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PLANNING AND DESIGN OF UNDERGROUND SPACE USE

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Abstract

Whole over the world, up to now, it is difficult to create new space in metropolitan areas. Especially, the complex facilities and people overcrowd urban cities in Japan. In this state, the functions of urban areas do not often work normally. It is necessary to develop urban areas by promoting the concept of three-dimensional development that utilizes ground surface and underground spaces as a whole. And it needs that the aboveground space and underground space compensate for each limitation. In this report, the authors studied about the underground spaces to clarify the future prospect of them. At first, the history and the opportunities of the underground spaces are arranged. Secondly, we classified the underground facilities with some examples. And then, the problems for constructing the underground spaces are surveyed by SD method and so on. Finally, it is clarified that the design for underground space should head to create the comfortable space like an aboveground according to future prospects.

Contents

1. Introduction

The Japanese archipelago is an integral part of East Asia and comprises about 3,500 islands. Hokkaido, Honshu, Shikoku and Kyushu are the four major islands. Japan stretches about 3,000 km from the northeast to the southwest in the Pacific Ocean. Japan passed through the past-war reconstruction and high economic development period and has entered into the times of software, multimedia information, and internationalization. However, the country is now facing to various urban problems such as high land prices, traffic congestion, poor living environment, destroyed urban functions and overcrowded cities. Japan is not the only country facing to those urban problems. Large cities in any other countries head to similar situation, too. It would be extremely important to improve the urban environment while preserving precious urban assets to solve these problems caused by overcrowd, congestion, creative safety, and comfortable cities where utilize there urban space effectively. Utilization of not fully developed underground space would be one of the solutions for re-developing the limited spaces in urban areas. Further, it is necessary to develop urban areas by promoting the three-dimensional development concept that utilizes ground surface and underground spaces as a whole. And it needs that the aboveground space and underground space compensate for each limitation.

2. History of Underground Space Use

In Japan, several caves which might have been used as dwellings about 20,000 years ago were found. For example, Gongenyama Caves in Gunma Prefecture, Taisyakukyo Caves in Okayama and Hiroshima Prefecture and Seigoku limestone cave in Ohita Prefecture are well known.

Since the end of Ice Age, Japanese archipelago has been separated from Asian continent. About 120,000 years ago, Japanese archipelago was stable to present form. In this period, people began to use bows, arrows, earthenware and stoneware. Small villages were formed and people lived in pit dwelling. This period is called as Jomon period characterized by the living style such as hunting and fishing oriented life. Jomon period is also known as New Stone era that lasted for several thousand years. Later, the advanced agriculture led people to the cultivation of rice on paddies. This new era is well known as Yayoi period that has characteristic such as relative thin earthenware and the instrument made of bronze and iron. In this era, people settled their living space on apparent place and built pit dwellings. It began to construct the ancient burial mounds for the monarchs in 3rd century. The largest ancient tomb was built in the end of the 5th century. It was 480 m in length and surrounded by moat.

Typical ancient tombs had a keyhole shape from A.D.400 to 600. In the middle of 7th century, mining began with supporting the gunpowder. It was the beginning of the other concept of underground space. Since 1603, in early Edo era, city constructions had been developed. Especially, waterworks and roads as well as water transport and flood control were constructed. At that time, use of artificial underground also began. For example, Akoh canal in 1612, Fukuyama water supply system in 1619 Edo-Tamagawa aqueduct in 1655 and Hakone canal in 1670 were constructed. Ao-no Domon which was first road tunnel was constructed in 1750. Then, through Meiji era, 1868–1912, and Taisho era, 1912–1926, Japan imported western concept for constructing structures. The first step of introduction to western constructing techniques is for underground military facilities, hydroelectric power station and storage facilities. Typical railway tunnels, for example Old Ohsakayama tunnel between Kyoto and Ohotsu completed in 1878 has 665 m long and Sasago tunnel for Chuo railway line completed in 1902 has 4.6 km long, were constructed in these era. First modern waterworks were constructed in Yokohama and completed in 1887. And then, in Hakodate and Nagasaki these waterworks were also constructed in 1889 and 1891. On the other hands, first modern swage works were constructed in Tokyo. In 1927, first subway tunnel in Japan was constructed between Asakusa and Ueno by open-cut method. The first shopping mall was opened in 1934 at Suda-cho subway store. The large project, Tanna tunnel was 7.8 km in length, was first long railroad tunnel in Japan and was completed in 1934.

The first undersea tunnel, Kanmon strait tunnel between Honshu Island and Kyushu Island, was completed in 1944. Various large underground facilities were built as results of economic growth after the World War II.

In 1950's a number of underground shopping malls were constructed along subway stations and underground parking lots.

In 1960's, several large underground hydropower plants were built. For example, underground power plant with Kurobe River forth dam was built in 1962. It was excavated over 95,000 m^3 of rock mass. Along the extreme progressive of economic activities and industrialization, large number of populations moved into urban area, especially Tokyo and Osaka. In the results, the infrastructure in urban area was improved urgently. In the same time, underground space use also advanced.

In 1975, oil shortage crisis called as Oil shock occurred in Japan. It was the beginning of the underground storage facilities for oil to avoid the next oil crisis. This planning was realized in 1992 at Kushikino oil storage in Kagoshima, Kuji oil storage in Iwate and Kikuma oil storage in Ehime. After fighting against gusting water through enormous faults in rock mass more than ten years, Seikan railway tunnel which has 54 km in length was completed in 1986. The tunnel construction was initially planned to connect between Honshu and Hokkaido in 1960's. This construction created many tunneling techniques to breakthrough many difficulties.

The underground space use in Japan has attracted with public attention since the latter half of 1980's. Considering the main reasons for public interest, we must take into account the social and economic prosperity. The traditional desire to stem the stagnation of domestic land policy has accelerated the development of underground space use. According to advance a fully systemized society, most of cities lure the concentration of social assets and population. These phenomena progresses increasing of land price inner and outer of urban area. These concentrations also make much needfulness for various underground spaces such as shopping malls, parking spaces and subways.

At first, Western countries brought the technology of underground excavation after Meiji restoration. After that, the Japanese improved and created many original techniques for underground construction through numerous numbers of experiences about the projects of underground space. Remarkably, the special characteristics of soil and rock, the behaviour of groundwater and the environmental factor have advanced the excavating machines. Especially, Japanese shield machines which have the top technology in the world provide many projects and one of them succeeded to excavate Dover channel tunnel with shortening the constructing schedule.

Considering to the underground use, it is not too much to say that Japan is one of the leading countries in the world. The opinion of the underground use will expand, as long as there is a needfulness to improve the infrastructure among people, even though the content and extent for improving the infrastructure depends upon the social awareness (Fig. 1).

3. Opportunity of Underground Use

(1) *Background of Underground Use in Japan*

According to the previous chapter, underground spaces have been used for various reasons and purposes since ancient times. It is extremely interesting and worthwhile to clarify these reasons in order to seek future prospects for the underground use. In this section, the reasons of underground space is clarified. In ancient time, underground spaces had been used for relatively simple opportunities such as dwellings, storage and hiding places from enemies. On the other hands, in modern society, the underground has developed for various opportunities. The properties for the underground space differ from those of aboveground. The underground is relatively constant temperature and humidity through the four seasons and is suitable to storage cereals, fruits, wine and vegetables.

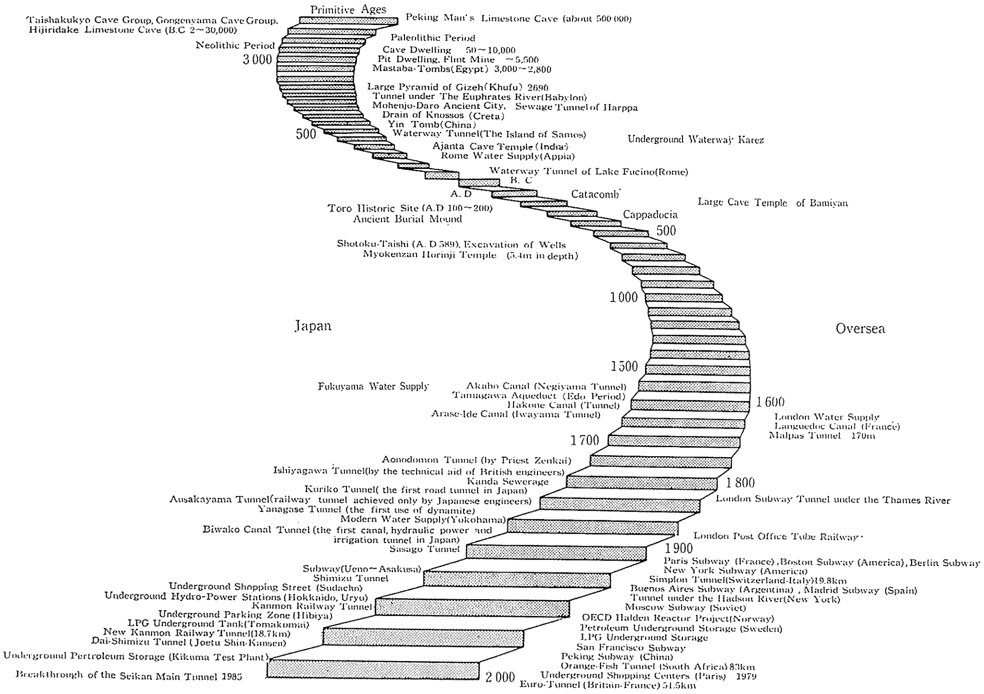


Fig. 1 History of underground space use[16].

In the cold countries, it is important that underground spaces maintain temperature more easily than the inner space of structure on the ground, especially during winter season. In the other words, underground spaces offer us effective protection against severe weathers with strong wind and heavy snow. On the point of saving energy, heating and cooling systems are more effective than the aboveground. In this reason, sidewalks and shopping malls are suitable to underground than aboveground. Underground space also maintains quiet and isolated between the aboveground. For example, a concert hall is a suitable application to maintain noise free properties. In the near future, underground or semi-underground homes also will be built to avoid aboveground noise.

Some experimental and observational instruments should be set underground because of getting its accuracy data. Some earthquake recording station and cosmic ray observation laboratories were set in deep underground. This isolate characteristic is useful as a nuclear shelter and place of refuge. Underground spaces can not only conceal unwanted odor and objects but also isolate germs and hazardous materials. In this reason, underground sewage treatment plants are constructed in many cities. Up to now, it is most interesting to decide where nuclear waste should be kept safely. Modern city life requires various facilities such as electric power and gas supply, communication lines, water supply and swage, train lines and stations, roads, parking spaces, walkways and stores. By placing some of those facilities underground, open spaces can be created on aboveground to make the amenities and to increase safety of city life. Indeed, many re-development projects are carried out with underground space developing.

The total land area which can accommodate the living space in Japan is approximately

20% (about 8 million ha) of the entire country. This land is about one half of the livable area in England even though the total area of England is about 65% of that of Japan. Thus, the urban areas in Japan are very crowded. Especially, in large cities or urban areas such as Tokyo and Osaka, most aboveground is occupied by building and facilities. These land prices are very expensive. Subway systems have been developed well in these urban cities. But, the trains of subway get unbelievably crowded during the rash hours in the morning and evening. On the other hands, in aboveground traffic congestion occurs daily. Unfortunately, as housing area is very expensive, almost people commute to work for long distance. It is extremely difficult to acquire open space on aboveground in the cities for new facilities. According to increase income, people expect their living standard and environment to improve. Intensive and effective land use is necessary for comprehensive land use required to utilize underground, aboveground and air spaces effectively not only from the construction economy but also from the viewpoint of comfortable and safe city life. Some city facilities which are not required to keep aboveground strongly should be settled in underground. A position of building could be constructed in underground to conserve the scenery or improve the aboveground landscape. At certain locations, new facilities could be constructed in underground to conserve a historic site. In this urban re-development, it is most important to obtain good consensus of residents about all proposed plans. Problems which do not occur normally in aboveground development arise in underground space development. For instance, special construction methods fighting against underground for safety measure and proper lighting systems are typical ones. Many underground facilities have been constructed in Japan through those difficulties.

(2) *Types of Underground Space Use*

Underground spaces can be classified in various ways. One is to classify them by their origins such as natural and artificial underground spaces. In ancient times, underground space use was limited to construct underground space naturally. However, when we talk about the use of underground spaces in the city areas today, we refer to man-made underground spaces that are constructed for particular purposes. According to various bases such as constructing depth, construction method, structure type and project scale, man-made underground spaces can be classified into various types. Based on the difference of constructing depth, these underground spaces are mainly classified into deep underground spaces and shallow underground spaces. The definition between deep and shallow is quite vague. For example, architects and civil engineers set the deep underground spaces that construct between 50 m and 100 m in depth. Recently, the spaces for supporting human activities in the city area have been limited to aboveground and shallow, vicinity of aboveground, underground spaces. Almost man-made underground space, except for some facilities which are constructed in relatively deep underground area, are located in a vicinity of the ground surface. Utility tunnels, underground shopping malls and parking spaces are generally built in the shallow underground. Underneath these facilities, subways are constructed between 10 m and 30 m in depth. Further underground development in large urban areas such as Tokyo and Osaka should take place in much deeper ground.

The construction method for underground spaces are classified as open-cut, cut-and-cover, shields tunneling and underpinning method. Most shopping malls, utility tunnels and parking spaces are constructed either by the open-cut or cut-and-cover construction method. In present day, subway tunnels are mainly constructed by cut-and-cover and shield tunneled method. A basement underneath an existing building is occasionally constructed by the underpinning construction method. For example, Tokyo Station continues to expand by the underpinning construction method.

Based on the functions and purposes for using such as transportation, energy transmission, information transmission and communication, water supply and drainage, storage, shelter, its production area, recreation facilities, business places and spaces, underground spaces are most commonly classified as follows.

1) Transportation Facilities:
   a. Subways and stations
   b. Underground roads
   c. Underground parking spaces
2) Utility and Communication Facilities:
   a. Electric supply lines and transformer stations
   b. Telephone lines
   c. Gas supply lines
   d. Water supply and swage lines
   e. Sewage treatment plants
   f. Garbage collection tube system
   g. Utility tunnels
3) Shopping Malls
   a. Stores
   b. Restaurants
   c. Walkways
4) Cultural and Recreational Facilities
   a. Libraries, museums and art museums
   b. Exhibition halls
   c. Gymnasiums and swimming pools
5) Natural Hazard Prevention
   a. Underground floodways
   b. Underground detention reservoirs
   c. Evacuation passage ways
   d. Place of refuge
6) Storage and Manufacturing Facilities
   a. Grain storage
   b. Vegetable and fruit storage
   c. Commodity storage
   d. Underground reservoirs
   e. Nuclear waste material storage
   f. Underground graves
   g. Underground factories
7) Energy Facilities
   a. Underground hydropower stations including pumped storage hydropower, transformer substations and compressed air energy storage (CAES) power plants (still in the planning stage)
   b. Oil storage tanks
   c. Liquefied natural gas storage tanks
8) Research Facilities
   a. Earthquake observation stations
   b. Cosmic ray observation stations
   c. Underground living environment research facilities

4. Introduction of Underground Facilities in Japan

(1) *Traffic Tunnel*

Underground spaces have been used because of various reasons and various purposes in Japan. In this section, representative underground facilities in Japan are introduced.

(a) *Motomachi Underground Access Road in Hiroshima*

To prepare for Asia much games in 1994 and National much games in 1996, Hiroshima City witnessed a number of development projects. One was Motomachi Underground Access Road to reduce the traffic congestion in the central parts of the city. This access road is the first underground road system constructed in Japan. These facilities consist of four underground parking areas settled under Hiroshima Bus Center Building, Hiroshima Postal Saving Hall, NTT Motomachi Building and Hiroshima Prefecture Sports Complex (Fig. 2).

The Access Road allows efficient use of the car parking areas that can handle 1,200 vehicles and help to alleviate aboveground traffic congestion. A park for public use was made above space of the Access Road.

