Utilization of Underground Space in China

by

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A Thesis Presented in Partial Fulfillment
of the Requirements for the Degree
Master of Science

Approved May 2021 by the
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ARIZONA STATE UNIVERSITY

August 2021

ABSTRACT

This thesis provides evidence that China has maximized building infrastructure by seeking new ways to utilize underground space. China is a shining example on how integrating underground space will improve quality of life, transportation, entertainment centers and national safety. China is rethinking how they develop its cities by creating tunnels, commercial buildings, parking lots, subways, utility service tunnels, military defense bunkers, and storage facilities underground. Hundreds of kilometers of tunnels alleviate China's growing traffic congestion problem, to help with vehicle congestion, other means of transportation are created like subway systems that sprawl underneath the city. Commercial buildings can be built underground to maximize the vertical growth of businesses in a city. A high number of personal vehicles means cities have to increase the availability of parking spaces, with underground parking garages, space can be maximized to hold hundreds of cars underground while maintaining commercial buildings above ground. The ease of having a central utility tunnel that houses all the utilities in one place is how China is forward-thinking of the maintenance of their future cities. As China grows, they must be prepared to protect their citizens and leaders so they store their most important military equipment underground so they can keep them secure. As a way of reusing old dried-up oil wells, natural gas is stored underground to mitigate risk and cut down on costs for storage facilities. China has made significant strides to ensure a bright future for its citizens, with the utilization of underground space, China maximizes productivity and quality of life for its people.

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INTRODUCTION

The change of human society from nomadic to concentrated gatherings has caused humans to abandon traveling homes and instead build a permanent residence. When cities emerged, humans began living comfortably in the safety of their homes. Fast forward to an industrial society, humans have modernized cities with technological innovations that allow for expanded vertical and horizontal growth throughout their environment. With the urban population's explosive growth, people have consumed natural resources aggressively. The limitation of city space can no longer meet the needs of society and urban development. In order to improve the quality of life, the survival, and the development of future generations, we must maximize all space available to us. Among the several spaces to choose from, 30% of the earth's surface area is covered by land and the rest of the earth's surface area is covered by water, the sea and seabed space have great potential for utilization, but it is more challenging to develop than land. (Li, B., 2017) Therefore, in addition to appropriately expanding ground space utilization, a more realistic and feasible option is to develop and utilize underground space on land. Besides just building vertically, we as a society should be looking to build downwards and it will profoundly impact the improvement of human's living conditions, living environment, and the formation of future cities. This issue has aroused widespread concern in many countries and related organizations of the United Nations. A large number of engineering practices and scientific researches have been carried out. The development and utilization of underground space

have been regarded as an effective way to alleviate various constraints in urban development, as it is also an essential part of building modern cities and future cities.

Although China has traditional ways of developing and utilizing underground space, about 30 million people live in various types of cave dwellings on the Loess Plateau in China. (文子，2020) Underground cave dwellings are also known as "patio kilns", "pit courtyards," and "sunken cave dwellings". Residents living on the Loess Plateau's flat surface often dig deep pits on the thick loess layer and dig cave dwellings into the four walls of the pit. This kind of cave-dwelling has the advantages of heat preservation in winter, heat insulation in summer, and sound insulation. (文子，2020)

Figure 1: Underground housing in China (文子心语, 2020)

Besides residence, the use of underground space as a warehouse has a long history in China. At the end of the 1960s, ancient underground grain storage was excavated in the northeastern suburbs of Luoyang City. It was built in the Sui Dynasty (7th century) and used until the Tang Dynasty. It is about 420,000 square meters, and nearly two hundred

semi-underground granaries were gradually excavated in China's history. (Li, B. 2017) In addition, there are also examples of the development of underground space in terms of water conservancy projects, such as the Lingqu Canal in Xing'an County. It was built in 214 B.C. and its overall length is 36.4 Kilometers. Lingqu Canal is one of the oldest canals in the world and it has the reputation of "the pearl of ancient water conservancy architectures."(Li, S. n.d) This shows that in the production and construction of ancient China, they were committed to utilizing underground space for residence and storage to protect their people and belongings.

In many countries, the process of urbanization is accelerating. However, the population, food, land, resources, environment, ecology, etc. are becoming increasingly acute. The general contradiction is in the growth and the improvement of urbanization level and the continuous decrease of land and water resources. As we continue to expand we as humans need to utilize the space underground to create more living environments for future generations to come.

China's Urbanization

As economic development is happening in most countries, the population has further gathered in central cities and metropolitan areas. China is undergoing a thorough government-led transformation from a country dominated by an agricultural economy to a modern society dominated by urban residents. The goal is to integrate 70% of the population, 900 million people, into urban areas in the next ten years. The current process of urbanization in China is incredibly fast. In 1980, the urbanization degree was around 19.4%. However, in 2010, the urbanization degree spiked to almost 50%. In 2019, the

urbanization degree hit 60.6%. By the rate of urbanization growth (at least 10% in 10 years), it is estimated that by 2050, the level of urbanization will increase to about 80%. Besides, China only had 51 cities with more than 500,000 people back in 1980. That number has quadrupled since then to 236 cities. (United Nations Reports. n.d.)

Figure 2: Shenzhen City (中国超大城市, 2019)

For example, Shenzhen developed from a small rural county in 1979 with 314,000 to a megacity of more than 10 million people. From 2015 to 2018, the average Guangzhou's population growth was 455,975 people per year. According to statistics, currently, there are 30 cities with a population of over 8 million in China. Among them, 13 cities have a population of more than 10 million. They are Chongqing, Shanghai, Beijing, Chengdu, Tianjin, Guangzhou, Shenzhen, Shijiazhuang, Wuhan, Harbin, Suzhou, Linyi, and Baoding. Among all of these megacities, Chongqing City has a total population of 30,484,300 people, the most populated city in China. (中国超大城市, 2019)

Along with the sustained, stable and rapid development of the economy, the construction of urban infrastructure, even urban public space has become one of the most important topics for society. Whether it is to improve the existing urban conditions or future development, China's urbanization cannot be achieved only by expanding the urban land

but by finding new ways to expand the urban space without occupying more land. It can save land resources and modernize urban life while maintaining the traditional style of the city. Underground space projects such as subways, light rails, and underground shopping malls have been developed and constructed one after another. The development and utilization of underground space in China have entered an era of vigorous development.

CHAPTER 2

Transportation facilities.

Underground tunnels

The high rate of urbanization in this country has led to the continued construction of underground tunnels. Bays and straits pose a significant constraint to transportation in these areas. The mountainous landscape is also a challenge that China has to overcome when constructing tunnels and roadways for their growing population. China has been utilizing tunnels to create underground passageways through mountains, under rivers and under their cities. These tunnels are increasing by 500 Kilometers each year, with the current distance approximated to be 5,100 Kilometers of tunnels throughout China. (He, 2013).

The Wuhan Changjiang Tunnel is located under the Yangtze River. This tunnel's construction began in the year 2004 and it connects two districts in Wuhan, Wuchang and Hankou. Finishing its construction in 2008, the tunnel's total length is 3.63 kilometers and cost 2.05 billion yuan; the tunnel was opened to the public shortly after. The Wuhan Changjiang Tunnel is a two-lane highway with a speed limit of 50 kilometers per hour. It is the first Yangtze River highway tunnel, with the most challenging geological conditions. This tunnel was constructed to resolve road connection challenges between Wuchange and Hankou. (Zhong, 2008)

Figure 3: Underground tunnel（Wikimedia, 2018）

In Haikou, Hainan province, the Qiaozhong Road tunnel, the only tunnel in the city, connects Qiaozhong Road to Yusha Road, it consists of two lanes separated by a solid wall running in the south-north direction. A low fence is used to separate the pedestrian walkways and the path used by two-wheel vehicles like motorcycles and bicycles from the primary motor vehicle traffic. This tunnel has good lighting and ventilation within it, enhanced by fans located at the tunnel ceiling, where the walls are made of polished cut stone sheets. (Qiaozhong, n, d.)

Figure 4: Qiaozhong Road tunnel（Wikiwand.,n.d.)

