Urban Underground Space Development

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Abstract - *The world-wide trend of increased urbanization demands for more space for setting up buildings and transport systems so as to meet the needs of the population. Population rise leads to an increased demand for reliable infrastructure, nowadays combined with a need for increased energy efficiency and a higher environmental awareness of the public. The use of underground space can help cities meet these increased demands for infrastructure and transport systems with the same facilities that are provided on the surface. This study deals with the various construction techniques of tunnels, a study on the development of major underground transport systems, a comparative study on urban underground space planning system between China and Japan, the major underground developments undertaken in India and, challenges faced during construction.*

***Key Words*: World-wide, Urbanization, Infrastructure, Energy efficiency, Tunnels, Underground development, Challenges**

1. INTRODUCTION

The world is increasingly an urban environment. Since 2008, more than half of the world population lives in cities and the world population are expected to increase to roughly 10 billion people over the next four decades. By 2050, 70% of all people will live in cities and the world urban population will have more than doubled. In developing countries, where most of this uncontained population growth will take place, the rapidly expanding cities will need to meet the increasing demands for infrastructure. Without efficient transport systems, cities will sprawl away from the urban core, which strains the environment by creating more traffic congestion and increased travel time, loss of valuable farm land, and inequitable allocation of resources.

Placement of infrastructure and other facilities underground demands on the opportunity to find the needed space. The complexity and the obstructed access to the underground, created by the lack of space for the problem to be solved, lead to higher cost, giving underground solutions an expensive image, which in turn leads it to be the leas readily considered solution. In newly developing metropolises, that paradox need not exist, as initially the access to the underground is not obstructed and unique opportunities exist, if engineers, city planners and decision makers can come together and recognize that in order to reach an optimal solution, the underground option needs to be considered and used from the start.

Probably the most recognized problem is the need for congestion relief in metropolitans. By adopting suitable underground transport systems, hundreds of hours per worker per year can be saved in this way. This study deals with the various construction techniques of tunnels, a study on the development of major underground transport systems, a comparative study on urban underground space planning system between China and Japan, the major underground developments that has taken place in India and the challenges faced during the underground construction.

2. LITERATURE REVIEW

A paper by **N. Bobylev (2009)** was reviewed [5]. He stated that, the placement of infrastructure and other facilities underground present an opportunity to find the needed space, but it is often considered only as a last resort. This idea came from a paradox that the underground is considered only when surface space is exhausted and no other solutions existed further for the complex urban problems to be tackled. This complexity and the obstructed access to the underground, created by the lack of space for the problem to be solved, almost inevitably lead to higher cost, giving underground solutions an expensive image, which in turn led it to be considered less readily.

A paper by **Gatti (2013)** was reviewed**.** He reported that an even greater impact on the surroundings may be caused by the elevated highways, mainly constructed in the 1950s and 60s in a number of, mainly US cities; for example Boston, Seattle, and San Francisco. Those giant elevated structures through down-town areas were later seen as unsightly, noisy, possibly unsafe, and as areas that provided only limited access to areas adjacent to the freeway. Many cities later had plans or were in the process of planning to replace the elevated highways by urban road tunnels. An example is the Alaskan Highway in Seattle, which when completed will be the largest diameter bored tunnel in the world.

A paper by **Bond (2016)** was reviewed. He studied that the significance of the interdependencies between UUS and the entire urban underground system seems distinctively eminent when making decisions on UUS projects or mapping out UUS development from the perspective of long term sustainability assessment.

An article by **Cornwell R (2009)** in one of the prominent newspaper was reviewed [4]. He reported that just as in the case of underground railways, the use of UUS for underground parking has also been promoted as a solution to parking provision. The first underground city car park is thought to have been constructed in Pittsburgh in the 1920s.

A study by **Tabelin (2018)** was reviewed. He reported that one of the most pressing problems was a large amount of excavated soil which will be generated in the process of underground space development, which will have an impact on the surrounding soil and groundwater environment.

A study by **H. Yuan (2014)** was reviewed [3]. He showed that Japan's underground use plan aims "to improve the efficiency of underground and urban suitability, improve the smoothness of traffic and the use of integrated private land use"; its development began with the use of underground space under the roads.

