CONSTRUCTION TECHNIQUES

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Summary

Construction techniques in various kinds of major infrastructures together with their histories are explained and overviewed. One will see that all these structures are build not only on the foundations with the state-of-the-art construction techniques but also on man's never-ending efforts toward improvement, advancement and evolution of the techniques.

1. Introduction

It is considered that ages ago human beings lived in caves or under trees. Then they would have arranged or removed pebbles to make their entry to the caves easier or would have cut tree branches and arranged the large branches to make roofs for shelter from the rain. As they walked on the ground, it became a beaten path. They dug the ground with stone tools to make traps for animals. As they learned to grow plants, they would have dug the ground to make water channels and made small bridges by placing logs over the channels.

These actions contain the basics of construction techniques, namely, digging the ground or rock, compacting the ground to make a foundation, transporting materials, processing and assembling various materials to make buildings or structures.

Searching for better living, mankind has refined construction techniques to make it possible. In other words, construction is a history of mankind's making many mistakes and overcoming past failures in the process of conquering the harsh nature.

Thus, the desire for better living was one of the major motivations for humans to develop advanced construction techniques. Development of construction techniques itself was one of the building blocks of civilization.

In the following chapters, the progress of various kinds of construction techniques is to be reviewed.

2. Development of Construction Techniques

2.1. Architectural Technology

Primitive structures, or buildings used for people to live and stay, are mainly pit houses, made up of pits in the ground with roofing. These structures have been unearthed at various parts of the world. Thousands of years ago, with simple tools which humans learned to make and use, they constructed dwellings for shelter from rain by making use of natural materials, such as grass, wood, stone, mud and animal skin. With the development of civilized society, they came to make buildings that have symbolic meanings, such as religious, hierarchical, or memorial, beyond the original meaning of dwellings. Those buildings are temples, palaces and theaters, one of whose representatives is the pyramids. Depending on natural conditions, under which civilization it was born, and social conditions, such as thought, religion or hierarchy, a variety of buildings with various architectural forms have been built around the world. These buildings expanded their dimensions vertically and laterally as new building materials and techniques were developed. Good examples are temples and churches existent in Europe dating back to the middle ages.

The emergence of modern architecture was timed with the industrial revolution in the 19th century in Europe. The industrial revolution accelerated industrialization and propelled the economy by leaps and bounds. Demands for buildings also drastically changed, requiring more functional, efficient and economical factories and other industrial facilities. Reinforced concrete and steel reinforced concrete buildings using such new building materials as steel, cement and glass have become a steady scene. The demand for dimensional expansion in height and space increased accordingly.

Today, we see cities growing intensively populated, spatially gigantic and more and more information-oriented. Requests for buildings also become more diversified. Building technology that makes “super highrises” and “buildings with big spaces” possible has never been more important.

A brief introduction of the advanced building technology is given in the following.

2.1.1. Super Highrise Building Technology

Super highrise buildings are supported by advanced structural analysis techniques and materials technology. Super highrises towering over 200 m high were once constructed mainly as steel-frame structures. Now, many super highrises we see today use reinforced concrete, which excels steel-frame structures in constructibility and economic efficiency. These buildings owe their structural excellence to the development of high-strength concrete technology whose strength is several times higher than that of ordinary concrete. Concrete with very high strength featuring 80 to 130 N/mm^2 is used in those new buildings under strict quality control. In addition, the CFT method, in which concrete is filled in steel columns to enhance compressive strength, was developed to achieve further economic super highrises.

One of the outstanding technological elements that support super highrises is earthquake resistant engineering, which is to be discussed in the next section. It makes very high buildings comfortable and safe living space by employing vibration damping structures, such as braces and reaction-generating pendulums to set off an external force due to seismic action or wind pressure.

世界の主な超高層ビル
The world's major super highrise buildings (as of 2005)

	name	location	height	stories	completion
1.	Taipei 101	Taipei, R.O.C.	509m	101	1998
2.	Petronas Tower?,?	Kualalumpur, Malaysia	452m	88	1998
3.	Sears Tower	Chicago, USA	442m	110	1974
4.	Jin Mao Tower	Shanghai, China(PRC)	421m	88	1998
5.	Two International Finance Center	Hongkong, China(PRC)	412m	88	2003
6.	CITIC Plaza	Guangzhou, China(PRC)	391m	80	1997
7.	Shun Hing Square	Shenzhen, China(PRC)	384m	81	1996
8.	Empire State Building	New York, USA	381m	102	1931
9.	Central Plaza	Hongkong, China(PRC)	374m	78	1992
10.	Bank of China Tower	Hongkong, China(PRC)	367m	70	1990
11.	Emirates Office Tower	Dubai, UAE	355m	54	2000
12.	The Centre	Hongkong, China(PRC)	350m	69	1998
13.	Tuntex&Chein-Tai Tower	Kaohsiung, R.O.C.	348m	85	1998
14.	Aon Center	Chicago, USA	346m	80	1973
15.	John Hancock Center	Chicago, USA	344m	100	1969
16.	Burj al Arab Hotel	Dubai, UAE	321m	69	1998
17.	Baiyoke Sky Hotel	Bangkok, Thailand	320m	90	1998