Underground tunnels can be built by utilizing a tunneling shield or grid extrusion shield machine. Tunneling shield is a practice used by China's engineers to construct long underground tunnels. As early as 1966, the Dapu Road Tunnel began its construction to cross the Huangpu River by using the grid extrusion shield machine. In June 1970, construction ended and allowed people to cross from Shanghai. (Shengjun, 2021) With the Dapu Road tunnel's completion, it takes 6 minutes for a motor vehicle to cross the river through the tunnel. There has been, since then, other shield bored tunnels under lakes, sea, and large rivers. In 1987, an immersed tunnel called Yong River Underwater Tunnel in Ningbo began and was completed in 1995. It is 1 kilometer long with a 420-meter section underwater. There are four 85-meter-long tubes used and one 80-meter tube all immersed in water (Hong, 2017). The construction of these tunnels as well as emergence of different construction methods is to meet the aggressive transportation demands with the continued urbanization and industrialization.

Shantou's Su'ai Tunnel was constructed using the shield boring tunnel and is used as part of the city highway. The design speed limit is 60 kilometers per hour, and its overall length is 5.3 kilometers. This tunnel has 6 lanes, making it ideal for use as part of a city highway. The tunnels mainline have a speed limit of 60 km/h and the project's overall length is six kilometers, with the tunnel accounting for almost 5km (KairongHong, 2017). With such a high-speed limit, it allows a high movement of vehicles per hour. It gives massive transportation in and out of the highly populated cities as well as within them.

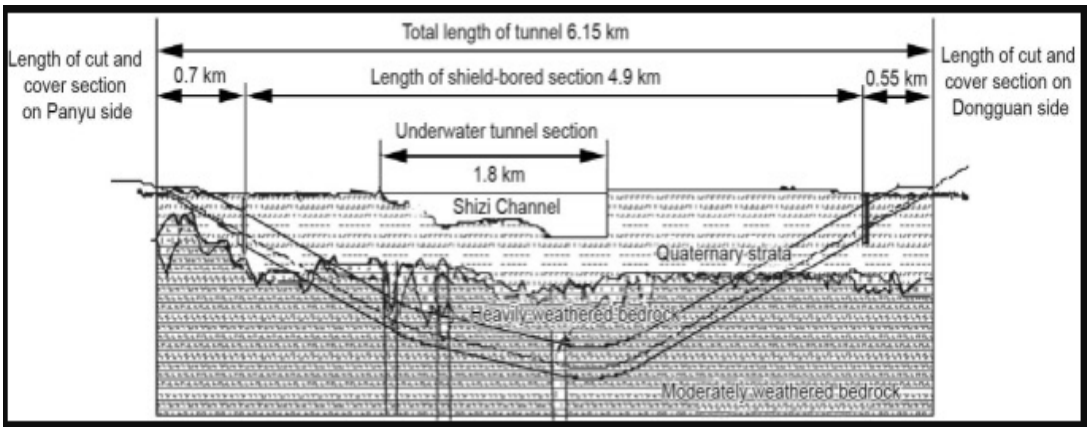

Figure 5: Shiziyang Tunnel longitudinal profile (Typical Underwater Tunnels, 2017.)

The drill and blast method has found application in the making of underwater sea tunnels. In Xiamen, Xiang'an Tunnel was constructed through this method and its usage began in April 2010 after being under construction since 2005. It was the world's first subsea tunnel using rock blasting method and it's also the first ever subsea tunnel in mainland China. This three-lane road tunnel's length is 5.9 kilometers, including a 4.2 kilometers section that cross the sea. The deepest point is about 70 meters below sea level. The travel distance between Xiamen Island and Xiang'an District has been reduced by 50 kilometers, and the travel time between the two places has been shortened from two hours

to 15 minutes. (工程, n.d.) Some additional tunnels built using drill and blast method include; Jiaozhou Bay Subsea Tunnel in Qingdao (2011), Liuyang River Tunnel on the Wuhan–Guangzhou High-Speed Railway (2009), Liuyang River Tunnel in Changsha (2009). The Shizi Channel is crossed by Shiziyang Tunnel on the Foshan–Dongguan Intercity Railway. It was constructed by using the shield method 6.5 km. The section underwater is 1.8 km and serves a great purpose on the Pearl Delta Intercity Railway's west-east axis (Hong, 2017).

Underground subways

Chinas' underground subways sprawl over 4,600 km throughout more than 30 cities. From 2010 to 2015, China built 373 km of underground railroad each year. (Schwartz, 2019) With an ever-growing population, the country knows to expand its public transportation system to increase accessibility from different parts of the city. By constructing underground subway systems, it mitigates traffic above ground, reduces the need for a car for transportation and increases the likelihood of its people to share a subway to reach their common destination. The widespread usage of the subway network in China has decreased mobility problems such as high pollution levels, traffic congestion, long bus wait times and traveling farther in a shorter time frame.

The first subway built in China was in Beijing. Later, Shanghai's metro followed with an improved design leading to higher efficiency in its operations despite being the world's largest by length. In 2010, the Chengdu subway was opened and was more modern than Beijing and Shanghai (Schwartz, 2019). Shanghai metro remains the longest, approximated as 670 km.

In China, there are many examples of underground space construction in transportation hubs. The Lanzhou west rail station is a central transportation node for China's "Belt and Road" urban growth system, linking Xuzhou, Lanzhou, and Urumqi. This multi-functional integrated transport center combines various transit services such as a train station, subway station, bus station, public parking lot, taxicab stand, and tourist coach depot and public entertainment, commercial, office, and hotel facilities.

Ningbo rail station is a major transportation node on China's high-speed rail line linking Shanghai and Shenzhen, as well as the city's transit hub. This transit hub incorporates various modes of transportation and employs the “zero transport interchange” interface principle. The transit center comprises services such as a bus garage, taxicab depot, public parking structures, and a local bus station at the north and south squares, in addition to the Ningbo train station. The rail station is well connected to the surrounding highways, forming a multi-scale spatial urban transportation network.

Chongqing West Station Transport Hub is a multi-functional integrated transport hub that integrates multiple modes of transportation such as train, subway, bus, public parking, and taxicab depot. Recreation, industrial, office, and hotel services are all included. The underground systems of the transit hub include the rail station's exit level, the station square's underground foundation, and the subway.

Lanzhou Zhongchuan International Airport is a secondary gateway airport in China's northwestern zone that also serves as the capital of Gansu Province. One ground level and one underground floor make up the two-story interchange hub. The underground level has a transit center underpass as well as a transfer point for other public transportation. The underground level has a taxicab bridge, two land platforms for long-distance coaches,

airport tram, and city bus, and four car lanes, one of which is reserved for VIPs and the others for public cars.

There are several advantages to developing underground space, including maximizing land use performance, optimizing the configuration of different services, increasing transportation interchange quality, improving the ground atmosphere, improving the link of split urban areas by train, fostering a pleasant and enjoyable travel experience, improving the accessibility of transportation hubs, and benefiting society (Jia, 2016).

CHAPTER 3

Commercial facilities in China

Underground shopping malls

The tremendous growth of the Chinese population in cities has necessitated the need to utilize the underground spaces to create commercial areas. The extensive utility of the available natural ground space creates the need to opt for the underground space to create more rooms for construction of commercial buildings. Shopping malls have been created underground, ultimately creating more jobs, boosting the economy, and maximizing available land resources throughout China.

Zhongguancun Plaza Shopping Mall is the biggest underground shopping center in Beijing. The whole shopping mall is about 200,000 square meters, including 140,000 square meters of commercial area and 60,500 square meters of parking garage. It is located at the heart of Zhong Guan Cun, Beijing and it is a comprehensive shopping center integrating leisure, entertainment, shopping, and catering. With the theme of innovation, fashion and relaxation, it is composed of five parts: large supermarkets, theme department stores, pedestrian streets, boutiques, and large cinemas. This ginormous shopping mall was opened in April 2006 with two floors underground and two floors above the ground.

Besides high-end shopping malls like Zhongguancun Plaza Shopping Mall, there are huge amounts of small underground shopping malls scattered in different cities in China. Chongqing, the city with the most people in China, also has many underground shopping malls to boost the city's economy. The Golden Eagle Ladies Street in

Jiefangbei, the Lightrail Store City in Linjiangmen, the Ladies Street in Yangjiaping, and the underground shopping mall of Sanxia Square, etc. (重庆游, n.d.) Small shopping centers like these sometimes have more traffic than most department stores. There is no set price for the products here, bargaining for the cheapest price with the owners is what most Chinese people do. Not only clothing is selling here, underground shopping malls like these also have restaurants, pet shops, nail salons, tattoo stores, glasses shops, etc. People can find everything they need here. However, pitfalls like unreasonable space layout, poor lighting and ventilation, lacking maintenance and the rise of E-commerce have led to the gradual decline of underground shopping malls in Chongqing.

