Subway engineering

Subway engineering is a branch of transportation relating to feasibility study, planning, design, construction, and operation of subway systems. In addition to providing speedy and comfortable services, subways consume less energy per passenger carried in comparison with other modes of transportation and do not produce air pollution. Therefore, they have been adopted in many cities as a primary mode of transportation for the purpose of solving problems associated with traffic congestion and the quality of daily life of people has indeed been improved as a result.

The first subway opened in London in 1863 with steam locomotives fueled by coal. In 1896, the first subway on the European continent was placed in service. In the United States, the first subway line was instituted in Boston, Massachusetts in 1895. Since then, subways have been constructed in cities such as New York City, Chicago, Washington D.C., Baltimore, Houston, San Francisco, Los Angeles, Philadelphia, Pittsburgh, Atlanta and many others. Elsewhere in the world, subways are available in numerous cities, including Tokyo, Singapore, Hong Kong, Seoul, Taipei, Shanghai, Beijing, Cairo, Toronto, Sydney, Moscow, Paris, Brasilia, Santiago, Caracas, and so on.

The modern subway systems are electrified with trains powered by direct current (DC). Trains are running at cruise speeds, normally, up to 80 km per hour and are fully automated with drivers for handling unexpected incidents only. Cars are air-conditioned for best comfort of the passengers and most of the underground stations are air-conditioned as well. It is also becoming popular to install screen doors alongside the platforms in air-conditioned stations for the safety of the passengers and for the purpose of conserving energy.

Feasibility Study. In layman's term, subways are underground railways, except that subways are for shorter trips with more frequent stops while railways are for inter-city travels with stations farther apart. Therefore, factors to be considered in the planning process of subway systems are quite similar to those for railway systems. Planning of subway systems starts with corridor study which includes forecast of ridership and revenues, estimation of construction and operational costs, projection of potential benefits from land development, etc. Feasibility of a subway system is normally governed by economical, social and political, rather than technical factors.

It is utmost important to integrate subway systems with other modes of transportation for maximum benefits. Air transport, railway, subway, and bus systems are the four major elements in mass transportation with air transport and railway systems for long-distance travel, subways for intermediate-distance travel within individual metropolitan areas and buses as feeders to the others. All these systems should form a web-like network to provide maximum convenience to travelers. In fact, integration should go beyond networking. In many cities, subway and bus systems have already been combined so they are managed by the same agency. In some other cities, unified fare-collecting systems have been adopted for the two systems so travelers would not have to purchase separate tickets for different segments of the same trip.

Planning. All subway systems have three major types of structures: stations, tunnels and depots. The most important task in planning a new subway system or a new subway line is to locate stations and depots and to determine track alignment. Subway lines are normally laid within the right-of-way of public roads and as far as possible they shall stay away from private properties and sites of importance. Protection to historical sites and monuments has been a reason for the re-alignment of quite many lines. Because stations and entrances are usually located at densely populated areas, land acquisition is often a major problem. One way to solve this problem is to integrate entrances into nearby developments, such as parks, department stores, public buildings, etc. This also lessens visual impacts of entrances to the environment and reduces their impediment on the pedestrian flow. Regarding vertical alignment, since underground structures are much more costly and take much longer time to construct, subway systems in suburbs and countryside are usually laid at-grade or, if necessary, elevated.

Environmental impact is a major issue to be studied with emphasis on disturbance to traffic, vibration, and noise due to construction. Since dumping sites are usually difficult to find in urban areas, dumping of spoils could likewise become problematic. Offshore dumping remains a plausible option, yet the effects of such an action must be carefully assessed and minimized.

Ground conditions are to be investigated for the purpose of providing design parameters and groundwater table is to be determined. In areas in which groundwater has experienced large drawdowns, long-term monitoring is necessary to establish the trend of groundwater movement.