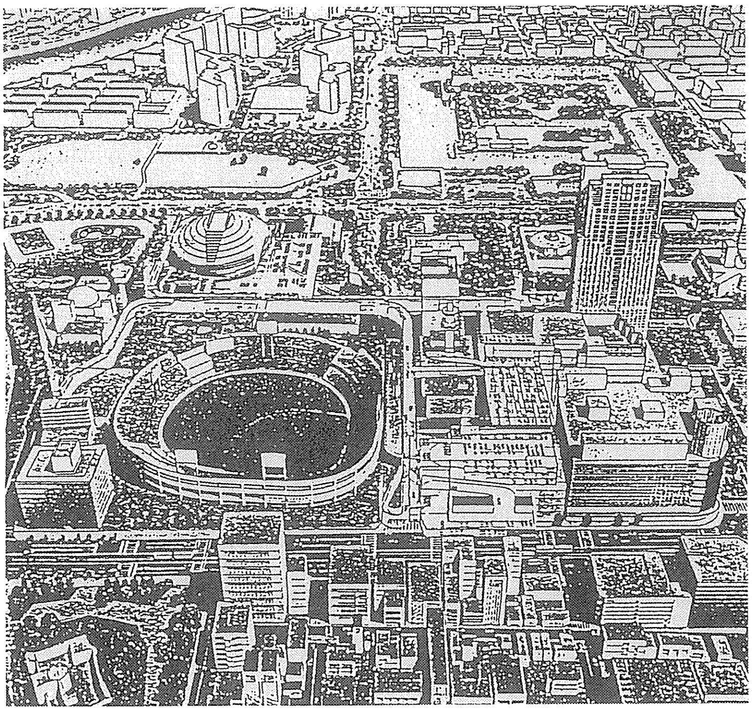


Fig. 2 Motomachi Underground Access Road in Hiroshima.

(b) *Tokyo Metropolitan Expressway*

The construction of Tokyo Metropolitan Expressway network began to construct in 1959. Up to now, about 210 km of expressway have been constructed. The number of vehicles that use the expressway network per day exceeds 1 million frequently. The expressway routes provide the main arteries for road transportation in Tokyo Metropolitan Region (Fig. 3). The construction of circular routes, however, have traffic jam constantly because of delaying the construction for radical routes and then placing heavy burden on the City-Center Circular (Toshi-Kanjo).

The Central Circular (Chuo-Kanjo) Route tends to contribute the formation of more efficient expressway network by providing a ring road connecting the radial expressway routes and the city center. In its total length of 46 km, about 10.1 km takes the underground expressway. The route is also due to link with the three "sub-city centers"; i.e. Shibuya, Shinjuku and Ikebukuro. And these are expected to contribute to ameliorate the urban functions and invigorate the economic activities. Most parts of underground section are being constructed by the cut-and-cover method, as the shield tunneling method is limited by the factors such as the presence of interchanges and entrances/exits as well as intersections with existing trunk roads, railways and rivers within underground section of Central Circular Route (Fig. 4). Of course, shield tunneling method reduces the unaltered cross sections together with the presence of special tunneling method according to the avoiding obstruction for aboveground and the earth cover conditions. According to the planned route, one part of the underground section of the expressway, about 3.3 km long will construct parallel to Metropolitan Subway Rout 12 and the expressway will be integrated with three stations of the subway.

(c) *Aoba Street Underground Passageway in Sendai*

Sendai is a city in northeastern Japan and has about 980,000 in population. Aoba Street Underground Passageway was constructed with the aim of eliminating traffic congestion

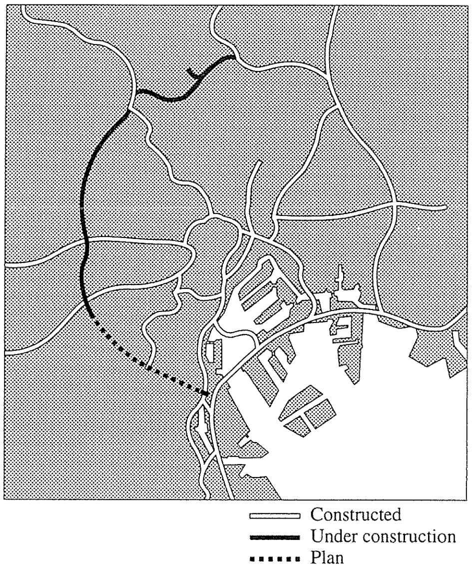


Fig. 3 Metropolitan Expressway.

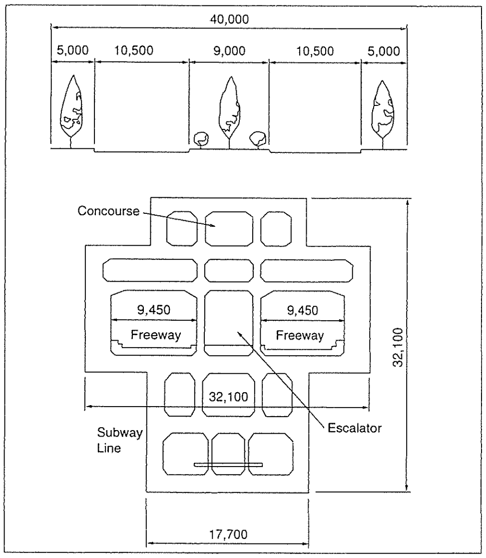


Fig. 4 Cross section of standard underground expressway and subway station.

around the Aoba-Dori Intersection on Aoba Street. The passageway has 1,730 m^2 as a total area. Elevators have been installed for the elderly and the handicapped. The incline alongside the stairways enable the cyclists to use the passageway. A special feature of this passageway is a function for rest place. The "plaza space" has been provided with the benches, the fountains, wall paintings and public telephones. The luminance level in the passageway has been set at 300 lux. that is the same level as standard department store.

(d) *Trans Tokyo Bay Road Underwear Tunnel*

The Trans Tokyo Bay Road is 15 km long highway connecting between Kawasaki and Kisarazu (Fig. 5). Because of extremely important sea traffic in the Tokyo Bay, these parts, about 10 km, at the Kawasaki side is designed as an underwater tunnel. The remaining 5 km at the Kisarazu side is chosen as a bridge structure. The tunnel section and bridge section are connected through the man-made island which has 100 m wide and 650m long, Kisarazu Man-made Island. The tunnel section consists of two tubes. The diameter of external tube is 13.9 m and that of internal tube is 12.6 m. The another man-made island, Kawasaki Man-made Island, is designed at the middle part of the tunnel section for installing ventilation facilities. The island has a donut-shaped structure of which diameter and depth is about 200 m

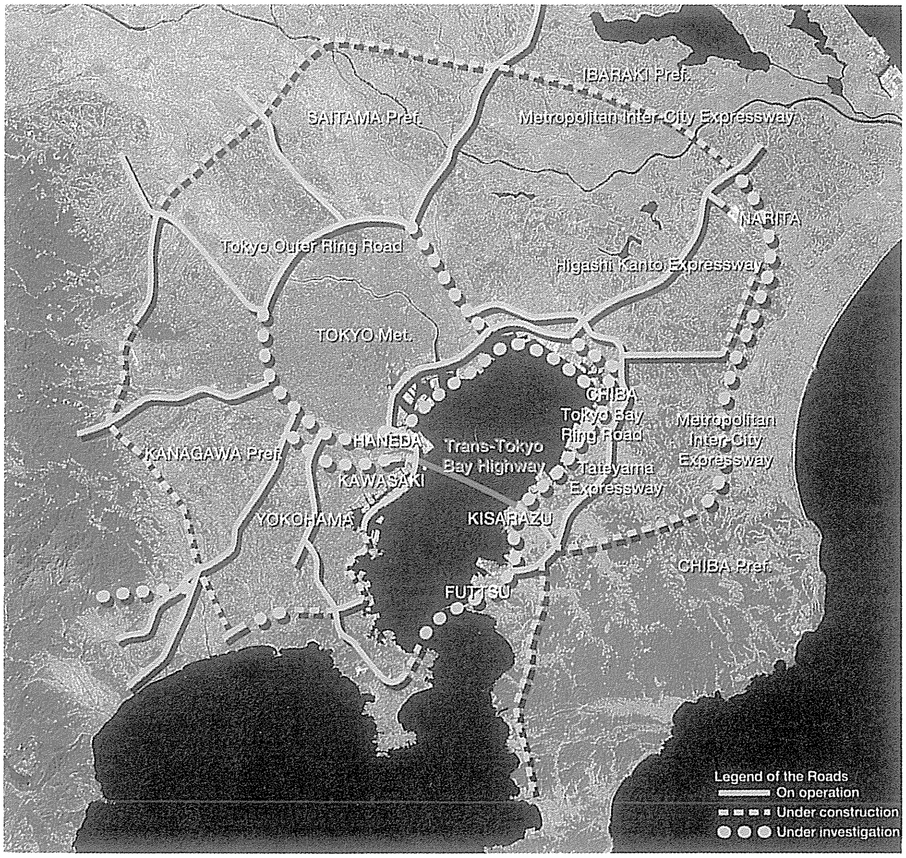


Fig. 5 Road network in the Tokyo metropolitan region.

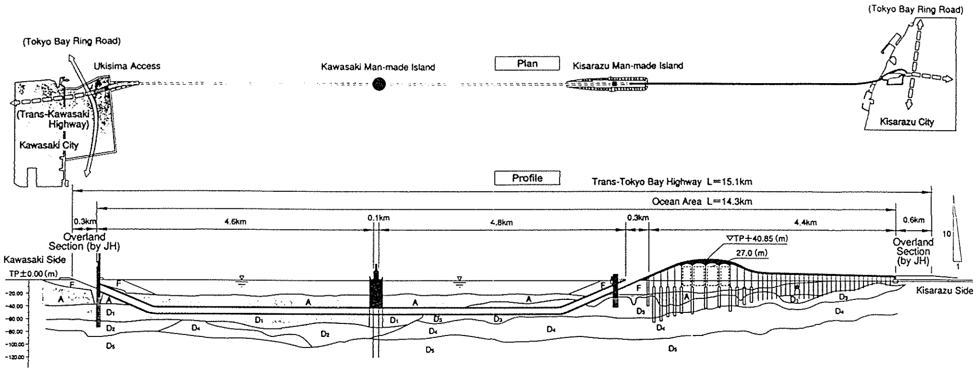


Fig. 6 Overall profile of the Trans Tokyo Bay Road.

and 70 m below the sea level, respectively (Fig. 6). Construction of Trans Tokyo Bay Road commenced in 1990. These constructions will terminate in 1998. The tunnel section was constructed in the soft ground by using shield machine. For these constructions, eight shield machines are employed; two machines are operated on two tunnel entrances. And two other machines are employed in two directions from Kawasaki Man-made Island. At certain intervals, escape tunnels that are constructed perpendicular to the main road tunnels are generally crossed-connected between two-way road tunnels. However, as the tunnel route is in the soft soil or weak mud, two tubes are not crossed-connected. In other words, these tunnels do not have general escape tunnels, because of avoiding difficult construction and insufficient structural strength.

(2) *Utility and Communication Facilities: Yokohama Minato-Mirai 21District*

Yokohama Minato-Mirai 21 District is well known as the area that has Yokohama Museum of Art, Pacifico Yokohama or Pacific Convention Plaza, and Land Mark Tower. They were constructed on the site of a former shipbuilding yard of Mitsubishi Heavy Industries. Ltd. Beside Nihon-maru, a sailing ship, being moored at the dock, there is a semi-underground square (dockyard garden), from the windows of peripheral underground restaurants, one can enjoy an inside view of masonry dock (preserved as monument) constructed during Meiji era.

This project started in 1983 and will be completed in 2000. The project aims at creating a coastal city of 186 ha. The population of the employed in this city is estimated as 190,000. The resident population is expected to be about 10,000 or 3,000 householders. Its land use plan covers 87 ha for a general building site, 42 ha for a highway and railway site and 11 ha for a site of parks and open spaces. Subway system of Minato-Mirai 21 Line connected among Yokohama Station, Motomachi, and Tokyu-Toyoko Line has been decided to construct. The multi-service tunnel containing many kinds of supply pipes to Minato-Mirai 21 District is the largest in Japan. The tunnel contains power cables, communication cables, water pipes, pipes for garbage collecting, gas pipes for medium pressure and regional air-conditioning pipes for chilled water and steam (Fig. 7, 8). Auxiliary facilities include drainage, ventilation, lighting, power receiver and distributor, alarms, security, grounding and monitoring systems.

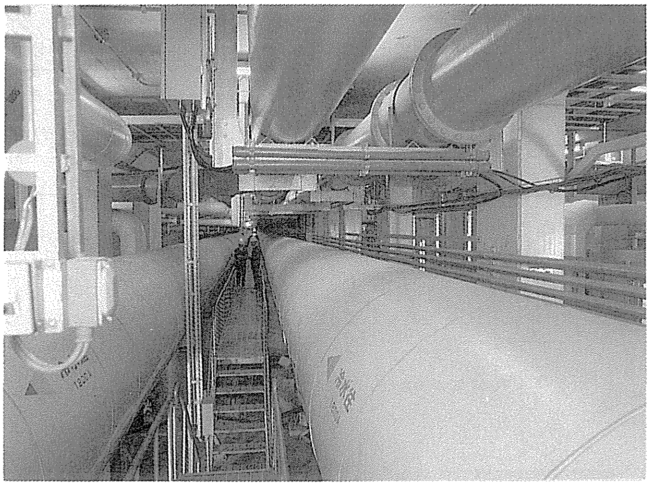


Fig. 7 Multi-service utility tunnel at the Minato-Mirai 21.

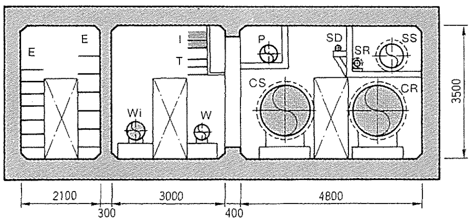


Fig. 8 Standard cross section of utility tunnel at the Minato-Mirai 21.

(3) *Shopping Mall: Diamond Underground Shopping Center in Osaka*

Diamond Underground Shopping Center in Osaka was mainly planned for alleviating traffic congestion by the re-development of Umeda area (Fig. 9). It serves to provide the connection among the existed railway stations and the new stations of Katamachi-Fukushima Line. The shopping center is linking between the surrounding large buildings to convenient for these users of these. It is planed that this shopping mall is extended and then connected to West Umeda in the future. Along with the formation of an expanded network for the facilities, an important consideration was the creation of a safe underground space for 2.5 million passengers who use six railway stations everyday. For this purpose a concept of "regional disaster prevention" is applied and a disaster prevention monitoring system is for the underground shopping center and the surrounding buildings.

The measures taken to ensure safety include the division of the precinct into blocks in order to curb fires within limited area, and an escape guidance system is installed to assist people. The underground shopping center is provided with the latest types of disaster-

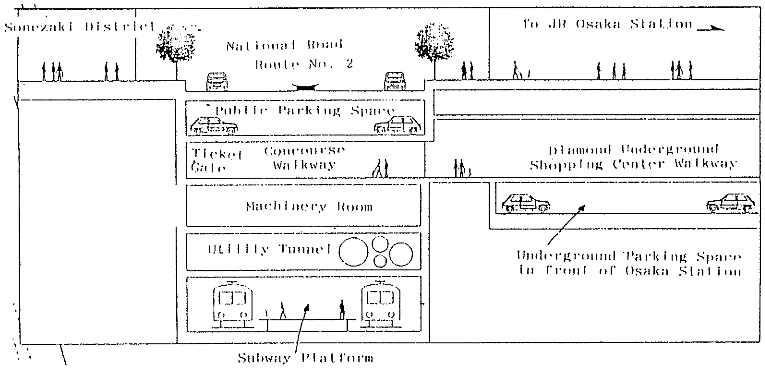


Fig. 9 Cross section of underground facilities in Osaka.

Fig. 10 Photograph of New Diamond Concourse.