Figure 6: Lightrail Store City in Linjiangmen（重庆游品, n.d.)

The Yatai Xinyang Fashion and gift market, also known as APA Plaza, is an underground collection of market stalls selling a variety of designer goods. This underground mall is connected to Shanghai metro station via the Science and Technology Museum. This mall is strategically located next to the metro so they can purchase last minute items before boarding to their next destination

Figure 7: Yatai Xinyang Fashion and Gift underground mall (上海亚太, n.d.)

People's Square Underground Shopping Centre has massive shopping outlets emerging in the People's Square Metro Station. The Underground Shopping Centre comprises several boutiques seeking attention from the customers right from the underground railway tunnel terminus. People's Square is situated in Shanghai's Huangpu Neighborhood, between Nanjing Road and Huaihai Road. Before the establishment of the PRC (The People's Republic of China), the People's Square was a horse race course, under the ownership of the Shanghai Race Club. The People's Square underwent major reforms in the 1990s, and the Shanghai Municipal Government, as well as the Shanghai Museum, were relocated here from the old HSBC site.

Zhongshan Metro Mall is a commercial underground street at Wendeng Road located in Shinan District. Zhongshan underground mall houses 81 services stores. The first section of mall was constructed and opened in 20th September in the year 1999 and later the third line opened in 27th December 2000. Several underground rail stations

connect to several underground malls such as Taipei rail station having numerous malls spanning all the way to the next rail terminals opening up business avenues to the town as well as people of China.

Figure 8: Zhongshan underground mall(新聞雲, 2016)

Throughout China, each city is able to utilize the underground space to create commercial buildings that attract a variety of customers. Underground malls in cities give business owners a new area to grow their business in a dense and constrained city that is limited to building horizontally.

Underwater music hall

Underwater music hall is playing a great role in the underwater space utility in the coastal cities of China. The National Centre for the Performing Arts(NCPA) is an iconic cultural infrastructure for performing arts. The entrance and exit are below the water's level, with pedestrians approaching the concert hall at a depth of 80 meters below the water's

surface. (Jingyan, 2008) The NCPA can comfortably house more than four million spectators with over two hundred and eighty-four rich collections of exhibitions. Oil sculptures, musical instruments, cultural heritage, music halls, opera halls, restaurants, art and theatre exhibition halls, audio shops as well as other auxiliary amenities all live within the National Centre for the Performing Arts. (Jingyan, 2008)

Figure 9: The iconic National Centre for the Performing Arts (Jingyan, 2008)

The NCPA is made up of a steel and glass ellipsoid dome. The NCPA hall is nearly ten stories deep, with 60 percent of the foundation submerged. The total construction area is approximately 165,00m^2, comprising 65,000m^2 of underwater construction and 105,000m^2 of the main building structure construction. The massive theatre shell is made up of 18,000 titanium metal plates and spans over 30,000m^2. These titanium metal plates are expressly oxidized with textured metallic luster color lasting for 15 years. The NCPA and its facilities cost 3.067 billion yuan to construct. (Jingyan, 2008).

The People's Great Hall, which opened in 1959, is one of the "Ten Great Constructions" designed to celebrate the PRC's tenth anniversary. The construction took

ten months with Zhang Bo as the chief architect. The hall was designed to symbolize ethnic equality and national unity of the people of China. In terms of features, descriptions, and proportion, the hall was to encapsulate the Chinese character of the time. The hall has a floor area of 171, 801 m^2, a span of 365 meters, a width of 206.5 meters, and a height of 46.5 meters. (Lina, 2015) The Great Hall of People is divided into three parts, with the central portion containing the Great Auditorium, Congress Hall, Main Auditorium, Golden Hall, Central Hall, and other important rooms. Salute State Guest Hall, State Banquet Hall, North Hall, West Hall, East Hall, and a few other large halls make up the northern section. This building is structured to have one underground floor and three other floors above the ground. The main office building for the Standing Committee of the Chinese People's Congress office shares the structure located in the southern portion. The standing committee uses this structure as their main office. The hall also houses the administrative region of all provinces within China. The Great Auditorium has a 90,000m3 capacity, with 3,693 seats in the lower auditorium, 2,5188 seats in the gallery, 3,515 seats in the balcony, and 300 to 500 seats in the dais.(Lina, 2015) The hall's ceiling is adorned with a galaxy of lights and a massive red star in the middle, as well as patterns of water waves reflecting Chinese citizens.

Figure 10: The Great Hall of the People (Tripadvisor. n.d.).

In China, the Great Hall of the People is a magnificent modern building. Both Chinese and international architectural elements can be seen in the structure. It portrays a distinct national style in a special way. From its inception, the Great Hall has served as a significant location for national festivals and activities. State business and international events are arranged here as well. The hall is the site of some of China's most significant historical incidents. All the pillars find The Great Hall to be an accommodation base. It represents the honor and pride of all Chinese citizens, regardless of nationality (Lina, 2015). China's reforms have been recorded in this Hall of the People for years now. The Great Hall has won the Chinese people's respect, awe, and appreciation, and has undeniably become a magnet for tourists from all over the world. The Great Hall of the People is currently undergoing renovations in order to preserve its majestic beauty and draw tourists from around the world. The designers have imbued the Great Hall with many imaginative jewel characteristics of the era's vivacity, which appropriately represent the sparkling

benefits and growth achieved in China's economy and cultural transformations, while maintaining the building's distinctive look.

Underground hotel

The world's first underground hotel was made from a quarry. This hotel is referred to as Deep Pit Hotel or Intercontinental Shanghai Wonderland. Several fascinating features of this hotel and its strategic location make it more attractive to its customers. It is located twenty miles outside Shanghai City, specifically in Shenkeng Quarry, which is in Songjian. Technically it has 18 floors with 16 below the earth's surface and 2 floors underwater. The environmental conservation created by this hotel is quite innovative as it only relies on geothermal power generated with its environs as well as solar power. The energy generated from these sources is used for lighting, heating and distribution of electricity for its residence. The roof of this hotel is covered by grass, plentiful flowers and plant life. (TUCKER) Apart from being just a hotel, Deep Pit includes a restaurant, bar, and a water sporting center. The water sporting facilities are

found on one of the floors built underwater, while the other underwater floor has a restaurant and hosting rooms.

Figure 11: Deep Pit Hotel (Shanghai 'earthscraper', 2018)

The construction of the Deep Pit Hotel was not easy. The original land was so rugged that many doubt the project was even feasible. The chief architect of the project even claimed that the quarry was an unusual site. During the construction process, the project was so demanding that innovations were born; forty-one patents were the outcome of many engineering problems which had to be resolved during construction. This project took 10 years to be completed, the labor invested in the project was quite high where more than five thousand personnel were involved. This team included architects, engineers, designers, and construction workers. In the end, it was all worth it and the world's first underground hotel was built. (GEDDO, 2018).