3. METHODS OF TUNELLING

The underground construction standard covers many topics of concern to those who work in the challenging environment of underground construction. A sampling of items covered by the standard includes requirements for safe access and egress routes, employee training in hazard recognition, a check-in or check-out procedure, and emergency procedures. Some of the common methods of construction of underground space are:

a. Cut and cover method
b. Pipe jacking method
c. Box jacking method
d. Bored tunnel method
e. Clay Kicking Method
f. Shaft Method

3.1 Cut and cover method

Cut-and-cover is a simple method of construction for shallow tunnels where a section is first excavated and then covered over with an overhead support system strong enough to carry the load of what is to be built above the tunnel as illustrated in figure 1. There are two methods in which this can be done:

a. Bottom up method in which a tunnel is excavated under the surface using ground support.
b. Top-down method in which side support walls are constructed first by slurry walling method or contiguous bored piling. Most of the underground metro rail stations are constructed using this method.

Fig -1: Cut and Cover Method

3.2 Pipe Jacking Method

Pipe jacking method is used to construct tunnels under existing structures like road ways, railways etc. In this method, specially made pipes are driven into underground using hydraulic jacks as shown in figure 2. Maximum size of 3.2 meter diameter is allowed for tunnels.

Fig - 2: Pipe Jacking Method

3.3 Box Jacking Method

Box jacking method is similar to pipe jacking, as shown in figure 3, but in this case instead of pipes, specially made boxes are driven into the soil, while the excavation continues at the tunnel face. Prefabricated tunnel sections are advanced horizontally using high capacity hydraulic jacks. The practice is used in highway construction as well as trenchless operations. Excavated matter is collected within the box. Larger size tunnels can be excavated using box jacks up to 20 meters.

Fig - 3: Box Jacking Method

3.4 Bored Tunnel Method

Bored tunnel method is a modern technology. In this method, as shown in figure 4, tunnel boring machines are used which automatically work and makes the entire tunneling process easier. It is also a quicker process and best method to build tunnel in high traffic areas. Tunnel boring machines are available in different types suitable for different ground conditions. These machines can be used in difficult conditions such as below the water table.

A special pressurized compartment is provided for TBM to work in below water table conditions. The workers should not enter that compartment except for repair works. Care should be taken while TBM is in working conditions. The only difficulty with this TBM is its heavy weight. So, transportation is difficult and costlier.

Fig - 4: Bored Tunnel Method

3.5 Clay Kicking Method

This method is used for strong clayey soil conditions. It is an old method and used for small works like sewage pipes installations etc. In this method, a hole is excavated into the ground to a certain depth, the tunnel is then excavated by the clay kicker as shown in figure 5, who lies on a plank at 45° angle. An excavating tool is provided under the foot of the clay kicker. The excavated soil using that tool is then collected by other workers. This is well famous because it is the method used by Englishmen to put mines under the German empire during First World War.

Fig - 5: Clay Kicking Method

3.6 Shaft Method

In this method, as shown in figure 6, the tunnel is constructed at greater depth from the ground surface. The shaft is built up to the depth where tunnel is required. Shaft is a permanent structure which is like a well with concrete walls. Shafts are provided at both inlet and outlet of tunnels. Intermediate shafts are also provided if the tunnel is too long. After the construction process, these shafts can also be used for ventilation purpose as well as emergency exits.

Fig - 6: Shaft Method

4. UNDERGROUND TRANSPORT

Transport systems play an essential role in urban, economic and social development of a country. Underground transport systems have been chosen by cities as potential solutions for solving urbanization problems such as traffic congestion, land shortage, and noise and air pollution.

4.1 Transport Systems

This study provides an overview of five main forms of underground transport:

a. Underground railway systems
b. Underground car parks
c. Urban underground roads and expressways
d. Underground freight transport systems and
e. Underground pedestrian systems.

4.2 Underground Railway System

An urban underground railway is typically defined as one which runs within the built-up limits of a city, connecting the city centre by tunnels. The first underground tunnel in the world that was developed in London is shown in figure 7.

Fig - 7: Inside London's Secret Underground Railway

Digital technologies are being deployed to increase safety for trains and more efficient signaling and improved network performance.

4.3 Underground Car Parks

Just as in the case of underground railways the use of UUS for underground parking has been promoted as one solution to parking provision as shown in figure 8. The possible advantages of underground parking include easier access control, a secure environment, no obstruction of views or sunlight and improved liquid and solid waste pollution control.