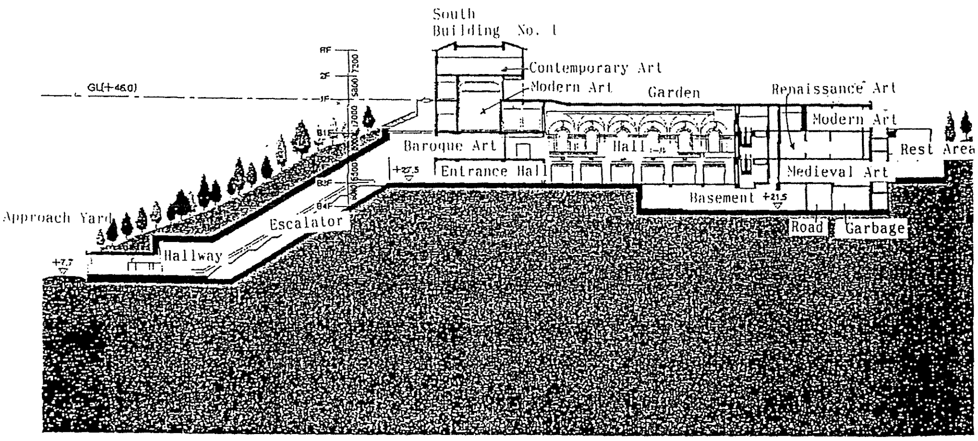


Fig. 11 Cross section of the Otsuka International Art Museum (Source: Pamphlet of Otsuka International Art Museum).

prevention equipment such as flame sensors and large capacity sprinklers. This shopping center was completed in 1995 (Fig. 10).

(4) *Cultural and Recreational Facilities: Otuka International Art Museum*

As the museum is located in a national park, most portions of the buildings had to be constructed underground to obey National Park Laws. The height of the three buildings is 13 m above the ground level (Fig. 11). After completing the construction of these buildings, the areas around the buildings and their rooftops were covered with plants to harmonize with the surrounding natural environment. Ordinarily, the museum exhibits more than 1,000 porcelain replicas of representative of Renaissance and Modern. Contemporary paintings are also exhibited.

(5) *Natural Hazard Prevention Facilities: Underground Floodways*

Since the earliest days, flood control has been a major concern in dealing with nature. Urban flood damage includes the inundation of houses, the flooding and submerging of basements and subway systems, the inundation of highways and the washout of bridges. The flooding of rivers does not only cause great inconvenience but also endanger human life.

Until now, various preventative countermeasures have been taken against flooding such as the dredging of riverbeds, the raising of levee height and the straightening of meandering river courses. However, these things have not proven to be decisive solution.

As far as urban flood damage is concerned, the significance of water circulation as a contributing factor has been neglected. To be more specific, rainwater collected on asphalt or concrete without being absorbed flows into near rivers.

In metropolitan areas, including Tokyo metropolis, the rainfall infiltration area had become increasingly small due to the extensive paving of roads and the spread of sewerage works with the advice of urbanization. A sudden inflow of storm water often makes a water level of river raise instantaneously and extraordinarily.

To deal with such urban flooding, Tokyo Metropolitan Government reviewed the "75 mm plan" for 4 rivers within Yamanote basin. In this situation, it was necessary to construct a large-scale underground floodway beneath National Road Loop 7 and 8 to serve as a regulating reservoir and drainage channel aiming at flood control (Fig. 12). Here, "75 mm plan" means a disposal plan for perception of 75 mm per hour. Tokyo Metropolitan Government has developed a future flood control plan with setting target value as precipitation of 100 mm per hour. "75 mm plan" was reviewed as the next step for the established "50 mm plan". The construction for this underground floodway was selected as an alternative plane based on the judgement that modification or an excitation of the existing rivers within the basin would change difficult. Storage and drainage functions are expected of the floodway after its completion. As the first phase of this work, excavation is being carried out at about 40 m in depth (Fig. 13). This site is located beneath National Road Loop No.7 adjacent to the Kanda River. The storage capacity of the floodway for the first phase is as large as 240,000 m^2, and its inner diameter is 12.5 m. A future underground floodway which may have 30 km in length will discharge the water from a number of rivers into Tokyo Bay. Upon completion, the underground floodway will allow the receiving rainwater from various rivers at different times, as well as perform its storage function. Prior to completion, the floodway is expected to a function as a regulating reservoir to contribute toward the flood control.

(6) *Energy Facilities*

(a) *Underground Hydroelectric Power Station*

Hydroelectric power generation in Japan is important because it utilizes river water

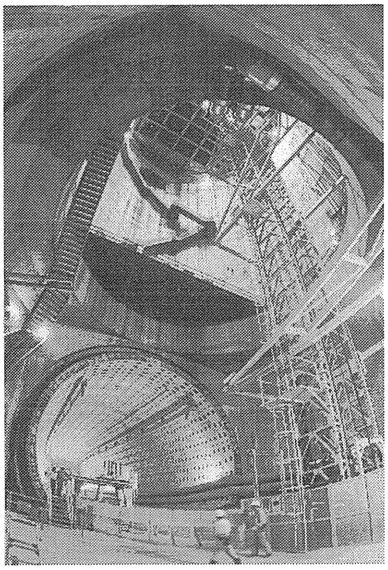


Fig. 12 Photograph of vertical shaft and floodway tunnel (Source: Tokyo Metropolitan Government Office).

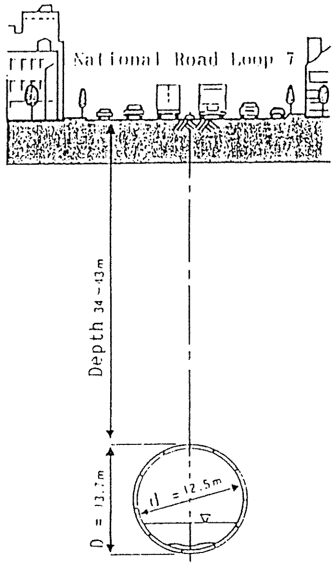


Fig. 13 Typical cross section (Source: Tokyo Metropolitan Government Office).

within the country as an energy source. These facilities oppose to thermal power generation that depends on petroleum energy imported from overseas. Japan has many mountains and dam sites are located between steep mountains or in the area of national parks. Hydroelectric power plants are usually constructed underground in such cases. The first underground hydroelectric power plant in Japan was the Uryu Power Plant (Hokkaido Electric Power Co.) which was put into operation in 1943. Since then, approximately 50 underground power plants have been constructed. Most large-scale underground power plants are pumped-storage plants, which aims to balance the demand of electricity between nighttime and daytime. This consuming unbalance has been a problem since 1960s. The pumped-storage plant generates the electric energy for peak demand in the daytime utilizing reversible pump-turbines as a generator by the water head gap between an upper reservoir and a lower reservoir. On the other hands, water is pumped up from the lower reservoir to the upper reservoir by using the pump-turbines as the pump during the nighttime or holidays. The powerhouse is settled underground because the pump-turbines should be located lower than the water level of the lower reservoir. Constructing a powerhouse in the underground greatly contributes to the environmental conservation and protects the powerhouse against natural disasters such as snow damage and rock fall. As there is a tendency that turbines and generators become larger recently, the scale of underground power plants have consequently increased with caverns. This section will reach to 1,500 m^2. Japan, unlike Europe and North America, is a mountainous country with many volcanic zones formed by the orogeny of the Pacific Plate. In this reason, faults, joints and complicated strata make it difficult to design and construct underground power plants. For this reason, much effort has been made in the research and development of technology of the monitoring and controlling system. These concern the stress and behaviour of the rock mass during construction such as the geological investigations which

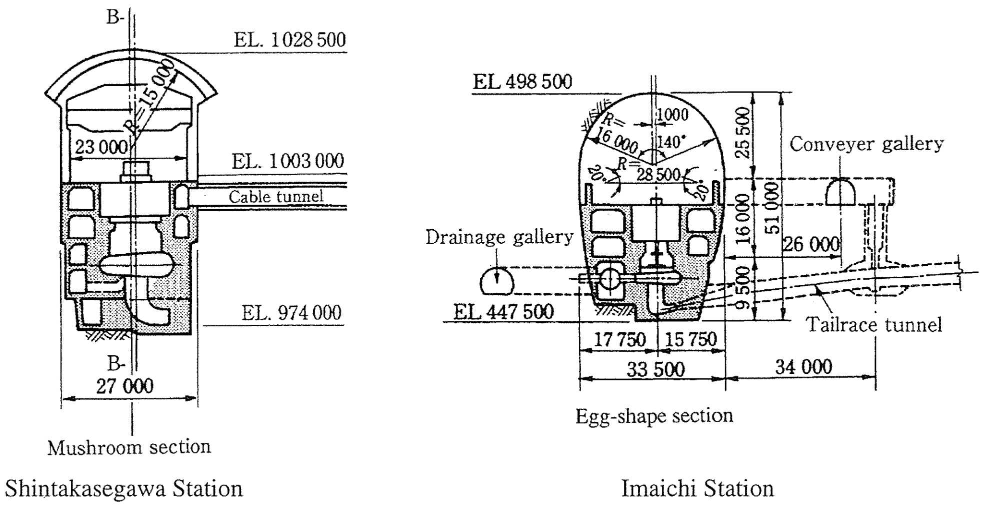


Fig. 14 Typical cross section of underground hydropower station[12).]

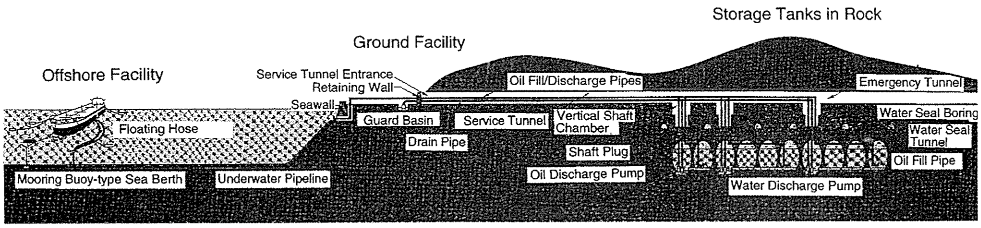
includes tests and analyses aided by computers. And the support system which employs prestressed anchor or concrete lining is also studied. The sectional shapes for powerhouse are mainly categorized into two groups. One is mushroom shape; a thick arch-shaped concrete roof is attached with sidewalls. Another is egg-shaped; a thin arch-shaped roof continues to the sidewalls keeping gently curve. These shapes are selected according to the geological condition (Fig. 14).

(b) *Underground Petroleum Storage Facility*

Japan must storage petroleum as a main fuel because fossil fuel is not buried sufficiently and enormous value of fuel is needed to maintain present life in Japan. In this situation, petroleum shortages occurred twice because of Middle East War in 1973. As a result of these shortages, storage of natural resources such as petroleum and LPG was officially discussed with referring the examples of other countries. Eventually, the underground storage method is chosen from several storage methods founded in the studies. Although semi-underground fuel oil storage tanks were constructed as the military facilities at the beginning of the 20th century, they were not full-scale types in the Western Europe. For this reason, technology for underground storage of petroleum was extensively introduced from Western Europe. In 1979, a project involving the first field test plant of an underground rock cavern for storing crude oil was started at Kikuma, Ehime Prefecture, Japan (Fig. 15). The data obtained during the project verified the safety and the effects of using the underground storage method. In this site, the water seal technique in which groundwater pressure prevents oil or gas leakage from a lightly shore cavern excavated below the underground water level is employed. As a result of findings, the construction of full-scale plants began.

(c) *Underground Liquefied Gas Storage Facilities*

A large quantity of liquefied natural gas (LNG) and liquefied propane gas (LPG) is used for domestic heating in Japan. As a result of the recent progress of technology and in consideration of safety and the aesthetic viewpoint, greater emphasis has been placed on the



Storage Tunnel Height: 22m, Width: 18m, Length: 540m, Total 10 storage Tunnels

Fig. 15 Sketch of underground petroleum storage facility in Kuji, Iwate Prefecture (Source: Pamphlet of underground petroleum facility, Japan Underground Petroleum Storage Co. Ltd.).

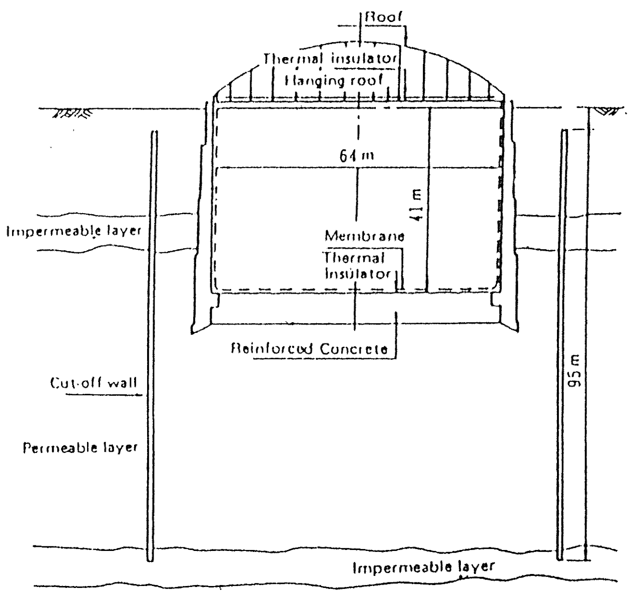


Fig. 16 Typical cross section of underground liquified gas storage tank.

construction of large-scale underground tanks rather than conventional aboveground tanks. A LNG storage tank is the subject of constraints relating to structural design and the materials used in the construction and requires advanced construction technology after LNG is stored as cryogenic liquid at −162°C. In Japan, the size of underground tanks being constructed is increasing yearly. And then, recently, the inner diameter of tank reach as large as 68 m and 55 m in depth of stored liquid. This kind of tank can store 200,000 m^3 of LNG. The construction method is selected according to the prevailing geological conditions. If the ground does not so strong, the tank body is constructed after setting the diaphragm walls that have about 100 m in height for cutting off underground water. On the other hands, if the ground is relatively solid and there is not enough working space, at first, the diaphragm walls should be constructed. And then, the earth retaining processes by using rock bolts and concrete lining is constructed. Finally the tank body should be constructed (Fig. 16).

(7) *Research Facilities: Research of Elementary Particles in a Deep Underground Space*

An abandoned mine has been used in an extraordinary research project and breakthrough in physics is expected. An elementary particles research facility, the Super Kamiokande, was built in an abandoned copper mine to observe the neutrinos and subatomic particles (Fig. 17). University of Tokyo mainly organized this research project. The Super Kamiokande is the largest facilities for observing the subatomic particles in the world. An element is a substance composed of atoms. Each atom consists of many kinds of subatomic particle. The subatomic particles or elementary particles are small packets of matter-energy which are the constituent of atoms are produced in the nuclear reactions or in the interactions among subatomic particles. Subatomic particles are found in cosmic rays or are detected under using particle accelerators. Neutrinos, it is presently believed that the rest mass is equal to zero, are subatomic particles and are produced in various decay processes of the sun and in the explosion of stars. They can easily penetrate through the Earth. In this occasion, it is very important to recognize whether the neutrino has rest mass or not. This conclusion may dedicate to conclude an argument of the universe expanding assumption. Through the report about observing a series of subatomic particle at the Super Kamiokande, this argument may be concluded soon. A tank that had 39 m as the diameter and 41 m as the depth was built in an underground space of the abandoned Kamio Mine in Gifu Prefecture. This tank was settled in about 1,000 m below. The interior of this tank wall was equipped with 11,200 photomultipilers or light sensor tubes. After terminating of the tank construction, the tank was filled with 50,000 tons of pure water. The underground research facility was completed in March 1996. And then, the observation of subatomic particles started in April 1996. At the

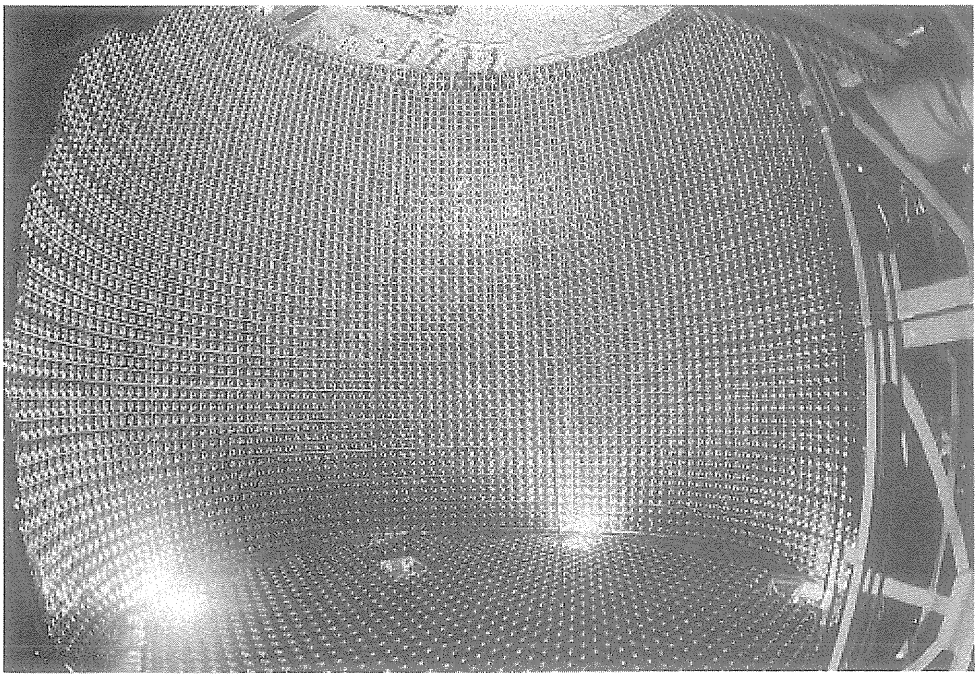


Fig. 17 Inner view of observation facility for the neutrinos, Super Kamiokande (Source: the home page of Super Kamiokande, University of Tokyo).