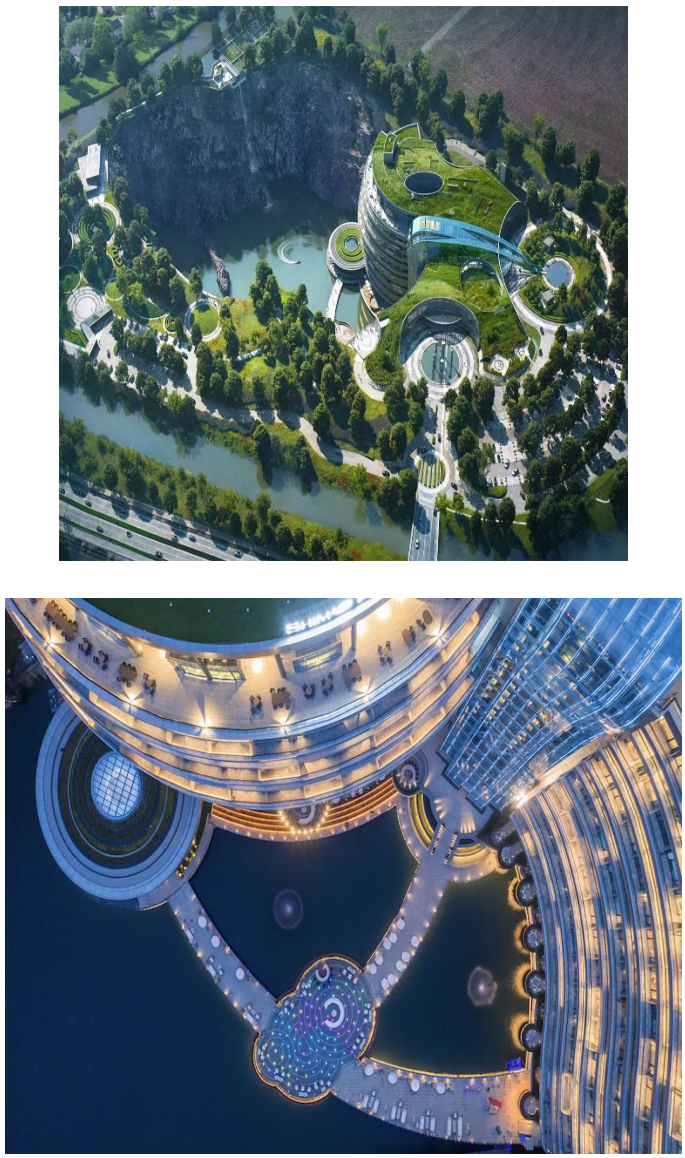

Figure 12: Greenery roofing and beautiful lighting of Shanghai Wonderland Hotel (Shanghai 'earthscraper', 2018)

Among the beautiful and sophisticated outcomes of the construction process included concave and convex wings, rock climbing sites, glass pathways, artificial glass waterfall among others. The rock-climbing cliff face is 88 meters high. Guests can also go canoeing around the quarry as part of their recreation. For high end residents, the helicopter

pad is in the middle of the hotel for easy accessibility. Apart from the luxurious objective, sustainability was a key motive during the design process. The green roofing and reclaiming of the abandoned quarry utilize underground space that would otherwise sit unoccupied. The use of the sunlight is maximized and protection from the north winds is enhanced. Other quarries within this locality were converted to national parks in the Chinese government initiative to revitalize them with a better purpose. (Gibson, 2019).

CHAPTER 4

Underground garage in China.

Parking has been a key concern in the transportation sector. China has addressed the issue with the parking problem in educational institutions, religious institutions, entertainment halls, commercial centers as well as city parking lots. This has necessitated the need for continuing collaboration and communication among enterprises, residents, organizations, and government agencies in order to meet parking needs collaboratively. In an ever-growing population that needs more parking spots, China has looked underground to build new parking capacities.

With the high percentage of vehicle traffic in China, the parking space becomes an issue of concern for many people all throughout China. The parking challenge ranges in several places such as airports, bus stations and major shopping centers. The in-availability of parking areas is a significant blow to the local businesses and results in decrease of life quality for the local residents. The importance of parking in cities has necessitated studies and analysis to provide solutions on the parking challenges (Yuan, (2019). The challenges in the community are caused by some inadequacies. Some parking lots fail to inform drivers the availability of parking spots as well as the cost. This irritates drivers who expect ample and free parking but only have restricted or costly parking, this causes additional traffic as they look around for another parking spot.

Extra costs have been levied as a result of excessive car usage and reliance in China. This results in higher parking prices, higher residential and car parking costs. External costs such as road and parking facility costs, uncompensated collision damages, congestion,

environmental degradation, reduced mobility for non-drivers, and unfavorable land use make matters worse.

The installation of parking spaces has a secondary effect on city residents and traffic. There are currently spillover problems in which the parking demand created by a single car exceeds the available parking space in the streets or in the garage. Owing to a shortage of parking space in urban cities, some residents chose to park their cars outside of town in residential areas. Lack of parking for motor vehicles to load and unload causes traffic congestion by blocking travel lanes. With the increasing urbanization, finding parking within a decent walking distance has been difficult. At times, confusing parking policies, rules, and fees can apply. Traffic congestion has resulted from issues with parking control and pricing, when cars cruise for parking or stop in a traffic lane looking for a spot, as well as parking congestion in the surrounding areas. When several cars are stored in an area for an extended period of time, the parking turnover rate is poor. (N. C. 2018)

Some parking management options have been provided in endeavors to curb the parking issues in different parking spaces. China is determined to provide long term commuter parking solutions through constructing underground parking garages. This has been addressed through providing adequate underground parking spaces to meet the cities demands. This is likely to increase the parking convenience and price levels for the motorists. Enhance the parking enforcement through development of convenient time options and payments. Sharing of parking facilities among different businesses in a common area as it will provide enormous parking space and peak parking periods. (Weiyuan, Z. 2020)

The centralized underground parking has provided the people in the city with an opportunity to walk freely thus promoting business in the urban centers, as people are able to reach multiple destinations without parking traffic. These parking lots will have mixed sharing between different facilities such as the commercial halls and the nearby sports centers. This will utilize the remote parking spaces for shuttle services. The large vehicles will be able to utilize the available parking lots without much congestion from small vehicles. People are capable of parking their cars within the underground provided parking and using alternative means to access their areas of interest. The use of shuttle services will be promoted, by using these alternative means to the parking lots. The use of shuttle buses from airports, large commercial halls, large entertainment centers to the underground parking facilities provide multiple alternatives for people to choose from.

The grand idea of using underground garages was meant to solve the problem of public parking in the center cities of China. This was also to curb the menace of parking in residential areas as well residential on-street parking. The use of underground parking lots increased the residential areas parking capacities as a higher number of cars can be accommodated. The above ground could be used to build commercial buildings on top of these garages. The completion of an underground garage reduces the spillover problem in parking lots. (Weiyuan, Z. 2020)

The underground garages have utilized the space close to major commercial centers and buildings. The underground parking lots increase accessibility by the pedestrians. This technique has maximized the space utilization, provided sufficient parking lots and improved the surface appearance of land. Underground parking lots maximizes the parking lots while minimizing the dimensions utilization of parking spaces. Incorporating the

intelligence parking system is quite resourceful as the advanced parking system guides the drivers based on the available parking spaces and thus enable them to easily access empty underground parking lots.

It is critical for Chinese government and department of transportation to consider key aspects of design that incorporate people with special needs. The underground parking facilities should reflect the Universal Design principles with features that enable maneuverability of people with special needs in the parking areas (Zhao, 2016).

Figure 13: Yicheng Underground Parking (Weiyuan, Z. 2020)

China has fully embraced the underground space utilization through the construction of underground garages. China constructed the first underground garage in summer 2016. The underground parking lot called Yicheng Parking lot is opened and is located in Hangzhou, east China's Zhejiang Province. The three piles of 19 stories extend

underground, and will be able to maximize parking space to accommodate 114 vehicles. This underground parking lot is 34 meters deep into the ground. The system is very efficient at most 50 seconds to park a vehicle, and 85 seconds to retrieve from the parking lot. (Rui, S. 2021)

Five years after Yicheng Parking opened, Hangzhou is currently building another vertical shaft parking garage and will finish construction in August 2021. Jingfangyuan underground parking can accommodate a maximum of 144 cars and is 45.95 meters or 10 stories deep. The biggest advantage of pit parking garage is to save land resources. After it gets built, it can solve the parking problem of a primary school, a kindergarten and surrounding residential areas. As of Janurary 2021, Jingfangyuan underground parking lot has completed the deepest earthwork excavation, and the concrete will be expected to pour next. (Rui, S. 2021)

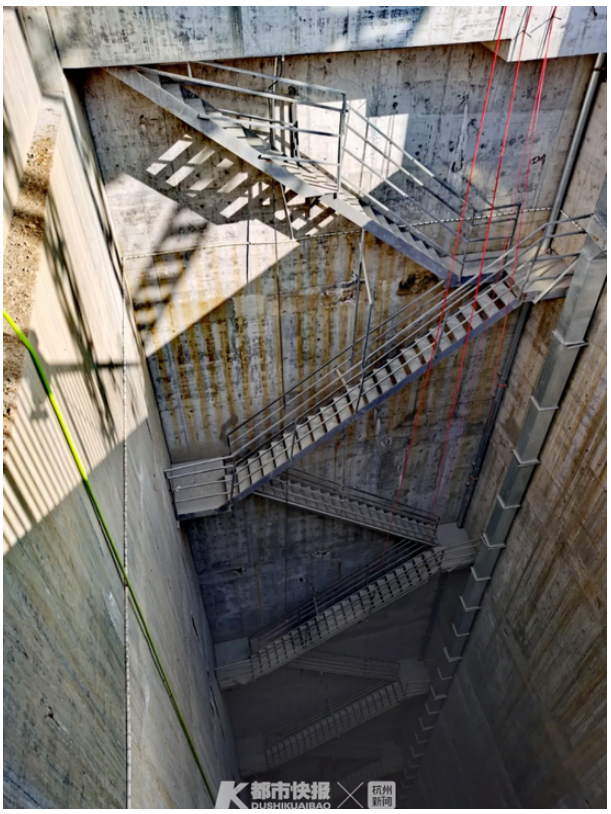

Figure 14: Jingfangyuan Underground Parking -the deepest underground parking lot in Hangzhou, China (Rui, S. 2021)

