the Atlantic Oceans across the Isthumus of Panama amidst the Caribbean. These two interventions significantly changed the time required and ease of transport for trade, becoming pivotal contributors to economic growth.

The **world's oldest and longest man-made canal** is the '*Great Canal'* or the Beijing-Hangzhou canal that connects the Yangtze and Yellow He rivers, across 1,782 – 2,470 Km with branches in length and varying width between 40-350m, having a depth of 2-3m. It is adorned with 21 gates and 60 bridges and has been recognised by UNESCO In 2014.