High Energy Physical Institute which belongs to the Ministry of Education in Tsukuba Science City and is located about 250 km away from the Super Kamiokande, Neutrino particles are emitted at 1° downward direction from the horizontal line to the observation tank of the Super Kamiokande. The experiment has been conducted by about 100-physicists for 24 hours in a day. About 30 neutrinos are observed in each day at the Super Kamiokande. World physicists are paying attention to the research project. Physicists believe that the experiment for observing this kind of neutrino is only able to carry out in a deep underground space because of neglecting the other needless rays.

5. Safety and Safety Measures for Underground Space Use

(1) *Introduction*

The characteristics of underground spaces are quite different from those of aboveground. In view of safety, particular attention must be placed on the planning, the design, the construction, the maintenance and the operation of underground space facilities for the reason as follows:

a) Underground causes people to feel oppressive.
b) Underground spaces cause people to feel isolated from life on the aboveground.
c) The average citizen does not have sufficient knowledge about the safety of underground structure.
d) As many people use an underground malls and walkways, there is a possibility about occurrence of mass hysteria during a power failure, a fire or an earthquake.
e) As an underground shopping mall is normally owned by a number of independent business people, the operation and maintenance system of the underground space is complex.
f) People are fearful about filling up heat, smoke and toxic gases when a fire breaks out.
g) Directions for evacuation and the number of emergency exits are limited in an underground space.
h) As a condition of underground facility cannot be accumulated directly from an aboveground, it is difficult to conduct rescues and fire extinguishment operations from the aboveground.
i) It is very difficult to restore or rebuild underground facilities, if once fire or any other type of disasters gives the damage there.

Human beings have primarily lived aboveground level since the time of their creation. In modern societies, people feel psychologically insecure upon entering an underground space. Most important point for constructing underground is not only structurally strong but also safe and comfortable from psychological viewpoint. Safety measures for underground space use can be classified into two categories:

a) Safety measures for underground space use under normal use conditions,
b) Safety measures for underground space use under emergency conditions.

The first category includes such structural requirements as minimum value for width, slope and ceiling height of walkway and necessary facilities for safe and comfortable use of underground spaces. This category also includes the lighting installation, signboard installation, ventilation systems and sanitary facilities. The second category includes various measurements against a natural disaster and a disaster caused by human. Natural and artificial disasters which should be considered with designing underground facilities are earthquakes, floods, fires and explosions. Especially, the earthquake must be considered in Japan. But, the most serious disaster is a fire. Fires followed by large earthquakes such as San Francisco Earthquake in 1923, Loma Prieta Earthquake in 1993 and the Great Hanshin Earthquake in 1995 cause the serious damage.

(2) *Safety and Safety Measures against Fires*

Here, the safety standards for underground space utilization which are most important for planning an underground shopping spaces are introduced.

In Japan, strict building codes and fire prevention laws have been imposed on the underground facilities. In spite of the severe safety requirements against fires in the past, several tragedies of fires in underground spaces occurred in Japan. In 1970, when a construction worker started a car engine at the subway construction site in Osaka, leaked gas within a tunnel ignited and exploded. And then, steel desk plates of which each weight was 400 kg were blown away from the excavated subway route by the explosion. After that, the flame of burning gas became strong. According to this fire, 78 people died and 465 were injured. And then, 65 houses were damaged and 26 were destroyed. Similar type of this fire hazard occurred at a subway construction site in Seoul, Korea in 1994. In 1972, a fire broke out on an express train while it was passing through a tunnel in Fukui Prefecture that was 13.9 km long. Unfortunately, the train came to a stop in the middle of the tunnel. The train conductors failed to extinguish the fire and a large quantity of smoke filled the tunnel. Passengers panicked and rushed from the train. 30 persons died by burns and suffocation. 66 persons were heavily injured. This fire caused by the failure of an electric heater located beneath a seat. In 1980, when a waitress of an underground mall restaurant in Shizuoka prefecture struck a match to light a fire under a hot water maker, a small gas explosion took place. The explosion blow from a metal shutter of a store. The shutter severed a pipe for gas supply. After that, petroleum gas leaked. When the inspectors of the gas company and firemen were checking the gas pipe after the first explosion about 30 minutes later, leaked gas, which was accumulated above the ceiling of the underground space, exploded. The second explosion was much stronger than previous one. 15 persons died and 222 persons were injured (Fig. 18). It should be pointed out that the leakage gas filled the dead space of underground space and this gas exploded. By taking into the past fire and gas explosion tragedies, the building codes and the fire prevention laws were revised and became much strict. According to the present code laws, underground facilities must comply with the following regulations:

a) Major structures of underground facilities must be made fireproof.
b) Each facilities unit such as a store or restaurant should be separated from other units by fireproof walls, floors and the Class "A" fire-resist doors. Fire resistant doors are classified into either Class "A" or Class "B" through the Japanese Architectural Standard Specification. The doors of Class "A" must have better capacity of resistance against fire than that of Class "B". Class "A" doors may consist ether steel frame plated with steel sheets which is thicker than 0.5 mm and steel plates which is thicker than 1.5 cm or reinforced concrete which is thicker than 3.5 cm.
c) Each facility unit should be divided into floor space portions less than 500 m^2 by fireproof walls, fireproof ceiling and floor materials or floor space portions less than 200 m^2 by fireproof walls and fireproof or semi-fireproof ceiling and floor materials. If a sprinkler system such as fog fire extinguishing system or foam fire extinguishing system is installed this regulation is eased to 1,000 m^2 vice 500 m^2, and 400 m^2 vice 200 m^2, respectively.
d) The clearances around any piping penetrating a fireproof wall, ceiling or floor must be sealed with cement mortal.
e) If a ventilation duct penetrates a fireproof wall, ceiling or floor, a fireproof damper must be installed at the point of penetration.

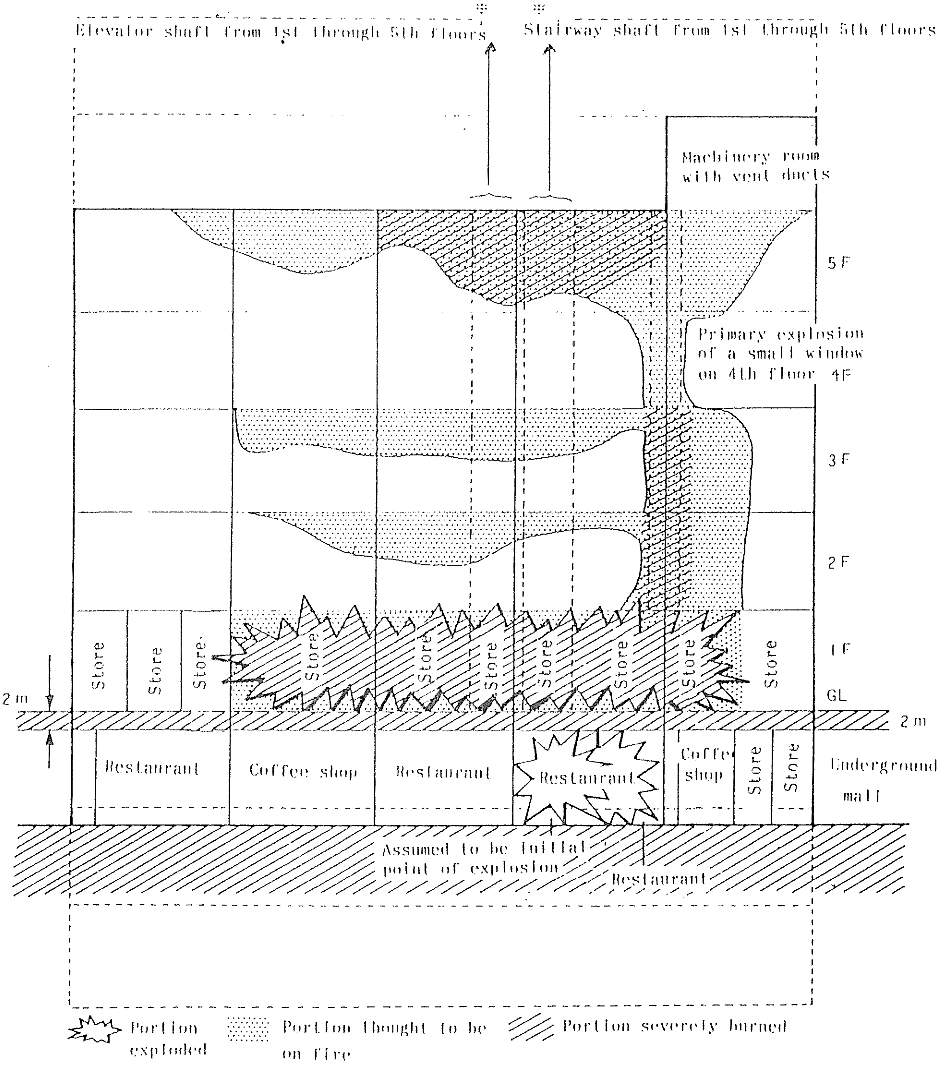


Fig. 18 Sketch of gas explosion and fire spread in the Golden Underground Mall and Daiichi Building in the Shizuoka Prefecture (Source: Urban Underground Space Utilization Research No.11, Oct. 1990).

To provide sufficient evacuation ways in the emergency events, each underground facility unit such as single store, restaurant, office and walkway must satisfy the following requirements:

a) In each unit length, more than 2 m, these facilities must face to underground walkway.
b) The distance from any portions of facility unit and an underground facility unit and an underground walkway, which leads to aboveground, must be less than 30 m.
c) A walkway must be more than 5 m wide and 3 m high. The walkway slope must be less than 12.5%, In other words, 1 on 8 slope.

In addition to the above structural requirements, the following fire safety systems must be installed in a public area of using underground space:

a) Sufficient number of fire extinguishing units must be installed.
b) Fireplugs must be installed in a space having more than 150 m^2 as a floor area.
c) An emergency announcing system must be installed.
d) An automatic fire alarm system must be installed in a space having more than 1,000 m^2 as a floor area.
e) A sprinkler system must be installed.
f) An automatic gas leakage alarm system must be installed.
g) Emergency lamps must be installed at the following positions: evacuation exits, evacuation ways, any exits connected to the aboveground level, stairways, hallways and vestibules.
h) A smoke exhaust system must be installed in a space having more than 1,000 m^2 as a floor area.
i) A cross connection of piping system for fire fighting water supply must be installed in a space having more than 1,000 m^2 as a floor area.
j) A wireless communication system must be installed in a space having more than 1,000 m^2 as a floor space.
k) Smoke barrier walls which are more than 80 cm deep must be installed to divide ceiling areas into the sections of which area is less than 300 m^2.

In addition to the physical requirements for underground facilities, what takes into a consideration to the past fires and gas explosion tragedies has enforced the following rules for fire prevention has been enforced:

a) If an underground facility unit accommodates more than 30 people, fire management chief for the unit must be selected.
b) The selected management chiefs in an underground space must form a group to establish the cooperative rules for fire fighting.
c) The group of selected chief must prepare the fire-fighting plan for the underground space. According to the plan, it must provide workers in the space with the education for a fire safety. The group must also provide a fire fighting drills and manage the equipment for fire fighting in the underground space.
d) A disaster prevention center must be established in each underground space having more than 1,000 m^2 as a floor area. It operates the fire extinguishing systems, evacuation systems, smoke exhausting systems, heating ventilation, air conditioning systems and power control systems. The various monitoring and alarm systems must be conducted by the center. This center is also responsible for issuing the evacuation and fire fighting orders as well as dispatching the fire fighters. Enforcing the very strict safety measures described above, no serious fire in the underground space occurred after the gas explosion in Sizuoka Prefecture in 1980.

(3) *Safety and Safety Measures against Earthquakes*

It is believed that underground facilities are safer than aboveground facilities against the earthquake. As a matter of fact, it is reported that seismic forces observed in an alluvial strata ground at about 10 m below from the ground surface were less than one half of those observed on the ground surface during the same earthquake. In the rock ground, seismic forces observed at 200 m below the ground surface were less than one half of those observed on the ground surface during an earthquake.

Although seismic forces acting on an underground structures are not as powerful as those acting on aboveground structures, it is important to prepare the safety measures against secondary disasters caused by falling objects, smoke and the clogging objects for evacuation and rescue ways. Great Hanshin Earthquake that had the magnitude as 7.2 hit Kobe area at 5:46 AM on January 17, 1995. Its hypocenter was located just below Awaji Island. The movement of a fault that ran through Awaji Island to Kobe caused this quake. The Meteorological Agency announced that the earthquake intensities at Sannomiya where was business district of Kobe City and the North part of Awaji Island. These disasters were classified into the 7th earthquake intensity, the highest record in Japan. Many buildings, highways, railways, bridges and other structures were destroyed instantly. More than 350 fires broke out. About 100 ha of the area where had a dense population in Kobe was wiped out. Major casualties until the end of May, 1995, included that 5,504 people died, were 41,500. And, 340,000 homes were destroyed or damaged. For long time, it was believed that the underground structures would be safe against the earthquakes. In the Great Hanshin Earthquake, however, three subway stations, Daikai, Sannomiya and Kamisawa, were severely damaged. In particular, Daikai station was most damaged. The station of which the structure was a reinforced concrete and had two levels of underground was built by the cut-and-cover construction method in 1964. In this station, the rectangular-shaped columns that supported the main concourse on the first underground level, which was 70 cm in width, 40 cm in depth and 2.6 m in height, were destroyed (Fig. 19). Several columns on the same level were also damaged: these concrete part spalled and reinforce steel bars were exposed. A horizontal crack appeared in the wall on the first underground level. And the mortar at dressing state on the wall fell here and there. On the second underground level, 25 reinforced columns of which dimension is 100 cm in width, 40 cm in depth and 4 m in height were completely destroyed. The concrete of column was crushed and reinforce steel bars were exposed. The hoop ties were cut off.

Due to the failure of the concrete columns, the road where was just above the station

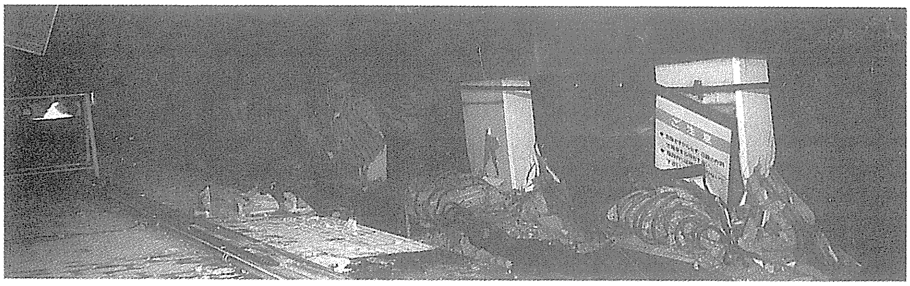


Fig. 19 Main concourse on the first underground level of the Daikai Station.