CHAPTER 5

Municipal underground comprehensive pipelines

Utility tunnels

China had a plan to have a world class network of utility tunnels by 2020. The maintenance and repair of pipe systems often cause a challenge for local citizens' traffic and quality of life. The state council gave a guideline on how these tunnels will help solve problems faced, especially during repairing such pipe networks. These utility services include communication cables such as television and telecommunications, water pipes, heating cables, storm drain pipes and sewage pipes. The creation of a utility tunnel will overall create a positive impact on the local urban communities. The efficiency of having a single tunnel that houses all the utilities will make maintenance and repairs cost less, require less time to repair, and doesn't disrupt traffic above ground. For effective development of such essential services, residents are required to participate fully and coordinate with the contractor for easy and efficient working toward project completion. (Xinhua, 2015).

Figure 15: Workers are seen in an underground tunnel (Xinhua, 2015)

An example of these utility tunnels is found in Baiyin city in the northwest of China. This tunnel in the Gansu province cost about $324 million US dollars. The tunnel was completed in the recent past to contain more than five types of utility pipes, there are heating pipes, waterlines, telecom, power cables and additional space to house other utilities if needed. Its length is more than 25 km (Mingmei, 2019-06-02).

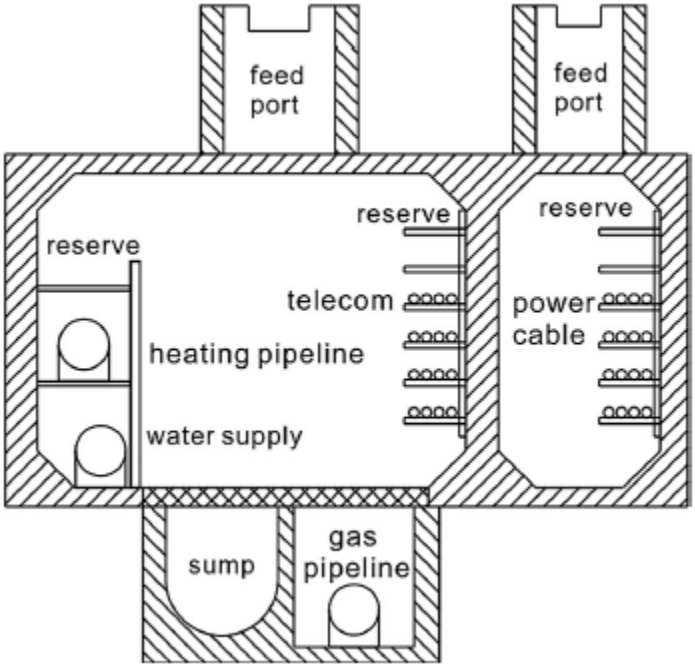

Figure 16: Layout of utility tunnel in Baiyin city (Wang, T, 2020)

Utility tunnels come in a variety of shapes and sizes. Each type signifies a distinct style of layout and design to accommodate the buildings that the utilities will supply. An example is the trunk utility tunnel is typically constructed more than 3m below major roads and is used to transport water, electric power, and other utilities from initial stations (such as waterworks) to branch tunnels; however, this type of tunnel does not specifically

serve the areas along its path.

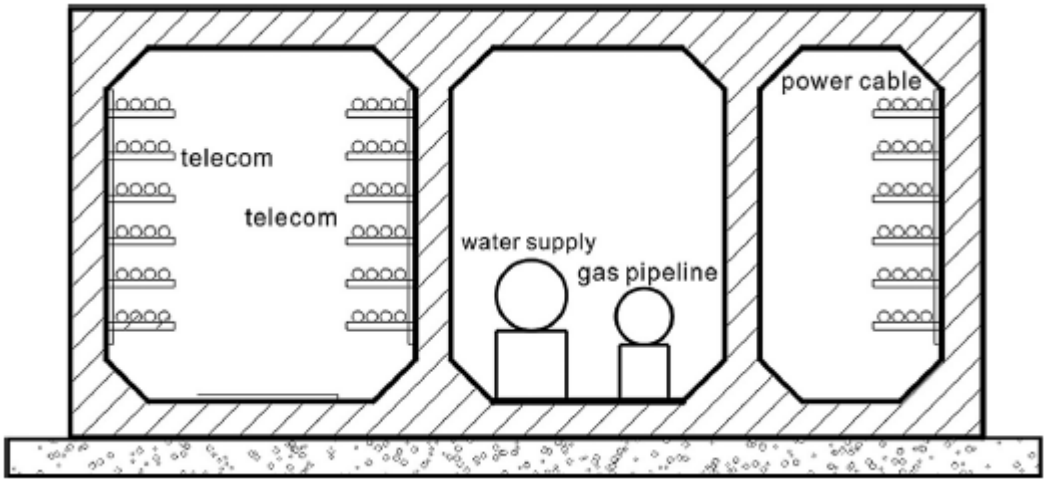

Figure 17: General layout of a trunk utility tunnel (Wang, T, 2020)

The other type is the tunnel's branch. The customers are served by a branch of the tunnel that distributes and transfers various supplies from a trunk line via the branch line, which usually includes water, telecom, and other pipelines. A cable underground tunnel whose layout is shown in figure 18 below was constructed from 2002 to 2004 in Guangzhou Higher Education Mega Center. This utility tunnel contains power cables, water supply, telecom, heating pipes and cooling pipes. (Tianyu Wang, June 2018).

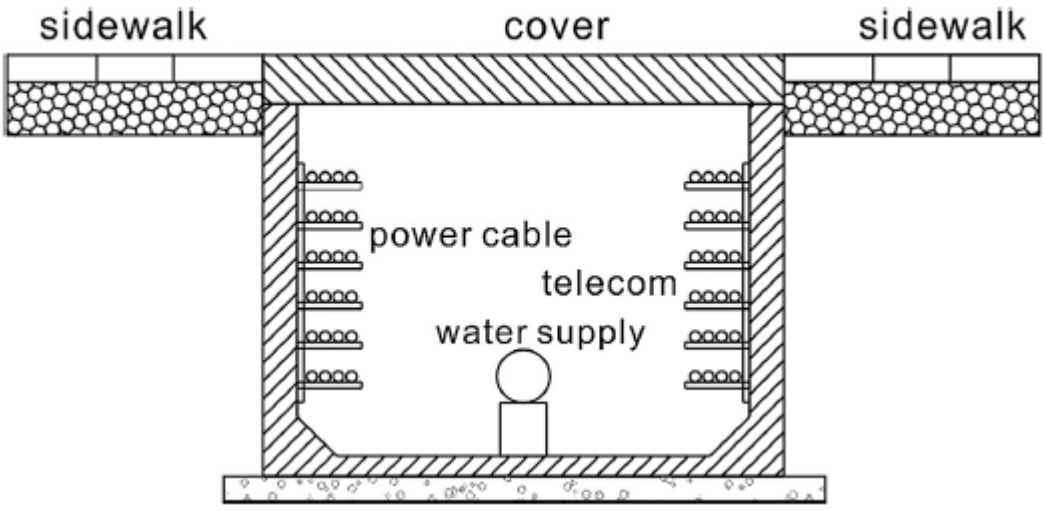

Figure 18: Typical layout of a cable utility tunnel (Wang, T, 2020)

Service tunnels are due to further dividing of branch tunnels. The majority of service tunnels were designed mostly for short-term purposes, with no regard for a long-term strategy and operation management. For example, during the 1993 construction of Shanghai's Pudong new city, little focus was put on the importance of long-term underground infrastructure. Underground service tunnels were mainly built under Zhangyang Road for testing purposes, rather than planning a network infrastructure, in order to keep up with political demands, resulting in poor tunnel reliability and high maintenance costs. Aside from the lack of regulatory controls, many municipal utility providers have opted to privatize.