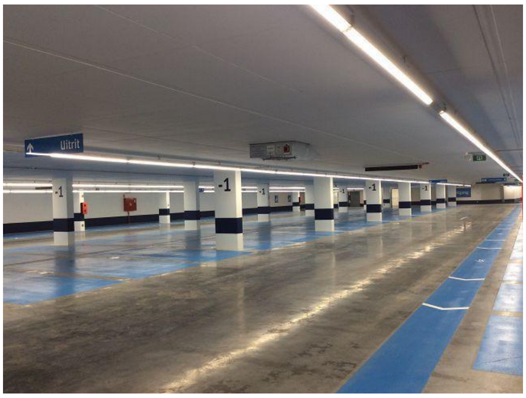

Fig - 8: Underground Car Parks

4.4 Urban Underground Roads and Expressways

A typical urban underground road or expressway shown in figure 9, travels through deep tunnels below a city, entering and exiting from portals that are integrated into the main surface road networks. A recent study summarized the functions of underground roads in reducing traffic on the ground and improving the road network, freeing land for redevelopment, providing landscape conservation opportunities, reducing greenhouse gas emissions, and lowering accident rates in bad weather conditions.

Fig - 9: Chenani-Nashri tunnel, India's longest highway tunnel on the Jammu-Srinagar national highway.

Hence, building underground roads and expressways in cities contributes to sustainable urban transport development.

The application of cost-benefit analysis has become one of the key topics in research on underground projects like underground roads and expressways. Though, underground space development is perceived to be associated with high costs of underground construction, potential geotechnical risks and archaeological risks, it provides enormous benefits once completed.

4.5 Underground Freight Transport Systems

Urban freight transport plays an increasing role in the smooth running of the urban transport system and is essential to the functioning of cities. It can take place in two forms: by vehicles or trains through underground tunnels; or by freight capsules through underground pipelines.

Researches have demonstrated the advantages and challenges of the implementation of underground freight transport. The possibility of reduction in a city's reliance on trucks, and alleviation of congestion on roads and traffic, and environment-related problems such as air pollution and noise are some of the major advantages. For freight in pipelines, characteristics such as unhindered movement in a sealed dedicated system for 24-hour operation daily, and electronic and computerized controls allow improved reliability and efficiency, and enable freight movement to be well-managed. However, there are planning, technological and political challenges for the implementation of underground freight transport. A typical underground freight system is shown in figure 10.

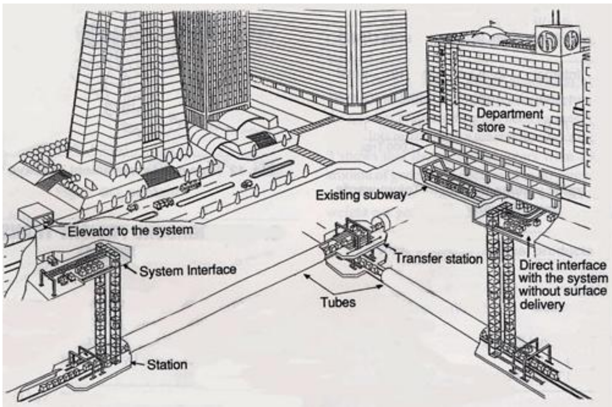

Fig - 10: Underground Freight System

4.6 Underground Pedestrian Systems

An underground concourse linked with shopping complexes or an underground transit can be viewed as an underground pedestrian system. A comprehensive definition of a well-developed underground pedestrian system is provided in a research based on Toronto's underground pedestrian system which contains a number of components, namely: **first**, a retail complex with many shops; **second**, a small city linking various buildings and spaces such as office buildings, department stores and underground parking garages; and **third**, a transport infrastructure integrating different transport networks, such as subway and national/regional transit networks as shown in figure 11. The development of underground pedestrian systems was believed to be initially driven by the need to provide shelter from poor weather conditions, such as in Toronto and Montreal with long and cold winters.