Fig. 20 Sunken Road above the Daikai Station.

sunk about 3 m at the deepest point in the subsidence area about 30 m wide and 100 m long (Fig. 20). Large cracks appeared in the round surface. Sannomiya subway station, which had three underground levels, was built as a reinforced concrete structure in 1985 by the cut-and-cover construction method. Caused by the Great Hanshin Earthquake, about 30 reinforced concrete columns which were set on the first and second underground level were damaged. Many parts of concrete partially spalled off exposing columns which is 55 cm and 65 cm diameter in the station were not damaged. Osawa station, which had two underground levels, was built as the reinforced concrete by the cut-and-cover construction. The damage type and degree caused by this earthquake in the underground space were almost similar to those sustained at the Sannomiya subway station. The Daikai and Kamisawa stations which were located approximately 4 km west from the downtown in Kobe, Sannomiya District, got most severely damaged. As the columns supporting the structure of underground station were heavily damaged, these needed 11 months to repair completely. The following aspects were pointed out

a) Although the vicinity of the buildings, which had same structure of the damaged station, was also damaged, these damages were not so serious.
b) These stations which have severely damages were located on a north-south line.

According to old geological records, Minato River had flowed on the location where the station was constructed. The river is presently diverted to a man-made channel. The station buildings were built on a formation of sediment deposit on the old river channel. Prior to constructing the station buildings, geological surveys were conducted. But, the magnitude of the earthquake and the degree of damage at the buildings were beyond the expectation involved surveys. There are several large underground shopping malls in Kobe. Although serious damage was inflicted on the aboveground buildings at these vicinity, only negligible damage was reported by the underground shopping malls. In Sanchika Shopping Mall, reported damages consisted of several number of broken windowpanes and a little number of falling the dressing panels on the entrance walls. No structural damage to underground parking facilities was reported. There are two large utility tunnels in Kobe. One has about 1 km long and its diameter of cross section is 5 m. It was constructed at 10 m to 20 m deep by using the shield tunneling method to deliver the electricity, supply the water and be through the telephone cables. The other tunnel is about 6 km long and has its diameter of cross section is 4 m. This tunnel was constructed at 10 m to 20 m deep by the shield tunneling method for telephone cables. Although aboveground structures, such as bridge piers and buildings near the utility tunnels were seriously damaged, in opposite, the utility tunnel had no serious structural damage. Some small cracks, however, occurred at the tunnel entrances that allowed the groundwater to enter through the cracks into the tunnel less than 10 to 20 liters/min. However, the rubber seals at the expansion joints between solid parts of tunnel were damaged at certain level. Some cracks, spalling concrete lining and exposure of some reinforce bars, were found at the sections where the earthquake fault pass in the mountain tunnels. But, the damage level was not so serious. As mentioned above, some underground structures were severely damaged by the Great Hanshin Earthquake. But, comparison with the damage level of the structures at aboveground, the damage was extremely small. It may prove the general sense that the underground structures are safer than the aboveground structures against the earthquake.

(4) *Power Supply System in Underground Spaces*

Electricity, gas and water supply are extremely important for the underground space utilization. Power supply to an underground space is described as followings. A power failure occurring in an underground space during a fire or an earthquake may cause people to a panic. Thus, it is essential that underground spaces must be provided with reliable power supply. Japan is divided into ten power supply zones that are managed by ten large electric companies. Each company controls one power supply zone. The power supply zone is crossed-connected with the other power supply zones to allow the power transmission from the neighboring zones. The electric companies have multiple power generating plants that can provide the sufficient electricity to their individual power supply zones. The underground spaces for public use are equipped with three steps of fail-prevent system for power failure. An underground space of a floor area which have more than 1,000 m^2 must be equipped with an independent emergency power generator at a plant provided by a management body of each underground space. If the power supply provided from the outside is shut down, the emergency power generating plant automatically will start and will reach to apparently electric capacity within 60 seconds. This sub-power supporting system at an emergency state should work sufficiently and supply electric power, at least, for an hour. The power plant should be capable of one sixth lightening against total lightening system in the underground space. Sufficient power, of course, should be supplied to operate the emergency systems such as the fireplugs, the sprinkler systems, the fire and/or smoke prevention shutters and the smoke exhausting funs. Once the emergency power generating plant shuts down, the lightening of underground space will immediately be restored by a battery operated system. Each store will be illuminated by the incandescent lamps of 40 watt. Walkway will be illuminated by the fluorescent lamps of 20 watt. The batteries must be able to provide the electric power for more than an hour. If the battery system fails, the fluorescent lamps for evacuation guide which is equipped with a nickel-cadmium batteries will immediately light up. This lightening will be provided for about 20 minutes.

(5) *Evacuation and Fire Fighting System: Undersea Tunnel of Trans Tokyo Bay Road*

The cross section of Tokyo Bay Undersea Tunnel has three open spaces underneath the road floor. After many discussions among academic people and engineers who had consider to the projects, it was decided upon to utilize the largest open space as an emergency evacuation way. As this type of evacuation way which had only 2.75 m high and 3.65 m wide in the largest space had never been constructed, the study committee which consisted of the scholars, engineers and rescue specialist was established to conduct further studies concerning the safety the evacuation way. A full-size tube model was built and rescue operation tests were conducted. As a result, the safety of the evacuation way was designed not only for the evacuating people but also for the emergency vehicles to pass when a rescue or fire fighting team is unable to reach an accident or fire site via the above road level. When people can not evacuate the road level at the ground from an accident or fire site, they can slide down from the road level into the evacuation way through an emergency exit according to voice information introduced automatically by the operated tape recorder. Then, the evacuating people are guided safely either Kawasaki side or Kisarazu side. When a rescue or fire fighting team can not reach an accident or fire site on the road level, they will approach the site through the evacuation way by a special vehicle and will go up to the road level via a rescue stairway at that time. The emergency exits (Fig. 21), evacuation slip way and rescue/fire-fighting stairway are to be installed at each 300 m according to the same rules for cross-connection tunnels. Traffic conditions on the road level within the tunnel are monitored at the monitoring station near each side of the tunnel entrances. Once an accident or fire occurs within the tunnel, its condition is observed at monitoring station. And then an appropriate route to the accident or fire site, either through the road level or evacuation way will be decided upon immediately and a rescue or fire fighting team will be dispatched to the site. Two fire stations, which are located at each tunnel entrance, will be built. It is planned to keep special rescue and/or fire fighting vehicles at each station and on Kawasaki man-made island. The vehicles are designed for using in the evacuation way that is 3.65 m wide and 2.75 m high. The

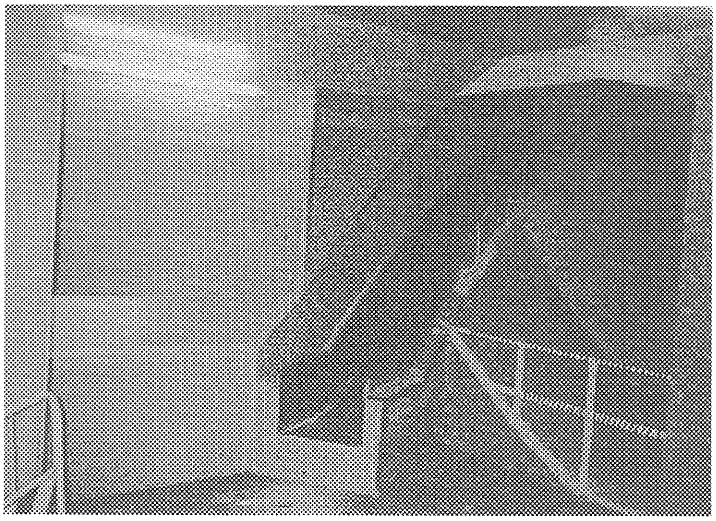


Fig. 21 Evacuation slide way[30].

vehicles can go into the evacuation way through the sloped ramp, which is built at each tunnel entrance. In addition, it is planned to install a large elevator on the Kawasaki man-made island which is capable of moving a rescue vehicle from the ground level on the island to the road level of the tunnel where is located 58 m below the sea surface. Ventilation in the road tunnel will be accomplished by using jet fans and fan units with electrical dust collectors. Their instruments are installed at the ventilation stations. To prevent the inflow of high temperature air and smoke into the road level, the ventilation in the evacuation way will be accomplished by using of an independent system that can maintain higher air pressure than the system in the road level. As Tokyo Bay Underground Tunnel is quite long, it is planned to set up a support system of rescue/fire fighting activities in the tunnel. A helicopter port and a small craft pier will be built on each man-made island.

6. Problems Relating to Underground Space Use

A wide variety of underground facilities have been constructed in Japan. Each facility was carefully planned and built. But, from the viewpoint of comprehensive urban planning, various problems have to be solved for the further development of underground space use. Problems, which relate to the existing of the underground facilities, should be clarified and the solutions against them sought for better use of underground space. Main existing problems and their proposed solutions are as follows:

(1) *Necessity Plan for Comprehensive Development*

In large cities, subway systems, underground parking spaces, walkways and shopping malls have been constructed on a "first come, first served basis". Tokyo, in particular, has many subway lines that were constructed on the first served basis. Each of these very intricate lines was constructed independently (Fig. 22). Further subway construction within a city should be conducted in a manner based orderly on a comprehensive development plan which covers not only single subway lines but also entire subway systems. To prepare a comprehensive development plan that would satisfy every company operating a subway would be difficult task. But, to construct the safely and reliably convenient subway systems for public use, the plan is necessary even if it takes a long time to prepare. Most underground facilities in the city areas are for public use. Once these are built, they are difficult to replace. During a rebuilding period, the general public would be inconvenienced and the environmental problems might be created. Thus, a constructing plan for underground facility should be carefully prepared by taking into consideration to the maintenance problems, the environmental problems, the future social changes and possibilities of natural disasters. Once the underground facilities are constructed, they will be a function of the aboveground facilities. Therefore, their design should be planned in the relation to aboveground. A plan for underground facility should be prepared together with the urban planning. A three-dimensional approach is needed to contrive a modern urban planning. Osaka and Kobe, for instance, have already prepared the guidelines for an approach of three-dimensional urban development. Other large cities are in the process of preparing the guidelines.

(2) *Cooperation between Public and Private Sectors and Citizen Participation*

Underground facilities for public use are mainly constructed on public lands and are based on the public finance. On the other hands, underground facilities, which are owned privately, are independently constructed on the private or leased lands and are, in general, based on the private finance. As a result, the types and size of underground facilities owned

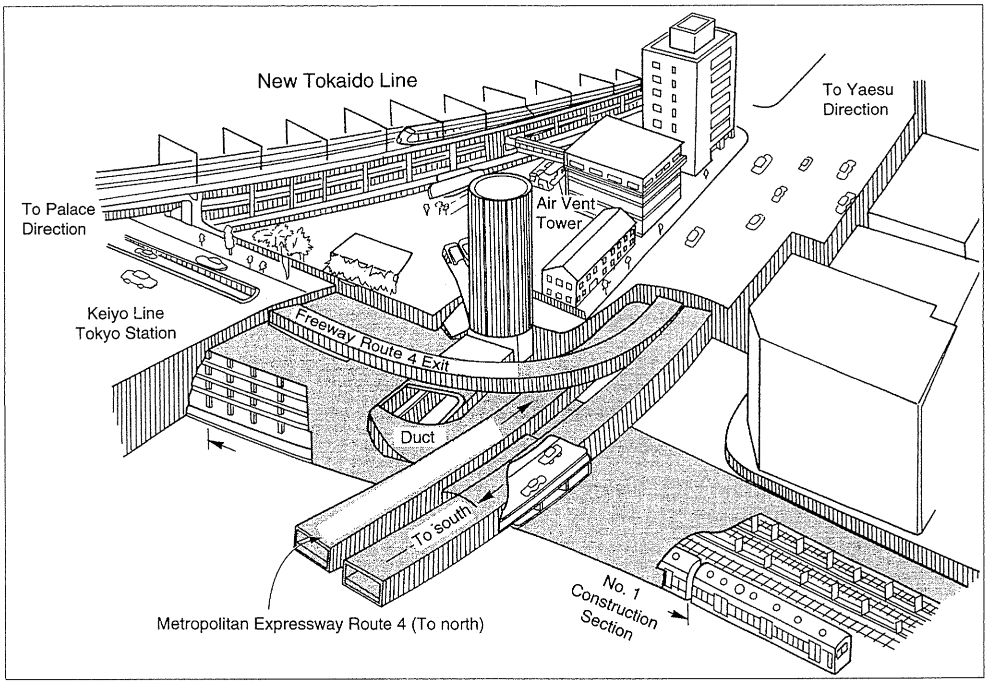


Fig. 22 Intricate underground facilities near the Keiyo Line, Tokyo Station[23].

privately are limited by the financial status of owners and business needs. Even if the demand for certain underground facilities was high, they may not be built unless they are feasible for business purposes. It may be possible, however, to construct such an underground facilities by sharing construction costs with the facilities of public use or those of other private use. With cooperation from the public and private sectors, public facilities may be constructed underground on the land owned privately or private facilities may be built underground on public land. Further, by re-arranging land owned privately and publicly, purposes of new large-scale facilities for using publicly and purpose for privately may be developed under a single project. By locating as many facilities as possible in an apparent underground space, the aboveground space can be utilized either as an open space or a park to enhance the urban environment. It would not be a simple matter to formulate such a project for developing underground space. But, to agree on the public demands and enhance urban environment, public and private sectors should cooperate in creating safe and comfortable facilities in large cities. Most underground facilities are intended for public use. They should be easy to use by the general public. Furthermore, they should satisfy the desires of the general public. Those underground facilities should be planned and desired not only from the viewpoint of the project implementor but also from the viewpoint of the facility users. The rural city center of the idealistic future is in mixed private area with public area (Fig. 23). These have about 400 m by 400 m. One block is about 100 m by 100 m and the width of the main road is in the range from 30 m to 50 m. Thus, the city center will have 3 blocks in each direction. Public and private land should be combined and developed for comprehensively mixed-use purposes of vertical direction about 400 m. Aboveground part is about 300 m and underground part is about 100 m.

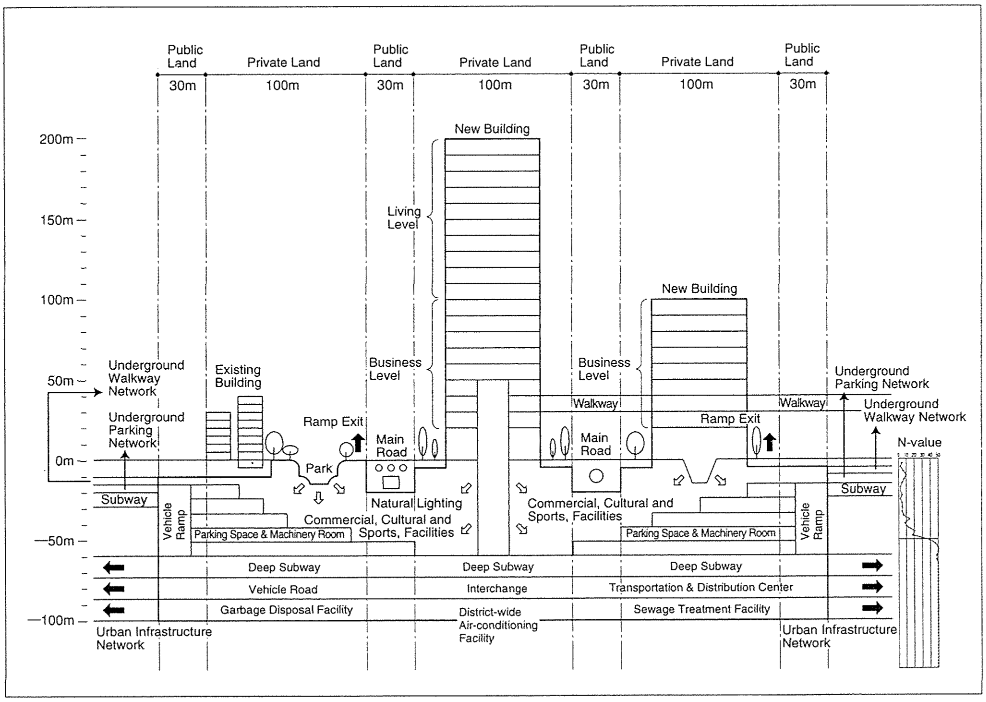


Fig. 23 Sketch of an idealistic future rural city center (Source: Hirai, T. (1991) "Is it possible to urbanize the underground?", Kashima Syuppan, pp.106).