The Chinese government has taken measures to gather accurate statistics and construct a database of local services, with the intention of preventing service disruption incurred by modification of streets for accurate positioning of utility tunnels and design of the grid. It can be used to assess the key development areas of service tunnels, which include

1. Areas with a heavy density of underground land, such as the CBD, financial center, and other high-rise areas;
2. Super-speed railway network, airports, and ports;
3. Congested traffic urban centers and utilities in the underground;
4. Building sites of subways, underground bridges, and underground complexes in the urban centers.

Improvement of the utilization of urban roads

Technological improvements in this country have led to great socialization. The great extent of socialization has shown to improve communications countrywide and even to other countries. Urbanization in this country demanded efficient transportation means for peoples and goods within the urban centers. With marketing and general business growth exceeding 50%, pollution in the urban centers is a big challenge that needs addressing with all emphasis it requires. The usage of modern underground urban passage has a significant practical step in reducing urban pollution caused by motor vehicles (Zhilong Chena J. D., 2021).

The challenge of traffic connections cities has further hastened the adoption of underground transport channels. Being the most populated country globally, China also faces a lack of enough space to expand roads and railways. Thus, extending the transport channels has to accommodate the increasing number of cars and vehicles that meet the travelling population's demands.

The municipal plans have gone to the extent of including plans for the underground spaces. The documentation has happened in several cities, including Shanghai and Beijing. This logistic system built underground is either tunnel transportation or pipeline

transportation. The tunnel transport includes tube and freight transportation underground. As for pipe transportation, this includes capsule pipelines, pneumatic and hydraulic carriages. Transportation of cargo through an underground tunnel will allow high speed transit, increasing productivity and supply.

Some of the research done on the underground logistics systems (ULS) in China are; A study on Beijing ULS was done by the People's Liberation Army University in 2004. It was funded by a committee of construction and traffic of Beijing. The impact of intense use of underground transportation means was evaluated and found to have eased traffic congestion in the city. In 2007 shanghai municipal design institute was engaged in research on the transportation of containers in the underground transportation system of shanghai. Funding for this research was from the committee of construction and traffic in Shanghai city. The target of the research was to establish benefits of underground transportation as well as utility tunnels. The research also concluded that underground transportation reduces the time it takes for cargo to arrive at their destination. The dedicated tunnels eliminate the traffic delay caused by vehicles above ground. More research is still going on to the present moment. The finding from these researches helps improve the use system to betterment their services to Chinese people (Zhilong Chena J. D., 2021).

Risk management and safety of underground engineering in China.

The Chinese dry land is mountainous making above ground construction difficult at times which has led to many ongoing underground constructions as well as finished underground projects all over China. Thus, there is a need to protect lives and property during both construction phases and usage of these facilities as deemed fit for use. For the

past decade, there has been a development in the legislation of how safely these facilities can be constructed and used. There has been the development of laws and establishment of other regulations by government bodies responsible for the safe construction of such underground facilities. The second step followed after such relevant laws have been established is implementing a good risk management plan; these laws are contained in the "Regulations on Production Safety Management for Construction Projects" and "Regulations on Safe Production License" guided by the constitution. (Group, G. 2020) The plan gives the guideline to be followed to assure the risk management of underground engineering work all over china and in specifics. Information technology is then used to provide early warnings about risks within these structures. A support system responsible for making decisions is then established. It uses information technology as the early warning system does. The last step in which China is continuously engaging itself in managing risk in the underground structures is improving risk-related studies.

According to China, an underground service tunnel's legal structure generally consists of three parts: management in a responsible manner, monetary guidelines, and additional legislation. The challenges involved are; service tunnel ownership and other land related legalities, poor coordination between sponsors, leaders, and the framework for coordination, sharing of original investment, and benefits of charging and disbursing systems. There are numerous variables that have contributed to unsafe human behavior, developing safe and reliable technology, and developing safety management guidelines and regulations. (QihuQianaPengLinb, August 2016).

The biggest and highly complex underground service tunnel system in China, Hong Kong–Zhuhai–Macau Bridge (HZMB), is completed in May 2018. The main bridge

extends for 29.6 Kilometers and the cost was $17.3 billion US dollars. Among a series of tunnels under the bridge, one 6.7-kilometer-long underwater tunnel was built to connect two islands for landing of the bridge. HZMB is now the longest immersed tube tunnel in the world and the longest bridge-tunnel highway in the world. (Verdict, n, d.)

Figure 19. Hong Kong-Zhuhai-Macau Bridge (Yang, 2016)

The building of these subsurface utility tunnels in China should adopt a sustainable development approach that requires an overall strategy as a concept, laws and regulations as a pledge, and a business structure to keep the project going smoothly and sustainably. Under this mode, China leads in the advancement and growth of underground utilization. (Yang, 2016).

CHAPTER 6

Military engineering

Military facilities

China has the fastest growing economy for the last 50 years compared to the whole world. Conclusions can be said that it is claiming superpower with the vast growth of industries and technology. Products from this country are being sold in most parts of the world with the current dominance in almost half of Africa and Asia's great extent. Chinese advancement has caused much imbalance in other sectors, especially security and the ability to influence critical decisions. Thus, China needs to have military advancement at whatever cost with all carefulness put in place.

Fallout bunker

This country has put measures to protect its leaders, troops and other essential staff in the country's leadership. It constructed a deep bunker under limestone mines 2 kilometers from the ground surface, as geological surveyors found. It is 20 kilometers from Beijing, the capital city, in the northwest direction. It is thus convenient for easy evacuation of the country's top leadership in case of any danger. This area's surrounding is a national park with a vast supply of clean water and ample space to build as a small city. This bunker was known to the public when President Xi Jinping visited it dressed in military attire in 2016. It was a part of the Central Military Commission's Joint Battle Command Centre at the time, with an uncertain start date for construction, but progress is expected to have been made recently. Military and political actions are made in this

bunker, with surveillance and military monitoring very intensely. Other activities include issuing orders and military intelligence across the Chinese battle zone. Access to this facility is minimal and is only through hills west of the national park. (chen, 2018)

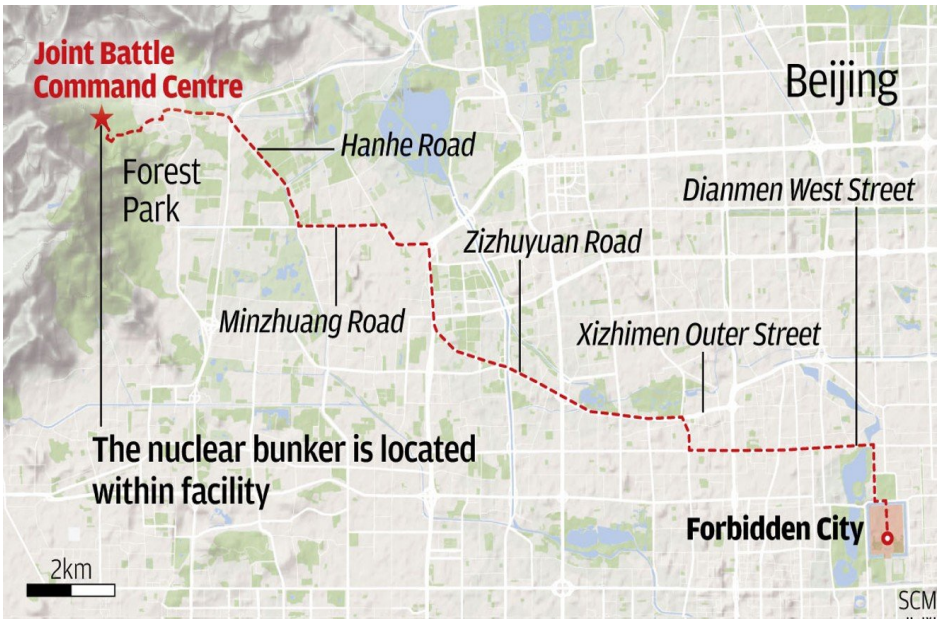

Figure 20: Location of underground bunker near Beijing (chen, 2018)

Many bunkers to be used as fallouts are believed to be all over China, but the government cannot disclose their localities. Some were constructed as early as the 1950s. They are built to be independent of any external supplies for an extended period and proof to any nuclear pollutant attack or any atomic bomb (chen, 2018)

The 3000-miles underground "great wall"

During his presidency, President Barack Obama directed research into the People's Republic of China's secret military tunnels. More extension was the country's nuclear capability concerning the United States of America's ability to respond to any nuclear threats from China. Later these tunnels were branded the name the "Chinese nuclear great

wall" by the American media. In 2012, the US president even publicly claimed that it is their enemy number one (Obama, 2013). The call to this research must have been triggered by the increment of Chinese nuclear capability at a very increasing rate, which were out of the public eye and knowledge had been kept very secretive. In the same year, China was the second after the United States of America to have large funds allocated for the military defense. The $106.4 billion US dollars was about an 11.2% increase from the previous year's budget.