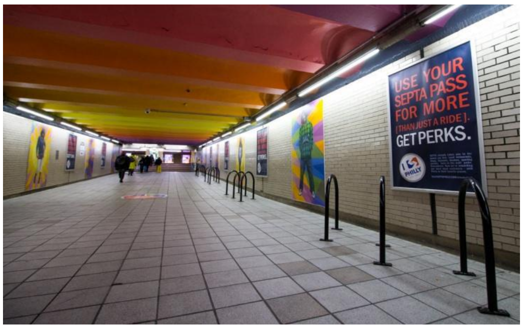

Fig - 11: Underground Pedestrian System

5. A COMPARATIVE STUDY ON UNDERGROUND SPACE PLANNING BETWEEN CHINA AND JAPAN

The Ministry of Housing and Urban-Rural Development issued the 'Thirteenth Five-Year Plan for Urban Underground Space Development', aiming to complete the planning and approval of underground space development by 2020 in more than half of China's cities and to establish a more complete management system for underground space planning.

Japan is one of the most mature countries in the world for underground space utilization. In the 1980s, the Japanese Ministry of International Trade and Industry (MITI) proposed the concept of underground space development and formed a mature planning system in long-term practice. Different from the western countries, underground space development and utilization in China and Japan have similar purposes. Urban population agglomeration, shortage of land resources, improvement of urban environment and improvement of urban efficiency are important driving factors for underground space development in both countries. China's underground space is developing rapidly, but the planning and management system is not well established and the development is not systematic. Therefore, when comparing underground space planning systems in China and Japan, it is of great significance for China to establish a well-built underground space planning system.

5.1 Comparison of the Planning Goals between China and Japan

Japan's underground use plan aims to improve the efficiency of underground and urban suitability, improve the smoothness of traffic and the use of integrated private land; its development began with the use of underground space under the roads.

China's underground space planning, meanwhile, aims to improve the efficiency of urban space resources, give full play to the comprehensive benefits of underground space, enhance administrative management efficiency, improve urban underground space planning and construction management level, promote the sustainable development of cities, and form an underground space system in all directions that can be used in times of both peace and war. Its development began with the peacetime use of underground civil air defense projects.

5.2 Comparison of Urban Underground Space Planning Contents between China and Japan

China's underground space planning pays more attention to the prediction of underground space demand, the layout of underground space, the layered planning of underground space development and utilization, and the investigation and evaluation of underground space resources.

In Japan, specific planning and management of underground streets, underground pedestrian traffic, and underground parking networks are carried out through underground transportation network planning, underground street planning, and Japanese building benchmark law.

5.3 Comparison of the Focuses of Planning Structure and Development between China and Japan

China's underground space planning, as with its urban planning, is divided into four categories: master plan, detailed plan, special plan, and professional plan. Although the current underground space planning in China is mostly in the form of special plan under the urban master plan, with the promotion of the above ground and underground three-dimensional process, the connection between underground space and ground space is increasingly close, and it has become an irresistible trend for underground space planning and urban planning to keep the same level.

Japan's underground urban planning system is an extension of the organization of urban planning system, which includes four parts: Master-plan for underground use, Guide-plan for underground space, underground transportation network planning, and underground street planning. There is no underground space planning in Japan for privately owned land. Underground streets are considered the most important transportation network since they are public facilities.

5.4 Comparison of the Environmental and Safety Planning Strategies during Underground Space Development between China and Japan

As far as Urban Underground Space development is concerned, the safety of the laborers during their working hours, are given much importance. They are well guided and educated in order to avoid risks in the future.

5.4.1 Recycling and environmental protection strategies of underground excavation soil

One of the most pressing problems is a large amount of excavated soil will be generated in the process of underground space development, which will have an impact on the surrounding soil and groundwater environment. In view of the problem of soil pollution in excavation, Japan adopted the classification scheme of natural polluted rocks and put forward the following strategies to solve the problem of pollution as shown in figure 12.

Fig - 12: Strategies adopted by Japan to deal with excavating soil pollution

China is still at the initial stage in this field, and it has not carried out systematic management of soil excavation from the aspects of excavation, transportation, environmental safety, etc., so the experience of Japan is of great significance.

5.4.2 Underground Space Security Strategy

When local underground space encounters natural calamities like flood, earthquake, fire and other disastrous events, people suffer more casualties due to the reasons of closed space, less refuge space and also due to the difficulty in evacuation. In addition, if the distance of underground walking passage of subway transfer is too long, and the evacuation opening is limited or the streamline is crossing, there will be potential safety risks, such as stepping on.