Table 1: The world's major super highrise buildings (as of 2005)

One of today's landmark super highrises (Table 1) is TAIPEI 101, the 509 m high world's tallest building of steel CFT structure completed in November 2004 in Taipei, ROC. The world's highest RC structure is the Petronas Twin Tower of 451.9 m high, completed in 1997 in Kuala Lumpur, Malaysia. Currently under planning in the UAE is a building over 700 m high.

2.1.2. Seismic Technology

The conventional standard of earthquake resistance is how to construct a building rigid enough to resist seismic force (rigid structure) or flexible enough to (flexible structure). Buildings constructed with either concept will suffer less damage and will not fail in the face of a major earthquake, but equipment, furnishings and installations inside the building will receive devastating damage.

The state-of-the-art building engineering concept aims at control and mitigation of seismic force itself that acts on the building in order to reduce vibration and protect the building as well as what is inside. These techniques are categorized into two types, vibration control and seismic isolation.

A vibration-controlled structure is designed to set off seismic force by giving a counter force in the opposite direction and is categorized into "active" and "passive" control depending on how to set off seismic force. Active damping controls vibration energy by giving a reaction force generated with, for instance, computer-controlled hydraulic power after detecting seismic vibration with sensors. Passive damping absorbs vibration energy with inertial force generated by, for instance, pendulums. Vibration damping is an indispensable technology for today's super highrises.

A seismic isolation structure has an isolation layer, in which rubber or sliding bearings are installed to absorb and reduce seismic force transmission to floors above the isolation layer for vibration mitigation. The isolation layer is generally set on the foundation, but some buildings have it among the middle-height floors depending on the building shapes. This technique is effective especially for low- to mid-rise buildings.

2.1.3. Large Space Technology

The world's oldest large-space building extant today is the Pantheon, constructed in the beginning of the 2nd century in Rome to enshrine Roman gods. Today, large space is very much sought after in various buildings, including railroad stations, airports, halls, stadiums and commercial complexes.

Large space technology is generally categorized into techniques of "structure", "erection" and "simulation".

The structural technique concerns with structures to support the roofs of large spaces. Regular plans so far proposed include a 3D truss structure composed of triangles, a semi-sphere shaped geodesic dome structure developed by Richard Buckminster Fuller, a beam string structure using pretensioned cables, and a membrane structure in which a roof is supported by enhancing internal pressure of a building over external pressure. An increasing number of newly built stadiums have their roofs capable of opening and closing, which shows that more and more complicated mechanisms are used for large-space facilities. The openable mechanism is also diversifying into sliding, folding and rotating types.

The erection technique considers how to construct the long-span roofs of large spaces which obtain sufficient strength when the entire roof structure is completed. The basic concepts are the temporary-support method and the lift-up method. In the standard procedure of temporary supporting, temporary supports and scaffolds are formed first to assemble each part of a roof at its position, after the entire roof assembling is completed and the required strength of the roof structure is confirmed, then those temporary installations are dismantled. In the procedure for lifting-up, on the other hand, the whole roof structure assembling is finished on the ground level and the required strength of the roof is confirmed. Then hydraulic jacks are set to columns, and the entire roof is lifted up with computer control. Although it depends on the scale and the structure, the lift-up method features quicker and safer construction and can save cost more.

The finds ways to accurately ensure environmental comfort, such as air-conditioning and lighting, for large spaces. Computational simulation is conducted for temperature, humidity, air current, illumination intensity and acoustics under the expected conditions assuming various shapes of roofs with open or close state, thus a high level of comfort and energy saving in actual structures are realized.

2.2. Tunneling Technology

Tunnel construction usually involves crushing of rock to remove it out of the tunnel, and supporting of the excavated space. According to this definition, tunneling technology generally covers "crushing of rock," "transport and removal of muck," and "supporting an excavated space."