Design. Design of permanent works includes structural and architectural elements and electrical/mechanical facilities. Basically, there are two types of structures: stations and tunnels. For stations, space optimization and passenger flow are the two most important subjects to be considered. Figure 1 shows CKS Memorial Hall Station of the Taipei Rapid Transit Systems and the major elements in a typical station, such as rails, platform, staircases and escalators, can be identified. Special considerations shall be given to provide convenience to handicapped passengers. Provisions shall be made for the movement of wheelchairs in elevators and at fare gates and blind-guiding tiles shall be available to guide blinds to platforms. In some countries, for example, Singapore, selected stations are designed as shelters, with structures strengthened, for civil defense purposes.

Figure 1 CKS Memorial Station, Taipei Rapid Transit Systems

In both stations and tunnels, ventilation is essential for the comfort of the passengers and for safety against fires. Sufficient staircases are required for passengers to escape from the station platform to a point of safety within the time allowed by fire codes and sufficient ventilation is required to remove smoke during a fire. The plastic curtains shown at the top of Figure 1 are required by fire codes for confining smoke to prevent it from spreading.

Electrical/mechanical facilities include rolling stock, signaling, communication, power supply, automatic fare collection, and environmental control (i.e., air-conditioning) systems. Besides, there are depot, station and tunnel service facilities. For stations designed for civil-defense purpose, extra air, water and power supplies are provided to prepare for emergency situations which necessitate the use of these stations as shelters.

Architectural design of station entrances is of primary importance. Entrances should be ethetical as well as functional. Their impacts to the environment can be reduced by landscaping and provision of art exhibitions. Parking lots and bus bays are to be properly located to avoid traffic congestion.

Corrosion has caused problems to structures in some subways, therefore, coating may be necessary if the ground is found to contain corrosive chemicals.

Efforts shall be taken to minimize noise and vibration from running trains. Floating slabs can be used in sections of routes crossing densely populated areas and commercial districts where disturbance due to vibrations and secondary airborne noise inside buildings is unacceptable. To do so, vibration-absorbing materials, such as rubber pads, are placed between the concrete slabs, on which rails rest, and foundation.

Ground conditions are important for both design and construction of underground structures and should be thoroughly investigated. Groundwater has been responsible for many major incidents and should not be overlooked. Construction of subway systems usually is complicated by problems involving traffic, utilities, and buildings and these problems are usually responsible for delays and accidents. The conditions of buildings in the zone of influence should be inspected and recorded and the influences of construction on these buildings estimated. Excessive ground movements as a result of inadequate retaining systems during excavations were responsible for most of catastrophic incidents, including collapses of buildings, explosions due to leaking gas pipes, flooding of pits due to dislocated water mains, etc. Therefore, instrumentation programs shall be well prepared to monitor ground movements for ensuring the safety of the buildings which are likely to be affected.

With the rapid advancement of computer technology, geographic information systems (GIS) have been widely adopted in construction industry and such systems can be used to compile information relevant to geology and ground conditions, utilities, and buildings. It is desirable to establish a data center to safe-keeping all the electronic information and to facilitate sharing of data via internet.

Construction. Underground stations are normally constructed by using the open-cut method. For open cuts in soft ground, the sides of the pits are normally retained by wall members and braced using struts. The pits are decked for maintaining traffic at surface. For new lines to underpass existing lines, it will not be possible to have open cuts. In such cases, stations have to be constructed by mining method.