(3) *Improvement of Condition in Underground Space*

Although many people use underground facilities in Japan, major opinion of users has formed a negative image of underground space. Some of them caused that an underground space is believed to be unsafe. When walking in an underground space, it may remained people of the accident at a serious mine cave in the past or the tragic gas explosion. People feel these situations uncomfortable. In general, underground spaces impress people dark, confine, humid, stuffy and hard to escape in case of emergency. In general, Japanese urban planning had been made by strong emphasis of the economic performance and efficiency. However, it is not emphasis on human nature such as feeling and aesthetic aspects. The percentage of persons who are 65 years old and over against total population is called the aging rate. When the aging rate exceeds 7.0% in a country, this country is called in an aged society. In this point, Japan entered into an aged society in 1970. Comparison with other industrialized countries, although Japan entered into the aged society relatively late, the aging rate increases rapidly. This situation has never experienced in any countries. Furthermore, it is predicted that the aging rate will get to about 25% by 2025 and high rate will continue until 2050. It is reported that the aging rate in other Asian countries will also increase rapidly according to the economic development rates. Further infrastructure should be planned to meet the aged society. Urban facilities, increasing in underground spaces, should be safe and comfortable for the elderly handicapped as well as for ordinary people. Constructing to a mild slop approaches and installation of benches for a rest may be desirable for elderly and handicapped people. To alter the image about existing underground spaces, the design for new underground facilities should be prepared by the strong emphasis on safety and comfort. These facilities should be also done on the artistic aspects as well as on psychological and physiological satisfaction; e.g. audiovisual satisfaction, of facility users and environmental aspects. Thus, further studies for evolving new design methods should be conducted. The characteristics of underground are much different from those of aboveground. Some of them may make an underground space more comfortable and attractive than aboveground space. On the contrary, some of them may make an underground space uncomfortable or dangerous. A great effort of underground space has been progressed to create a comfortable environment of which condition is similar to aboveground. But, further efforts to create underground spaces, which fully utilize the characteristics of underground, make underground space more comfortable than aboveground.

(4) *Safer Underground Space*

Main causes of disasters in underground spaces are fires, gas explosions, flooding and earthquakes. Once a fire or gas explosion occurs in a space, evacuation from the incident area would more difficult in an underground space than aboveground because people have to evacuate towards a vertical direction. Smoke and gas tend to remain in an underground space. Evacuation, rescue and fire fighting operation in an underground would be harder than those in an aboveground would. Although the provision of disaster prevention must be carried out, a process to evacuate people from an underground space should be provided. Special elevators or escalators that dedicate for evacuating people would be effective. People who are left behind may be led to a compartment for temporary refuge. And then, they must evacuate to the aboveground. Although the existing underground spaces are equipped with various measurements for maintaining safety, further development of hardware and software for accumulating a reliable safety should be undertaken to maintain the good condition and make the underground spaces safer in the future (Fig. 24).

Fig. 24 Light opening of Nagoya Central Plaza, comfortable underground space with natural lighting.

(5) *Further Development of Construction Technology*

Technology for constructing underground spaces by taking into account depths, geology and environmental conditions according to the purpose as shown in Table 1 are required.

Tunneling construction method such as New Austrian Tunneling Method (NATM) and Tunnel Boring Machine Method (TBM) are most commonly used in a mountainous area because of geology and construction depth. NATM can be adopted not only for single section of underground space but also for a multi-section of underground construction. For underground construction, the shield tunneling method is mainly used. However, as aboveground and shallow underground spaces are already used in urban areas, the use of future underground space should take place in the deep underground. By taking into account the possible interruption of social activities at aboveground, it is believed that the tunneling construction method such as the shield tunneling method, pipe jacking method and NATM would be very effective method for constructing underground space in urban areas. In the progress state of past time, underground structures were conducted by adopting the cut-and-cover construction method. For the construction of very intricate underground structures, special attention is paid to conduct the enlarging work of underground structures. Most underground structures are built below the underground water levels. These structures are required to maintain

Table 1 Structure types of underground space use and these approximate dimensions[29].

Structure type of Underground Space	Size of Space Width (m)×Height (m) ×Length (m) Volume (m³)	Ground Type	Depth (m)
Urban-life Related Structure:			
Underground shopping mall and parking space	120 × 2 levels × 250 (60,000)	Earth	0 ～ 20
Subway	9×5.3 10(D)×	Earth	10 ～ 40
Underground station	50 × 30 × 500 (600,000)	Earth	0 ～ 40
Utility Tunnel	5.6 × 8.9	Earth	0 ～ 10
Underground reservoir	11.2(D) × 1,270 (125,000)	Earth	22
Transportation Related:			
Railroad Tunnel	9.5 × 8	Soft to hard rock	Over 50
Road Tunnel	10 × 6	Soft to hard rock	Over 50
Energy Related Structure:			
Pumped storage hydropower station	25 × 50 × 150 (190,000)	Hard rock	100～500
Transformer station	46×37×80, (140,000)	Earth Hard rock	0～4 0 70
Petroleum storage (Kuji Storage Base)	18 × 22 × 555,(220,000)per tunnel	Hard rock	500
Superconductive electricity storage	8×44×1,250,(440,000)	Hard rock	600
Compressed air storage	15 × 20 × 50 in each 8 unit, (120,000)	Hard rock	100～500
Nuclear power station	30×50×230 in several units, (1,000,000)	Hard rock	500～1,000
Radioactive waste storage	6×6×1,000 in each 150 unit	Hard rock	

D: diameter

their functions in the surroundings until long life. In other words, as underground spaces are related to human activities, they must be safe for apparent period. On the other hands, in the countries where earthquakes occurs frequently, underground structure has reliability against seismic forces. To make underground structures durable, it is necessary to improve their capabilities of waterproofing, seismic resistance and erosion resistance.

7. Comfortable Design of Underground Space

(1) *Purpose and Introduction for Comfortable Design*

For long time, the effective utilization of limited urban underground space has discussed. At present, underground spaces of large scale are principally located in urban districts with severe climate where they are commonly used on a daily basis. However, it cannot be said that these spaces are at a satisfactory level in terms of safety, comfort and cost. Accordingly, the extensive studies have been conducted to extend the studies for underground spaces that provide favorable environments. In general, designers tend to intend the functionality rather than the psychology of uses. Ordinal users emphasize a congenial environment about facilities. Underground spaces where users can behave naturally should be designed without any senses of awkwardness, as if they were in aboveground. In certain cases, users may find these spaces either more restful or more exhilarating than the space of aboveground. Here, based on the results of surveying about an underground environment, it is discussed what is the comfort in the underground spaces. It is considered to the meaning of congenial underground spaces through the planning for them.

(2) *Procedure for Surveying the Comfort.*

Forty slides which consisted of various landscapes were shown to two groups. One group consists of the professionals whose professions are designers and planners of urban structures. The other group consists of the amateur belonging to a university. In this context, an approach was assumed that people could evaluate the specific scenes directly through their own senses. Based on the common senses in daily urban life, the survey that a subject person classifies 40 photos into seven-rank is carried out. This photo group includes the 20 scenes of aboveground spaces and 20 scenes of underground spaces. 21 pairs among adjectives or adjective verbs and these negative words that explained the environmental characteristics of underground and aboveground were selected for environmental descriptors. These people rated each photo by applying Semantic Differential Method (S.D. Method). The results were subjected to a computer correlation matrix and subsequent Principal Component Analysis. Following varimax rotation, the factor analysis was interpreted.

(3) *Evaluation of the Results between Two Groups*

An image profile for each photo was prepared for getting the mean values. For all items in the 40 photos, the mean values were estimated for the professional and amateur groups, respectively. As a result, 23 items from 10 photos were found to have significant differences in the mean values between two groups (Table 2).

As many as 20 items showed a significant difference for underground photos. On the other hands, there are some differences among only three items for aboveground photos. These photos and Fig. 25 show items for which the evaluation differed greatly. This typical example indicates the discrepancy between the designers' conception of an underground space and how general users perceives the same space. Evaluation is quite similar for most of the items in the aboveground photos. But, it tends to differ in the case of underground photos. One reason about the difference is that underground spaces are occasionally used and not experienced daily.

(4) *Results for the Factor Analysis.*

On the basis of the averaged scores of the professional and amateur groups for each photo, a factor analysis was made by using 21 environmental descriptors to determine the

Table 2 Signification differences between professional and amateur groups.

Underground Photos				Aboveground Photos	
Photo No.	Items	Photo No.	Items	Photo No.	Items
Photo -1	9	Photo -17	1	Photo -11	1
Photo -5	2	Photo -22	1	Photo -24	2
Photo -6	1	Photo -32	1		
Photo -9	1	Photo -35	4		

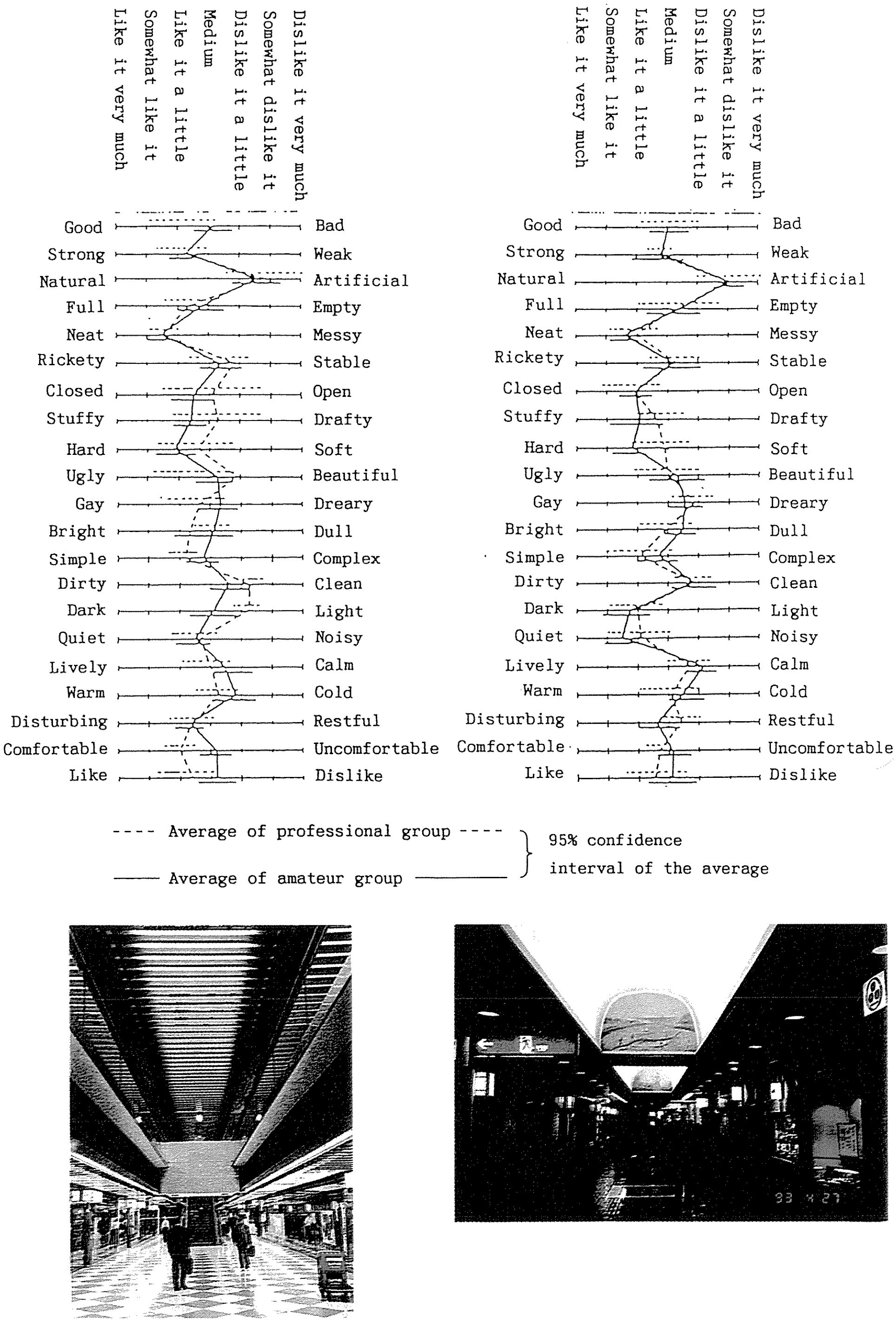


Fig. 25 Seven ranks sensory test.

eigenvalues. The top three eigenvalues are interpretable factors with their cumulative contribution ratio being estimated as 87.9%. Then, the varimax rotation method was used to interpret the factors. After rotation, the factor of load matrix was drawn and the factor analysis was made. The results are shown in Table 3. As a result of the interpretation of the factors in Table 3, it becomes evident that the first factor is a sense of "natural-soft"; e.g. restful, natural, soft-disturbing, artificial and hand, the second factor is "strong-clean"; e.g. weak, rickety, dirty-strong, stable and calm, and the third factor is "liveliness"; e.g. noisy, lively-silent and

Table 3 Results of factor analysis.

Evaluation item	1st factor	2nd factor	3rd factor
Disturbing - restful	0.921	-0.186	0.090
Natural - artificial	-0.893	0.088	0.022
Hard - soft	0.852	-0.192	0.367
Stuffy - drafty	0.807	-0.483	0.233
Warm - cold	-0.753	0.273	-0.504
Closed - open	0.734	-0.407	0.398
Like - dislike	-0.682	0.660	-0.214
Gay - dreary	-0.650	0.515	-0.500
Full - empty	-0.647	0.524	-0.442
Dark - light	0.629	-0.567	0.354
Strong - weak	-0.014	0.863	-0.182
Dirty - clean	0.368	-0.860	-0.079
Rickety - stable	0.334	-0.827	-0.146
Neat - Messy	0.058	0.825	0.506
Ugly - beautiful	0.555	-0.791	0.056
Good - bad	-0.644	0.715	-0.163
Comfortable - uncomfortable	-0.675	0.678	-0.181
Bright - dull	-0.597	0.632	-0.414
Silent - noisy	-0.018	0.108	0.903
Lively - calm	-0.457	0.293	-0.787
Simple - complex	0.412	0.212	0.642
Interpretation of factor	Restful – Disturbing	Weak – Strong	Noisy – Silent
Eigenvalues	13.73	3.44	1.29
Contribution ratio	65.4%	16.4%	6.1%

Note:*1 People ┬ Professional Group .... Designers, Planners
└ Amateur Group .... Students (General Users)

Table 4 Distance between the amateur and professional groups in the space for three factors.