The scale and quantity of underground street development in Japan began to be tightly controlled after the underground street fires occurred in the 1970s and 1980s. Subsequently, Japan formulated laws and regulations relating to disaster prevention and safety in underground street development and raised the threshold for development to improve the underground street safety and quality.

Research on underground space safety in China is still in the exploratory phase, such as the safety of underground space behavior, the safety of defense, the safety of disaster prevention and so on.

5.5 Challenges faced by Urban Underground Space Development in China

China does not have a proper plan for its underground development. Some of the problems faced by China in urban underground space development are listed below:

5.5.1 Land acquisition

Urban underground space is an important natural resource to be considered in the development of societies, economies and in the use of space in modern metropolises. By studying the cost benefit analysis between land price and underground space development, Chinese and Japanese scholars proved that urban agglomeration leads to the shortage of land resources and the rise of land prices.

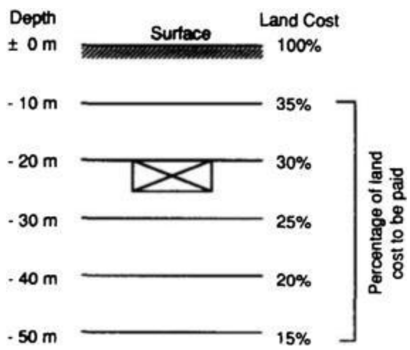

Fig - 13: Reduction in land cost with depth, based on a subway construction in Tokyo

Although the construction cost of underground structures is 2–10 times than that of surface structures, the land acceptance brought by the development of underground space is enough to offset the increase of construction cost as shown in figure 13. The cost of land decreases as we go deeper below the ground level compensating for the higher construction costs.

The development depth has thus extended from shallow to deep, showing trends of diversification, complexity, and integration. Underground space has become an important resource for optimizing urban spatial structure, increasing urban capacity, improving urban efficiency, enhancing disaster prevention and mitigation, alleviating traffic congestion, and improving public services and infrastructure. Considering environmental factors and social benefits in the whole life cycle of the project, underground facilities can become the number one priority for infrastructure development.

5.5.2 Imperfect management systems and insufficient systemic development

China's underground space planning system is still in the exploratory stage. Problems include unclear or insufficient planning objectives, authority clearance, and principle standards. The construction of an underground space management system is still in its infancy, with scattered management as well as the lack of systematic requirements. The underground space regime remains imperfect in terms of planning, ownership registration, project quality, safety, and information management.

5.5.3 Status of Underground Space Planning in China

There are no official national guidelines for underground space planning in China. Since the scale of development is difficult to predict, master planning in China can only work at the conceptual, regional, and principle levels. In fact, the regulatory detailed planning and construction detailed planning play a guiding role in planning.

6. URBAN UNDERGROUND DEVELOPMENTS IN INDIA

India has begun urban underground space development through the smart city mission. Smart City Mission is an urban renewal and retrofitting program by the Government of India with the mission to develop 100 smart cities across the country making them citizen friendly and sustainable. The Union Ministry of Urban Development is responsible for implementing the mission in collaboration with the state governments of the respective cities.

6.1 Lucknow Metro

Lucknow Metro is a rapid transit system serving the city of Lucknow in the Indian state of Uttar Pradesh. Construction of the metro line began on 27 September 2014 with the 8.5 kilometers stretch from Transport Nagar to Charbagh Railway Station, which began its commercial operation on 5 September 2017, making it the fastest built metro rail system in the country. Full operation on Red Line stretch from Chaudhary Charan Singh International Airport metro station to Munshi Pulia metro station began operation on 9 March 2019. Passengers would be served by a total of 22 stations, with nineteen stations being elevated and three stations below the ground.

6.2 Mumbai Metro (Line 3)

The Aqua Line of the Mumbai Metro, also known as Line 3 or the Colaba–Bandra-SEEPZ line, is a part of the metro system for the city of Mumbai, India of which construction has been initiated. When completed, the 33.5 kilometers long line will be the first underground metro line in Mumbai. The metro line will connect Cuffe Parade business district in the extreme south of the city to SEEPZ in the north-central with twenty six underground station and one at-grade station. The track width is of standard gauge. The cost of this corridor is estimated at Indian rupees thirty thousand crores (US$ 4.3 billion). Line 3 is expected to reduce road congestion, besides reducing the load on the Western Line between Bandra and Churchgate.