An American professor called Philip Kaber, a former top official of the pentagon conducted a research with his students' help and found out that the Chinese army had constructed more than 3,000 miles of tunnels, a piece of information that was entirely secret. The Chinese government, in its boastful character to show its citizens how secure they are in case of a nuclear strike, showed journalists these tunnels and even allowed them in. This proved that Philip's research was correct. This act of allowing journalists was done in December of 2009. CCTV, a channel run by the Chinese government, admitted that there are over three thousand miles of military tunnels in China (Obama, 2013).

Nuclear missiles of china are stored in the great underground wall. Most of these tunnels were dug by the Second Artillery Corps. The Second Artillery Corps has very secretly served as a branch attached to the military of China. This branch is also responsible for the deployment of missiles as well as other nuclear weapons and warheads. This body is well known to the public. Karber and his students' research led to numerous congressional sittings and hearings revealing the fears which China inflicted on them. Their research collected their data and information from military forums, reports from Chinese

TV channels, and YouTube clips. They were also able to access the military website to download military documents. Smaller revelations arose as a result of their reporting, such as how the missiles were kept mobile and transported from structure to structure, as well as photos and stories of a "missile train" and disguised passenger rail cars used to transport China's long-range missiles. They also approximated that China has about 3,000 nuclear warheads (wan, 2011).

The Chinese army is also believed to have built 5,000 kilometers of this tremendous underground wall in the northern part of China, Hebei. China is very much prepared for war at any moment. The secrecy involved in building these tunnels is to enable the successful launch of their missiles if missiles hit them. The Second Artillery Division is mandated to respond to any attacks in the country, and to do so, they must be well protected. (China Builds Underground 'Great Wall' Against Nuke Attack, 2009).

Many of these tunnels are well linked and cannot be detected from space. Trucks and trains are used to transport personnel and equipment from one location to the other within this sophisticated network under the rugged mountainous landscape (Zhang, 2012).

Airbases

There are more than 40 impenetrable underground air bases for the Chinese army. They are used to store fleets and another airborne military equipment. The bombing of this well-reinforced structure is believed to not affect the equipment stored inside. The construction of what is believed to be 40 or more airbases began back in the 1950s. Several of them are said to have lost military value, and thus they are now used as tourist attraction sites and

museums. The cause of the abandoning may have been due to the continued advancement of the underground military tunnels, and interconnecting challenges may have led to their abandonment. (Johnson, 2012)

Engineering design is summarized in the figure below with reinforced concave roofing. Any successful attack can only approach the bunkers from the entrances. There is no clear path for any outside middle to penetrate to the hangar center where the most valuable equipment and personnel are located. Upon hitting a few meters from the entrance, only vertical walls could be compromised, leading to the collapse of doom shaped roof. But the reinforcement will ensure that the ceiling remains intact and no harm meets any component inside. The floor strength may, however, be compromised. (Johnson, R. 2012)

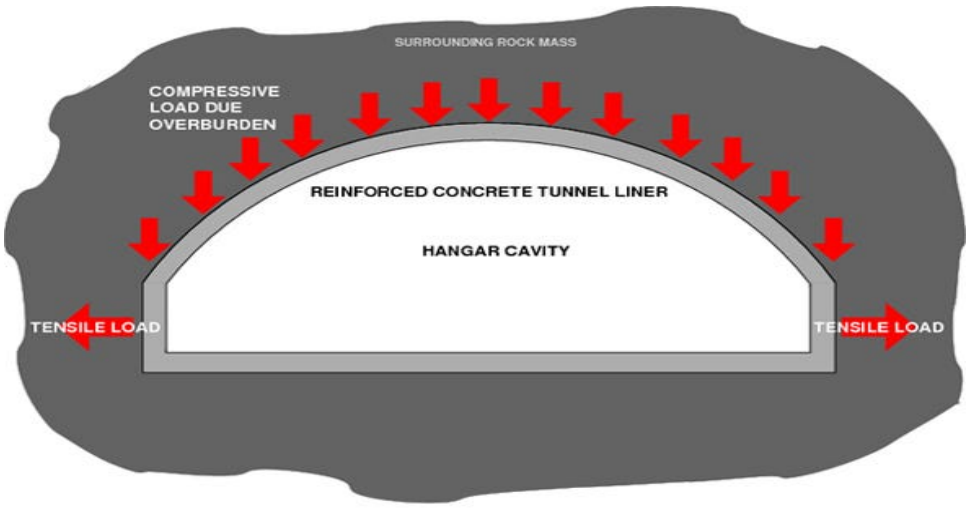

Figure 21: profile of underground Chinese air bases (Johnson, R. 2012)

CHAPTER 7

Storage facilities

Depleted oil and gas wells have found good use as underground gas storage facilities primarily in the western, north-eastern, and central regions of China. The first site of this kind was constructed in 1969. The advancement of this storage technology was after constructing a long-distance gas pipeline that connected the Beijing and Shaanxi regions. The underground storage facilities are managed mainly by the china national petroleum corporation and by China Petroleum and Chemical Corporation. Projections were that by the end of 2017, the country's capacity could only hold up to three per cent of the domestic demand. (Staff, 2018).

The Chinese government has dramatically influenced the underground storage facilities to fill the gaps left from the demand and supply. The national oil companies had to build storage facilities of up to 10 % cent of the country's demand. This country, by 2020, had a 30% demand increase in the domestic natural gas demand, and by 2040, it is expected to have a 25% side in the global demand. A system of pipe networks joins these underground gas storage facilities. This storage technique is chosen for the following reasons; ability of proper risk management, well detailed, enforceable, and informed regulations, the operations are competent in technicality, and there is an implemented environment, safety, and health system (Dan Mueller).

Some effective ways to keep these gas storage facilities are; collaboration with other departments and regulators, industry, government priorities, and public stakeholders;

and consistency in regulatory response through reliable and open procedures that result in justice for both entities and entities, as well as effective and productive results.

Construction of the first large-scale underground storage facility in the Tianjin region started back in 1999. They hold up to 41.5 m3 of the gas due to the compressibility property of the gas. The volume of these storage facilities is 18 billion m3. In Panjin City, there is a storage facility constructed from 15 depleted wells that daily supply 10, 000, 000 m3 of natural gas. The procedure filling wells with this natural gas first began in 2014 April, after construction commenced in 2011. They were parts of the Liaohe oil fields. It is the first of its kind to be constructed in northeast china (Guosheng Dingab, dec 2015).

Originally the wells were for oil in Liaohe. This field is among the largest ones in the country. Work to turn them into storage facilities began in 2011 as production dried up. From April 2014, it started to be filled with natural gas. The construction ended in 2014 after the wells dried in 2011 (China's expanding underground gas storage may reduce LNG winter price volatility, 2018).

Strategic petroleum reserve (SPR)

It was expected that by 2020 china would have built an underground cavern with the ability to hold at least one-quarter of its oil reserves which had undergone a strategic expansion. The development of this petroleum reserve initiative was to solve the expensive and dangerous tanks exposed in the highly populated coastal region. China has been quite secretive regarding the progress of the SPR, with speculations showing that there are five

facilities built underground. The investments by the country have been quite intense (Meng Meng, reuters, 2016).