○Photo- 1	2.05	○Photo- 2	1.21	Photo-29	0.86	Photo-38	0.71
○Photo-16	1.71	○Photo-15	1.12	Photo- 7	0.84	Photo-37	0.64
○Photo- 5	1.55	Photo-24	1.12	○Photo- 9	0.84	Photo-12	0.62
Photo-39	1.51	Photo-30	1.12	○Photo-21	0.84	Photo-40	0.59
○Photo- 6	1.49	Photo-19	1.11	Photo-26	0.84	○Photo-33	0.57
Photo-11	1.40	○Photo-17	1.07	Photo-13	0.82	○Photo-20	0.47
○Photo-25	1.40	○Photo-35	1.06	○Photo-22	0.75	○Photo-14	0.46
○Photo- 3	1.31	Photo-10	1.03	Photo-28	0.73	Photo-36	0.43
Photo-27	1.25	Photo-23	0.95	○Photo-34	0.73	Photo- 8	0.33
○Photo- 4	1.22	○Photo-32	0.95	○Photo-18	0.72	Photo-31	0.18

○:Underground, Others are aboveground.

calm. Fig. 26 and Fig. 27 show that the factor scores of landscape photos were plotted on a plane coordinate. These figures show the position of photos. The axis called the item for evaluation of "Comfortable-Uncomfortable" is a projection of the factor for the item of the "Comfortable-Uncomfortable". As photos approach either extreme of the arrows, the degree of their comfort or discomfort increases. It is evident that the evaluations differ between the amateur and professional groups for Photo 1 and others (Table 4).

In the space for the three factors, the distance was determined for the same photo by amateur and professional groups with the mean distance tending to be longer. Based on Fig. 26 and Fig. 27, as it is difficult to classify these photos, they were classified into the group of

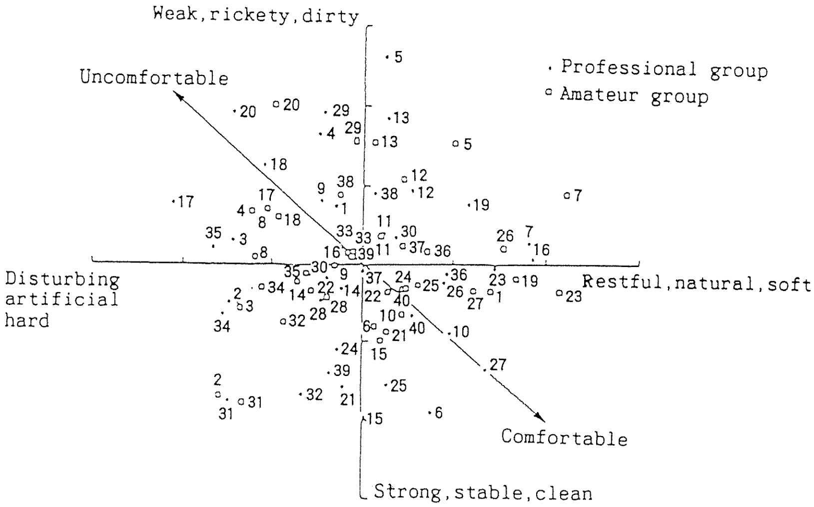


Fig. 26 Distribution of factor scores (1st—2nd factors).

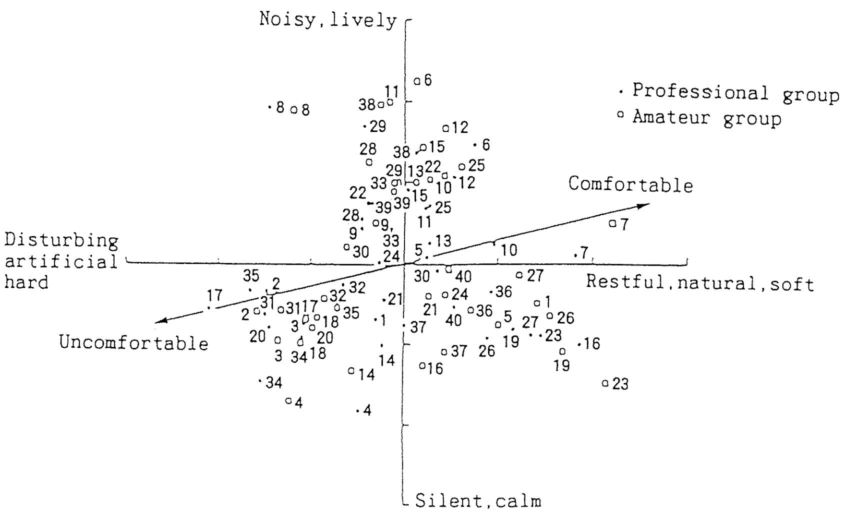


Fig. 27 Distribution of factor scores (1st—3rd factors).

aboveground and underground, respectively by referring to the symbols each other (Fig. 28).

(5) *Estimation of "Comfortable – Uncomfortable" by the Method of Multiple Regression Analysis*

Multiple regression analysis was made to evaluate the comfort-discomfort sense of each landscape photo. Factor analysis was carried out for 20 items excluding the item "comfortable-uncomfortable" and multiple regression analysis was also carried out by using three

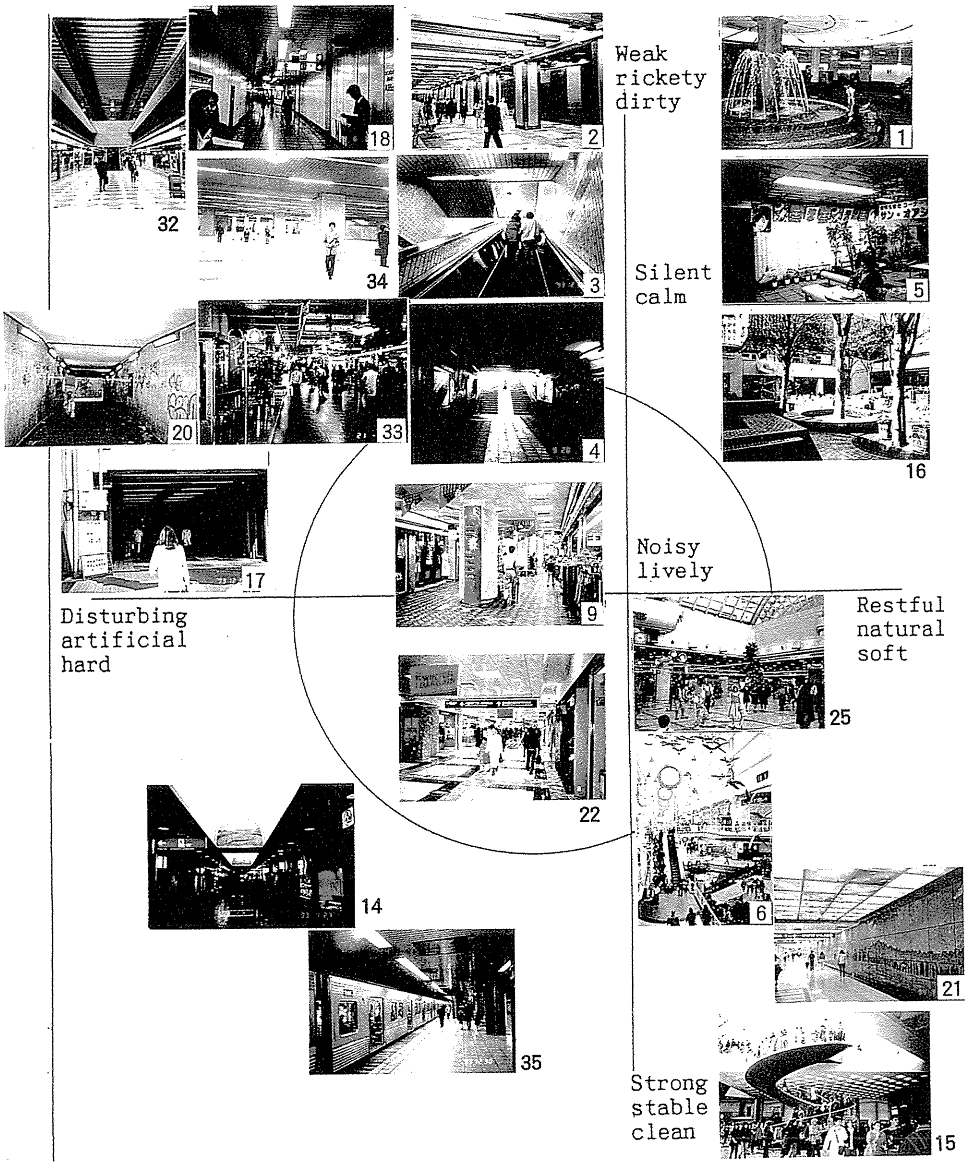


Fig. 28 Classification of underground landscape photos by factor scores.

factor scores as independently explanatory variables; i.e. x_1, x_2, x_3. The mean value of primary scores for "comfortable-uncomfortable" was used as an objective variable y. This is shown in the estimated equations as follows:

$$\text{Professional group} : y = -0.653\ x_1 + 0.687\ x_2 - 0.162\ x_3 - 4.06 \qquad (1)$$

$$\text{Amateur group} : y = -0.627\ x_1 + 0.563\ x_2 - 0.144\ x_3 - 3.86 \qquad (2)$$

To compare the degree of influence in each factor, the coefficients of partially standard regression was determined (Table 5). From this result, it is clear that "y" value becomes smaller, the photo offers a sense of greater comfort according to the scores for items of restful, strong and lively. On the contrary, high scores according to the items of disturbing, weak and silent indicate that the photos offer a greater sense of discomfort. It is also evident that first and second factors that are natural-soft and strong-clean, respectively. And the third factor which indicates liveliness is more effective to explain comfort/discomfort than the former factors. The degree of contribution for the first and second factors is different between the professional group and the amateur group. Namely, the professional group tends to consider that the items of restful, natural and soft are more important than other items. On the other hands, the amateur group considers that the items for strong, stable and clean are more important.

The determined scores for comfortable-uncomfortable items which form the estimating equation (1) and (2) are shown as the degree of comfort and discomfort for each photo of the underground and aboveground. In these photos, the evaluation results of the amateur group prefer to take the medium evaluation than those of professional group. This means that the amateur group was indecisive about evaluation. So the evaluation tends to differ between the groups of underground photos in the factor analysis.

The evaluation was divided into three opinion groups; the first group evaluated as highly comfortable, the second group evaluated medium opinion and the rest evaluated as highly uncomfortable. Few aboveground photos were evaluated as uncomfortable, and the degree of comfort was relatively high (Fig. 29). On the other hands, underground photos were distributed widely in the comfortable – uncomfortable range. This state does not mean that the underground space is always perceived the uncongenial one. It means that there are many elements, which make the underground space feel uncomfortably. Namely, it is impossible to draw an all-embracing conclusion that concerns comfort/discomfort from the photos. Here, it is suggested that the words such as restfulness, natural, soft, strong, clean, stability and liveliness are important elements to make the space comfortable.

(6) *Conclusion of Estimating Confortable of Underground Space*

Landscape photos of underground spaces were shown to subjects and their impressions were evaluated by the S.D. method. From the Principal Component Analysis used to analyze the various factors, it was clear that (i) natural and soft (ii) strong and clean spaces were

Table 5 Coefficient of the standard regression.

	First factor	Second factor	Third factor
Professional group	-0.575	0.709	-0.128
Amateur group	-0.778	0.595	-0.205
Overall	-0.661	0.668	-0.183

evaluated as being highly congenial. In addition, a comparison between professional and amateur group shows that the former group tended to evaluate (ii) more highly than (i). For example, in order of preference photos 6, 15, 21 and 25 were evaluated favorably by the professional group. On the other hands, photos 1, 6, 15, 16 and 25 were evaluated favorably by

Fig. 29 Comfort-discomfort of aboveground photos.

the amateur group. Namely, the ceiling lighting and the wall finish of photo 21 appealed strongly to the professional group. But, the reaction of professional group to photo 1 was "slightly uncomfortable" because the reddish component of lighting might be too strong and give the space somewhat "unrefined" impression.

As underground spaces tend to be closed, plain and artificial, much attention needs to be paid to create a congenial environment. The viewpoint of general people and users should be considered as well as those of professionals and designers.

The authors are confident that the S.D. method is an effective evaluation method to aid in the design of congenial underground space. These researches will also be proceeding with a study on underground space design.

8. Underground Utilization with Traffic Problem in Urban Area

(1) *Introduction of Traffic Problems in Urban Area*

Presently, urban traffic have a problems in Japan as follows:

a) A lack of infrastructure that shows a chronically traffic snarl of cars and public traffic facilities.
b) A lack of capacity for the source of water supply, the high price of land, residential area and shortage of houses.
c) An increase of crime, a misdeed, poverty and a desire for culture.
d) A change of worse urban environment, park and landscape.

To deal with such an increasing urbanization, the cities are making progress of three-dimensional utilization for improvement of a city function and a living environment. And underground facilities also have been arranged gradually. A process of arrangement for underground facilities with growth of a city is common sense in the world. However, a procedure for utilization of underground facilities has various characteristics, which reflect the economic power culture and social history of each city. And these characteristics show each city's individuality (Fig. 30). It is important for future utilization of underground space to be considered not only improvement of urban function but also comfort, safety and landscape of urban line. Here, the effective utilization for underground spaces and considered. And the traffic problems in large cities are investigated to solve the inconvenience.

(2) *Urban Traffic System and its Improvement*

Although infrastructure of modern large cities are arranged as a railway, subway and road, an absolute lack of infrastructure has appeared for a planner, supplier and user in a future city since 1990's. Especially, it becomes a problem to be solved for the next century how to arrange corresponding with an increase of cars. A plan of an underground is, therefore, thought out. But, many problems are caused to reinforce fairly in developed cities. At first, it is important to harmonize the constructed urban facilities. Secondly, it is necessary to link the underground space with the aboveground. Thirdly, an underground space has three problems in the technical site, cost site and psychological site. Indeed, it is most important for utilizing and developing the underground space to solve a psychological problem because it is necessary to plan underground facilities with the consciousness of the users.

Traffic is generally classified into man movement and goods distribution. These problems are shown in Table 6. In this state, the problems are indicated as

a) Lack spaces for developing the arrangement of a road in urban area.
b) To scatter the populations and industries for decreasing those density.

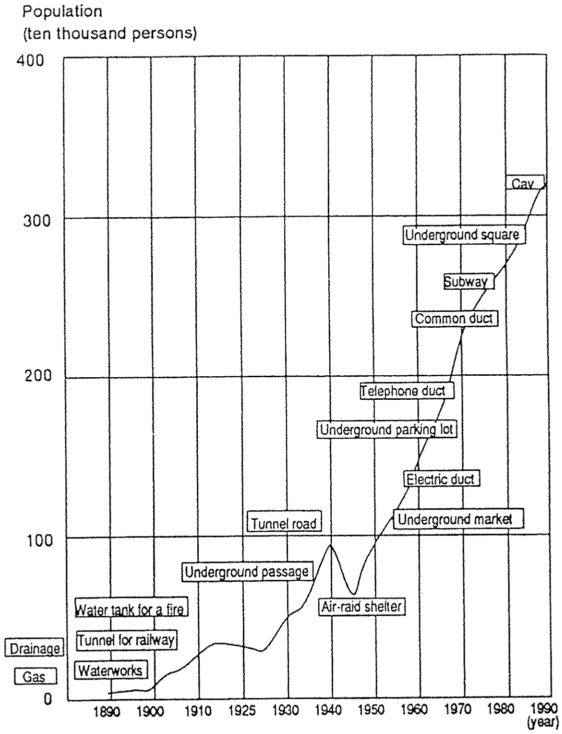


Fig. 30 Transition of population and underground facilities.

Table 6 The condition of urban traffic systems in present and near future.

Time / Purpose	Present	Near future
Man movement	· Subway · Bus · Private car · Walking	· Expansion of the network · Connection with underground parking lot and the ground · Introduction of escalator and moving side walk
Goods distribution	· Road on the ground (car)	· Arrangement of a network for underground motorway · New system of goods distribution in the underground

c) To collect the facilities related to goods distribution for improving the convenience. However, it is difficult to purchase the sufficient land to arrange the road and the ground. And it is also hard to expand the transferring volume, especially, in Tokyo area. To break-through the problems, the facilities should take into the underground to create and grow up the mutual connection between the traffic system and the other facilities.