6.3 Ahmedabad Metro Rail Project

The Archaeological Survey of India has permitted the Ahmedabad Metro Rail Project to carry out construction of the underground corridor which passes close below the ASI protected monuments. The metro track passes at a distance of 106 to 289 meters from the monuments. A detailed vibration studies had been carried out and the National Monument Authority was satisfied with the arrangements and future plan for protecting ASI monuments in this World Heritage City.

6.4 Kolkata Metro Rail

Kolkata metro rail is India's first completed underwater river tunnel with the deepest metro shaft. Of the twenty two kilometers long east-west stretch, five hundred and twenty meters is under the river bed. It is the first big tunnel under any river in India. It consists of seventeen stations of which eleven are elevated and six underground. It connects Kolkata's two largest commuter railways and long distant railway terminals along with two of its largest business districts. A mind map of Kolkata's underground metro rail network is shown in figure 14.

Fig - 14: Kolkata Metro Rail

7. CHALLENGES DURING CONSTRUCTION OF URBAN UNDERGROUND SPACE

UUS possesses the unique characteristics of being capable of providing extra amount of urban space with excellent properties of earthquake and bomb resistance, thermal insulation, soundproofing and visual opacity. With the rapid spread of urbanization, urban underground space development is capturing more attention especially in developing countries like China due to its potentials of further increase in the land use pressure caused by the ever-increasing global urbanization, and the need for improved quality of living environment to meet the demands of urban regeneration.

Although urban underground space development puts forward a number of benefits, there are a number of challenges that has to be faced during the construction of the same. This is because the working environment, machineries used and various other factors are entirely different from those used when working on the surface of earth.

7.1 Losses Caused by Urban Underground Space

The losses caused during the development are measured using certain criterion. Prior to setting up the monetary valuation framework for calculating the losses, the valuation indicators and valuation approaches should be determined. In this study, valuation indicators refer to the categories of socio-environmental losses caused by urban underground space use from the perspective of sustainable development.

A triple-bottom-line sustainability assessment structure, which coordinates some crosswise elements from social, economic and environmental issues, is considered to be more appropriate than just environmental assessment whose detailed aspects are explained in table 1.

Table -1: Losses during construction of urban underground space

Asset	Detailed Aspect
Geothermal Energy	The construction process of UUS will cause the loss of soil and rock mass, thus changing the characteristics of the groundwater table and the thermal properties. Constant temperature is a valuable asset of underground which will be altered.
Underground Water	Daily heating and cooling of the UUS will affect the groundwater temperature.
Historical heritage	If proper site selection is not done nor if the site is properly investigated, there are chances that the development may encounter and destroy buried or inland historical heritages.
Space continuum	The influence zone of any excavation is within 3 times the excavation depth, largely depending on factors like soil parameters, methods of construction, levels of groundwater etc.

8. CONCULSIONS

Urban underground space is an important natural resource to be considered in the development of societies economies and in the use of space in modern metropolises, and also provides an important portion of the local economy.

With the increase in population and rapid urbanization, the need for space has increased that has urged the world to develop urban underground space development programs. These programs are sustainable and are built with suitable entry and exits from the surface providing easier access control, a secure environment, no obstruction of views or sunlight and improved liquid and solid waste pollution control.

Underground space development is established with the technique of tunneling. The transportation systems developed underground are similar to that in the surface like underground railway system, underground car parks, underground roads and expressways, underground freight transport system and underground pedestrian systems. The case study included deals with the comparison of the urban underground space development between China and Japan. The authority for urban underground space development in Japan has a prescribed set of rules and regulations and abides to it. Japan is more oriented in providing services to its citizens whereas China is oriented in development alone. Japan has also implemented proper measures for treating the contaminated rocks that are dealt with while excavation. India has also achieved urban underground space development through its smart city mission. The major developments are the Ahmedabad Metro rail project, Mumbai metro rail project, Lucknow metro rail project and Kolkata metro rail project with, Kolkata metro rail project being the first underwater metro rail development project of India.

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