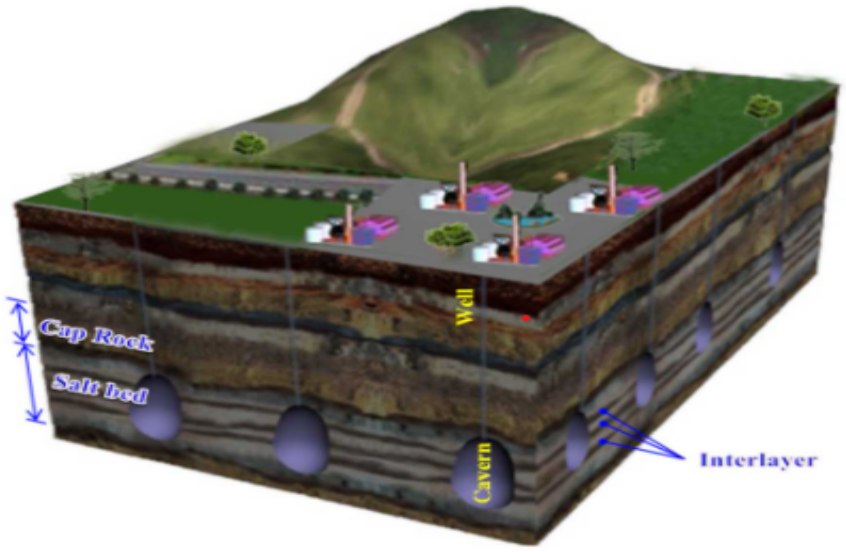

Figure 22: Illustration of salt cavern oil storages in a bedded salt formation (Shi, X. 2017)

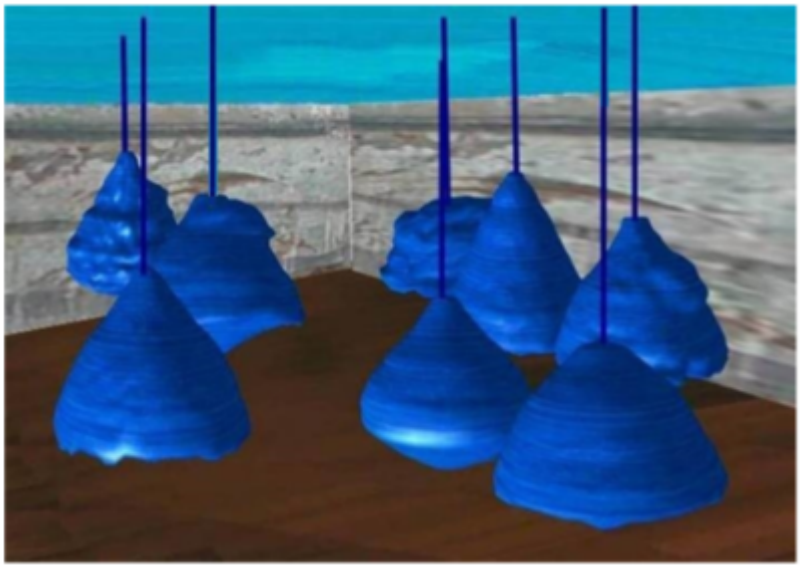

Figure 23: Sonar surveys of several existing salt caverns (Shi, X. 2017)

The only completed one is in Huangdao of Shandong province. Even though there is a lot of digging and intense use of expensive construction machinery, the total cost of making underground caverns is far much less by about 67% compared to the construction of tanks above the ground. (Meng Meng, n,d.).These underground tanks come with extra packages of advantage, including lower risks to the environment, low construction costs, and perceived to be highly protective.

By 2020, Beijing alone was set to have its underground storage site accommodate up to 130 million barrels. This storage is quite a significant percentage (about 25 per cent), the strategic petroleum reserve's total target was 550 million barrels. (Meng Meng, n,d.) Other ongoing construction sites of these caverns are in the Liaoning region, Zhanjiang, and Huizhou in southern Guangdong. The first underground refinery opened in Beijing could process 19 million barrels. (Meng Meng, n,d.)

This technology is a source of headache, especially for engineers at sometimes. It may take longer than expected to build these caverns, especially when water seepage from the rocks is tough to control. This type of scenario will be costly to manage even after completion, for there will be very high chances of oil leakage. The topography of this country, being mountainous, further disrupts engineers' operation as they try to adapt to the challenging condition geographically and further causing a lot of delays to the project. Sometimes, there may be an abandonment of these construction projects entirely due to the poor geological structure's high health risk. The Chinese are constantly forced to excavate hard rocks nearly two hundred meters below the ground to make the caverns. The excavation is close to the height above sea level of South Korea. Contrary to what other

competitive countries like the United States of America are challenged with, they only use salt domes that are deep and hollowed-out.

It is quite a tremendous calculation of how stored oils' pressure balances water with the underlying rocks. This sort of balance prevents oil from seeping into rock. Hubei is holding these underground depots' future, especially after identifying potential storage sites for oil in Qianjiang and Jintan. PetroChina company is one of the companies involved in gas storage in Jintan. The other companies are Hong Kong's Towngas and many more. (Shi, X. 2017)

Lanzhou Crude Oil Commercial Reserve

This plant is a significant storage facility for crude oil. The sources of this oil include Kazakhstan and Turpan. Others are Tarim and the northern region of Xinjiang. The location of the plan is Gansu province, a place called Lanzhou. Its functionality commenced in mid-2013 after being under construction since the beginning of 2009. Supportive and essential facilities such as drainage, contact, and firefighting are installed. The storage sector includes eighteen double-deck external floating roof steel tanks.

Figure 24: Lanzhou Crude Oil Commercial Reserve (Oil & Gas Storage, 2018)

Yunnan Product Oil Pipeline Company loading center

This project began in 2015, November going all through to the end of July 2017. There are 4 ten thousand cubic meters storage tanks of floating roof type and four similar types about half the volume, five thousand cubic meters. Other facilities within this center are processing systems for both information and automated control and fire control, including many more support facilities. It is located in Yunnan Province in a city called Anning (Caopu town) (chinese petroleum pipleline engineering co. ltd, n.d.)

Figure 25: Yunnan Product Oil Pipeline Company (Oil & Gas Storage, 2018)

CHAPTER 8

Conclusion

China is the highest populated country in the world, and her economy has been growing at the highest rate in the past few decades. This country has positioned itself as a super power with great and sophisticated infrastructure. The challenge of mountainous landscape has been a challenge in its development but the Chinese government has thrived and overcome it, revealing that if a mountain blocks your way, go through the mountain.

China is aggressively developing underground routes to ease traffic congestion in its cities. These tunnels have enabled the reduced cost of running motor vehicles by minimizing the amount of time they take on road. If people can get to work in time, the businesses keep running efficiently thus continuously improving the economy. The high population in this country requires massive transport by public means bearing in mind that the number of private vehicles has increased tremendously. Tunnels have been constructed in the sea to connect islands with mainland china easing the access of the islands. Also, bridges to cross rivers have been outshone by tunnels underneath the rivers. The technological improvement of the country has had a great role in the designing and construction of these roads and tunnels. Railway transportation has not been left behind whereby subways like in Beijing and Shanghai serve the high number of travelers satisfactorily. High speed trains have most of their route's underground. The biggest public transport means in this country is by rail.

Shopping malls have been built underground in the effort of battling with the challenge of scarcity of land. Some of these malls are synchronized with subway tunnels

to enable easy access by travelers as they board or alight trains. The first in the world underground luxurious hotel was opened in this country in November 2018. This was in the effort to redeem an abandoned quarry and in the process more than 40 patents were born in a span of 10 years.

Similarly, other important sectors like utility tunnels for supportive functions in these cities are also advancing through these underground tunnels. Power lines, telephone cables, water pipes and sewer facilities are some of the municipal services within these utility tunnels. The great development ensures that during their downtime, the utility services do not cause disruptions like blocking of roads especially during installation and repair.

Military in this country has developed very sophisticated protective bunkers and storage facilities connected by underground tunnels. This linking of military infrastructure is called the Great Wall. This country has also shielded its powerful weapons from nuclear threats by storing them deep underground in reinforced bunkers. In case of an imminent threat to the country, fallout bunkers are strategically located to ensure that the leadership of the country and also the defensive capability is not compromised. Air bound weapons like fleets are kept in underground classified bases where they cannot be attacked from outside.

The energy sector has also ensured that safety of gas and petroleum is improved by turning into underground storage facilities. This has been initiated in the underground gas storage (UGS) and the strategic petroleum reserve (SPR). Depleted oil wells are converted

to gas storage units where the risk of inflammation is reduced by a great extent. The oil is prevented from seeping by use of underground water sealed storage sites.

Generally, humans are now building downwards, even though not as equally as they are building upward, but with time the rest of the world will soon follow the steps of China. These underground facilities have demonstrated to be efficient, just like on surface ones and their safety is more guaranteed so long as the design work and construction have been done with all care and precision required.

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