(3) *Classification Methods for Traffic Problems*

In constructing an underground motorway that will solve a traffic snarl and a shortage of parking lots, it is most important to make clear problems. In order to clarify the viewpoint of problems, a structural modeling method which is classified into "Problem fining" method and "Structural decision" method is adopted. Here, "Problem fining" method is famous as brainstorming and Dalphi method, and it is useful to make a list for many kinds of need and seed. On the other hands, "Structural decision" method relates to pick out factors by applying Interpretive Structural Modeling (ISM), Fuzzy Structural Modeling (FSM) and Cross Impact Study, which gives the relation among the surveyed elements and finally combines the elements and/or makes layers. As between Problem finding method and Structural decision method generally have no direct relation, researchers must choose each method or use them after combining. These methods are carried out as following procedure: Step 1 is to make a list about subject problems of which each person can think. And it is to evaluate by giving marks to the problems. Step 2 is to sum up the marks and to examine the problems by the researcher of utilizing underground spaces. Step 3 is to set out a questionnaire for the comparison between a pair of problems whether the solution of Problem A has a connection with that of Problem B. Finally, Step 4 consists of calculating a structural decision by applying FSM. It becomes possible that these methods make the regions of the problems wider. In the sense of underground use, the general rationality is kept with objectivity condition. In other words, the simultaneous covering and quality bring the relatively easy exchange between the methods.

(4) *Extracting Problems of Underground Transportation*

The questionnaires, which are about constructing underground motorway, are sent to 130 persons who have good insight and belong to the field of civil engineering and transportation, and 75 answers got. Table 7 shows that a list of the problems from ranks 1 to 19 picked out at Step 1 and Step 2. "Safety plane in the case of emergency, especially in the occurrence of a fire", "Necessity of master plan for underground utilization" and "Necessity of countermeasure for exhaust and ventilation" which are over 200 marks are ranked in high order. People also point out the problems such as "Decrease of easiness for driving", "Indispensability of forming a network for underground motorway", "Necessity of positioning in urban planning", "Profitability and ensuring a source of the revenue", "Connection with the aboveground and underground motorways each other", "Staying at an exit", "Taking the special notice of maintenance, management and operation", "Difficulty of construction works", "Environmental impact assessment and environmental countermeasure for subterranean water and sinking the foundation" and "Psychological residence for a driver". All of these problems have over 100 marks. As Table 7 is including all problems of the underground motorway in the urban areas, this works are accomplished the purpose to get the clear comprehension of the problems about underground motorway. The problem which has the mark 20 below should be recognized that there is significantly difference from over rank 19. In this point, their marks are also low. A group of researchers about underground spaces rate them low mark. Some problems shown in Table 7 are possible to solve immediately. And some problems needs expense and time to do. Others are on the premise for solution of the problems. After classifying the problems of the first questionnaire, the second questionnaire was sent. It included almost all combinations, $19 \times 18/2 - 19 = 152$, of questions whether the solution of Problem A was connected with that of Problem B or not. These were sent out about 75 persons who answered the first questionnaire, and 28 persons sent back these answers. As a result of FSM for the data of the second questionnaire, 5 problems are clarified in the construction of underground motorway in urban areas (Fig. 31):

Table 7 Picking up the underground traffic problems and these analyses.

Order	Problem	Voting number	Voting items 1	2	3	4	5	6	7	8	9	10	Total marks	Explanation
1	Safety plan in case of emergency, especially in occurrence of a fire	61	0	1	3	1	8	6	8	9	5	19	456	In occurrence of a fire in tunnel, it needs a rescue of a driver and a fellow passenger in a burning car, a system of refuge and guide to following cars, and an advanced system of prevention of disasters. It is supposed that costs for smoke removal equipment and arrangement of personnel necessary for an emergency increases, and settlement of a digestive and repair after suffering require unexpectedly much time.
2	Necessity of making agreement of a land owner in spite of underground	41	0	2	4	2	9	3	3	5	1	12	277	In existing laws, it is necessary to get an agreement of a land owner of the ground or to follow the necesssary procedure based on the land expropriation law in spite of public works, and to discuss drawing a line between the right of ownership and the right of utilization.
3	High costs of construction	34	0	0	3	0	5	1	5	6	7	7	256	Construction costs become several times high compared with high bridge structure and canal structure. A short section opening of a road on the ground is effective in a way. But an underground tunnel needs a large early investment as its opening becomes a long section to a certain extent.
4	Necessity of a master plan for underground utilization	39	2	2	7	3	6	4	7	6	3	3	247	It is necessary to give the order of priority for underground space utilization, and to advance a use intentionally and orderly, from the viewpoint of necessity•urgency•public benefit to construct underground. It is also necessary to adjust to a railway, rivers and a main line of a sewer pipe (level, depth, time of arrangement).
5	Necessity of countermeasure for exhaust and ventilation	37	0	5	2	2	12	2	1	7	4	2	215	Environmental countermeasure for exhausting gas needs. Costs including running costs of a duct and a tower of ventilation increase. It needs larger land. (Expecially, construction of a tower of ventilation has many problems for residents.)
6	Decrease of easy driving	30	3	4	5	1	3	8	0	2	1	3	148	It is generally not easy to drive in a tunnel, particularly at a diverging point. As it is difficult to see even a devised sign, it easily causes a mistake of choosing a route and a traffic accident (As height of a ceiling is limited, a distance view lacks). Only a sign system seems to be insufficient, as a means of confirming a place.
7	Indispensability of forming a network of undeground motorway	20	0	1	2	1	3	1	3	4	2	3	134	It is necessary to make a network of a principal road on the ground, an underground public parking lot and an underground private parking lot (including a facility for goods), forming a network of underground motorway. It is to be desired that it complements an exisiting road network on the ground.
8	Necessity of positioning in urban planning (harmony with land-use planning and urban facilities planning)	21	0	0	5	5	2	0	0	1	2	6	131	As it is anxious that the arrangement of infrastructure by constructioning an underground motorway encourage acceleration of concentration to urban areas and concentration of a car to urban areas, it must be take notice of arrangement and harmony with what a total image of a city is (a long-term urban planning).
9	Profitability and ensuring a source of revenue	20	0	2	2	2	0	5	5	0	1	3	122	It is necessary for a countermeasure how to supply a source of revenue from public and others, as it has a problem of profitability in an independent project.
10	Connection with the ground and with underground motorways each other	21	1	0	2	4	4	2	3	3	0	2	120	It needs a long ramp to cnnect a large difference and a huge structure as a space. Therefore, it needs a land of a certain extent on the ground, and also a certain depth for a distance between tunnels each other.
11	Staying at an exit	18	0	0	2	3	4	1	1	2	3	2	114	Even though a driver can drive smoothly in a tunnel, it is possible that a snarl on the ground at an exit extends to a main route in a tunnel and causes staying in a tunnel.
12	Taking special notice of maintenance, management and operation	22	0	0	3	5	2	3	2	3	3	1	112	It needs a more special device than a structure on the ground in maintenance, management and operation at ordinary times and in emergency. As it is said that it is difficult to manage in part, it especially needs an unified operating organization.
13	Difficulty of construction works	25	4	4	3	1	6	2	1	3	1	0	107	As underground construction is proceeded in unarrangement of information about underground, it takes with difficulty in construction works even in expectation of development of technology in future.
14	Environmental impact assessment and environmental countermeasure for subterranean water and sinking the foundation	20	1	1	4	1	5	2	2	2	2	0	104	As it causes cutting of a subterranean water vein and subsidence in some place constructed an underground structure, it needs an advance environmental impact assessment and some countermeasure according to the result.
15	Psychological resistance of a driver	19	1	2	5	1	3	0	1	1	3	2	101	A driver becomes be unable to enjoy a view out of the window in driving. As he must only drive a car in a dark space like a cellar, it perhaps increases fatigue and psychological resistance.
16	Difficulty for reconstruction and repair	9	1	0	0	1	1	1	1	3	0	1	57	As it probably needs fairly trouble (cost•system•substitutiive traffic facilities) compared with structure on the ground, it needs a plan and structure in taking a long view.
17	Existence of matters laid underground	6	1	0	0	0	1	0	0	2	0	2	42	Underground of a main road in the center of urban areas has already been utilized highly. It needs to plan the future in consideration of conditions of the laid matters and geological features.
18	Making common consent of residents and the citizens	6	0	0	1	1	1	0	0	0	2	1	40	The general public has a feeling of avoiding a word of underground itself. On realizing one big project of a road network utilized underground, it needs prepare a fair attentive program for making agreement.
19	Treatment or practical use of remained soil from construction	4	0	0	0	0	2	1	0	0	1	0	25	Under the conditions that reclamation is difficult under present environment, is it possible a treatment of remained soil from construction of an underground passage and an underground parking lot ?

a) Problem group 1: Necessity of the agreement with a landowner in spite of the underground

Existing laws in Japan also apply the right for ownership to the underground and the air. Therefore, it is important to try "making agreement with a landowner" and "necessity of a master plan for underground utilization" is raised to make the consensus of the landowners and the citizens.

b) Problem group 2: Indispensability of forming a network of underground motorway and staying at an exit.

If forming underground motorway is positioned as a complement to an existing city on the ground, it is necessary to complete a network of underground motorway solving the problem of "connection among the ground and the underground motorways" and making "a master plan for underground utilization" under establishment of "positioning in urban planning". An organic network united the aboveground and underground in a body must be aimed. And it contributes to dissolve "staying at an exit".

c) Problem group 3: High costs of construction and difficulty for re-construction and repair.

One of large factors which have been hindering urban underground space utilization is problem system 3. It indicates high costs of construction and difficulty of destroying the constructed buildings. Construction removing a laid pipe of gas, telephone cable and water is dangerous, and this construction takes its difficulty. Therefore this problem causes as increase of construction costs.

d) Problem group 4: Psychological resistance of a driver

It means that human being essentially has a feeling of avoiding underground itself because of the qualities of closing and maze in the underground. In addition, as a driving in a present

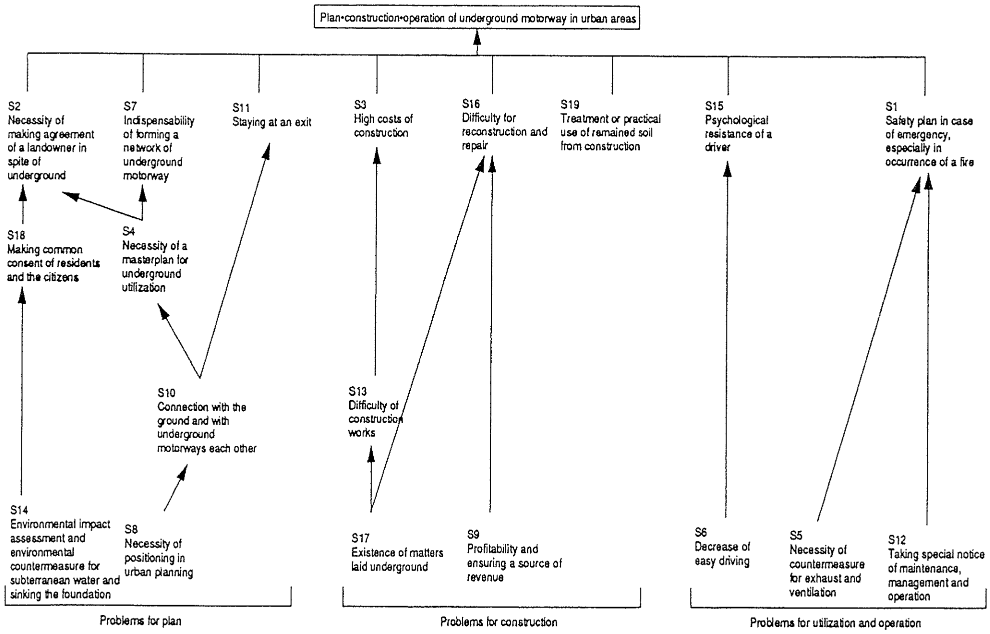


Fig. 31 A structure of problems for underground motorway.

tunnel is not always comfortable, plan and design to drive easily must be advanced in the future.

e) Problem group 5: Safety plan in the case of emergency, especially in the occurrence of a fire

It is highly important to take a safety plan in case of emergency, especially in occurrence of a fire. For example, it is shown in the accident at Nihonzaka tunnel as human being drives a car and rides together at the present stage. And structure of Fig. 31 indicates that safty plan is obtained by "take special notice of maintenance, management and operation" and "countermeasure for exhaust and ventilation". As the mentioned above, the middle and lower level problems are doubly and threefold increased in the systems of five problems to solve the upper level problems.

(5) *Conclusion of Traffic Problem in the Underground Space*

Underground utilization is expected to be effective by means of solving series traffic problems in urban areas such as Tokyo. Although infrastructure of modern big cities are arranged by a railway, subway and road, a planner, supplier and user in the future have realized an absolute lack of infrastructure since 1990's. Especially, it becomes a problem to be solved for the next century how to arrange a road corresponding with an increase of cars. A plan of the underground motorway utilizing urban underground space is, therefore, thought out. But, many problems are caused to reinforce fairly developed cities.

At first, it is important to harmonize constructed urban facilities. Secondly it is necessary to link with the aboveground. Thirdly, an underground space has three problems in technical site, cost site and psychological site. And a problem of psychology is, indeed, most important in utilizing and developing underground space. It is necessary to plan in consideration of user's consciousness. The biggest barrier of underground utilization is how to settle uneasiness feeling for underground space and how to arrange a plan in consent of the citizens. That is to say, it is necessary to plan in consideration of consciousness for a user. It is essential to choose suitably analytic method for characteristic of problems. To develop a plan suitable for the purpose and to estimate are also essential things.

As underground space utilization for traffic depends upon how many users want to use this system, the utilization needs to solve various problems of not only safety, environment and labyrinth, but also how to create a plan, how to design a space, how to manage it and how to operate it in ordinary state and emergency state. Thus, we should arrange the conditions which make the underground utilization possible. "A system of underground motorway without an exit" becomes one of good ideas. It will be not only for smoothing transportation for man and goods under difficult condition of constructing road in urban areas, but also for promoting a plan that the ground is used mainly for human being and a town is safety and comfortable.

9. Conclusion: the Future Prospects for Underground Space

In this report, the authors introduced the history, examples and survey about underground structures in Japan. These emphasized that the number of main underground constructions will increase in the future, even though these have many problems; e.g. negative images of uncomfortable and darkness, which must be solved.

Concerning the future prospects of living environment, the roles of underground space use are discussed. The following three points should be regarded: (1) the fact that the general public has become aware of the objectives for global environmental preservation is closely related to the environment of their own area. (2) The aging society is demanding barrier-free spaces. (3) The demand for public using spaces should be raised to a higher level that not only includes their functions but also their qualities, comforts and looks. In other words, the points are how to relate and how to contribute to the objectives and themes of sustainable development, barrier-free spaces and space design.

An underground space has mainly two advantages: One is convenience as follows: (1) the connecting between Point A and Point B in underground. (2) Creating the space, which can not on the aboveground, for the human being and some goods. The other is the maintenance of urban environment, for example, the keeping the landscape of urban area. In other words, the creating underground contributes the constructing the sophisticated town. To realize this situation, the engineer and planner should improve the underground space more psychologically comfortable for users under maintaining reliable and safety. Of course, in general, there is a dangerous sense caused by the many past accidents. When the accidents occur underground at once, the response for many kinds of rescuing act has possibilities to be constrained during the accidents because the underground space is a closed space. The underground spaces, however, are useful for the shelter or the deposit space for dangerous substances such as Dioxin and the nuclear waste under using the closure as an advantage. These conflict characteristics should be controlled to create the expected space in the underground.

The future tasks will be how to design the urban area by utilizing underground space. This concept follows the integrally coupling among the facilities of aboveground and underground to create the new space. The underground space will support the following options: (1) development of infrastructure, (2) Securing of greenery and open spaces, (3) Preservation of urban landscape (4) Traffic system, (5) The use of underground characteristics underground. Once the necessity of underground occurs, we must create the expected underground space for human being. At that time, the demerits of underground such as intricate, isolation and lack of natural light should be solved, through the experiments and researches for designing space. Finally, the users and designers, respectively will show the future viewpoint for comfortable underground: (1) Underground spaces having similar conditions with an aboveground (2) Creation of an artificial ground on the ground level (3) Utilization of underground characteristics such as sound proofing, isolation.

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