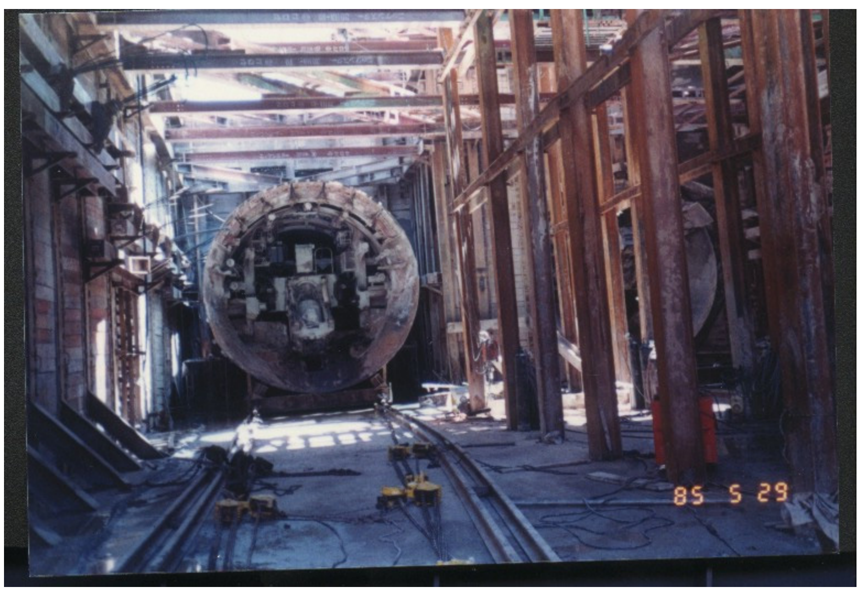

Figure 2 Arriving of a shield tunneling machine at a station

Tunnels linking stations can be constructed either by using the open-cut method or by using the mining method. In competent ground, mining can be done by using light machines or by using tunnel boring machines (TBM) with minimum support. In soft ground, it has become popular to bore tunnels by using shield tunneling machines and line the tunnels with reinforced concrete segments. Figure 2 shows a shield machine which just completed a section of tunnel and entered the station which was still under construction. For tunnels running across waters, submerged tubes are frequently used, for example, between Oakland and San Francisco (Bay Area Rapid Transit System), and across Hong Kong Harbor (Hong Kong Mass Transit Railway).

Wherever there exist water-bearing strata, construction shall proceed with great care. This is particularly true when openings are to be made on structures at great depth. Once leakage occurs, the soils surrounding the water path may quickly liquefy due to the great hydraulic gradient and the flow may become uncontrollable in short time. Grouting is usually carried out to cut off water path, however, its effectiveness is difficult to be ascertained. Ground freezing has been adopted in many cases, either as a precautionary measure or as a remedial measure in rehabilitation, and has been proved to be effective in dealing with problems involving groundwater. Freezing is carried out by circulating coolant in looped pipes inserted in drilled holes for the purpose of blocking water path by solidifying a large volume of soil into ice.

Ground settlements are to be minimized for protecting structures in zones affected by construction activities. Ground settlements and performance of temporary works shall be closely monitored and instrument readings are nowadays processed by using computer software. Alert systems have been adopted in the construction of many new subway lines and warnings are issued as soon as instruments show abnormal readings. This enabled relevant parties, including contractors, designers and construction managers to take preventive actions in time and effectively eliminated potential dangers, such as collapse of retaining walls, flooding of pits, and building damages, in numerous cases.

Operation. Modern subway systems are fully automated with minimal staff. Train movements are monitored and regulated by computers in control center and drivers are required to deal with emergency situations only. Therefore, engineering is limited to the function and maintenance of electrical and mechanical facilities. The electrical and mechanical devices requiring constant care include rolling stock, signaling, communication and broadcasting, power supply, elevators and escalators, automatic fare collection, and environmental control systems. Also included are depot facilities, station and tunnel service facilities.

Bibliography. Hulme, T. W., Chapman, P.H.J., and Foo, P. S., Singapore Mass Rapid Transit System: planning and implementation, Proc., Instn, Civ. Engrs, Part 1, 1989, 86, Aug. pp.627-665; J. P. Copsey, Hulme, T. W., Kraft, B., Sripathy, P., Proc. Instn Civ. Engrs, Part 1, 1989, 86, Aug., pp. 667-707. Lambrechts, R. N. Hwang and A. Urzua, Big digs around the world, Geot. Special Publication No. 86, ASCE, 1998