2.2.1. Crushing Techniques of Rock

From time immemorial holes have been dug in the ground with chisels, hammers, shovels and pickaxes. In some ruins of ancient people, deer horns were unearthed, which were probably used as pickaxes. In around the 8th century BC, people in today's Persia started construction of irrigation canals, which were called "qanat", using pickaxes and shovels. The qanats ran without supports for 5 to 10 km and sometimes went as far as 70 km because the route was chosen following the ground firm enough for nonsupport excavation. Tunnels for military roads or water supply were also built in Roman days, by manual digging. When they encountered hard rock, they tried to slacken the rock by heating it up with fire and cooling it down with water. After gunpowder was invented, it was used to explode the rock into pieces, although it was in the latter half of the 19th century that modern blasting technique was developed with the invention of dynamite and development of rock drills.

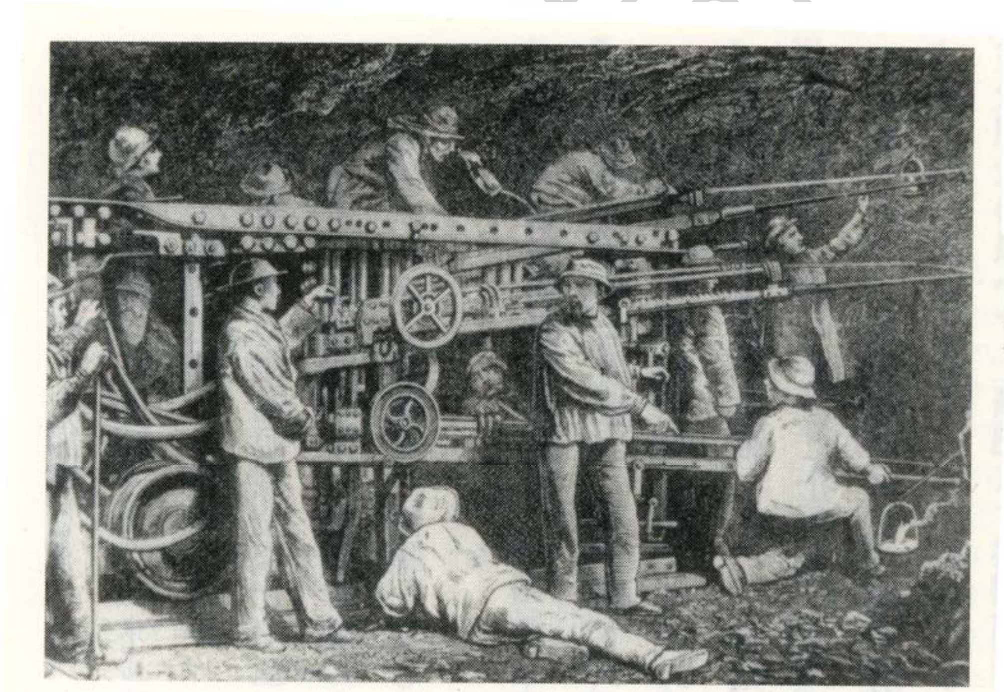


Figure 1. The Mont Cenis tunnel
from : "Le Tunnel Ferroviaire Du Frejus"

Improvement of machines to dig tunnels was accelerated when the Industrial Revolution promoted expansion of the railroad network and the construction of long tunnels for railroad over the Alps was started. Alfred Nobel invented dynamite in 1866 and the blasting cap in 1867. Improvement of rock drills started in the early part of the 19th century with a rotary drill using steam developed by Richard Trevithick in 1813, and a hammer drill by the Singer Brothers in 1838. Browton made use of compressed air in 1844, and a compressed air hammer drill that rotates a chisel to hit and break rock was then developed by Fowl in 1851. In 1861, Germain Sommeiller started to use improved drilling machines and he built the Mont Cenis tunnel (Figure 1) in the Alps between Italy and France in 1870. In 1897, J. G. Rheiner invented the "water liner" method, in which compressed air is sent through hollow steel chisels to the drilled hole bottom and blow off crushed muck to remove. Combined use of the improved rock drills and dynamite led the construction of the Simplon Tunnel to its completion, a 20 km long transalpine tunnel connecting Italy and Switzerland, in 1905.

The dawn of the 20th century saw the debut of a jumbo, which is equipped with many large compressed air rock drills. In 1970, hydraulic rock drills emerged, which provide enhanced drilling performance with higher pressure and greater hammering rotation than those of compressed air drills. The latest models of rock drills are excellent in various functions as well as in improved performance of drilling. Some are equipped with angle sensors and hydraulic sensors to ensure parallel drilling, accuracy in positioning and setting of angles. Computer-aided jumbos (Figure 2) equipped with an automatic drilling management system have also been developed and widely used due to improvement of the automation techniques.

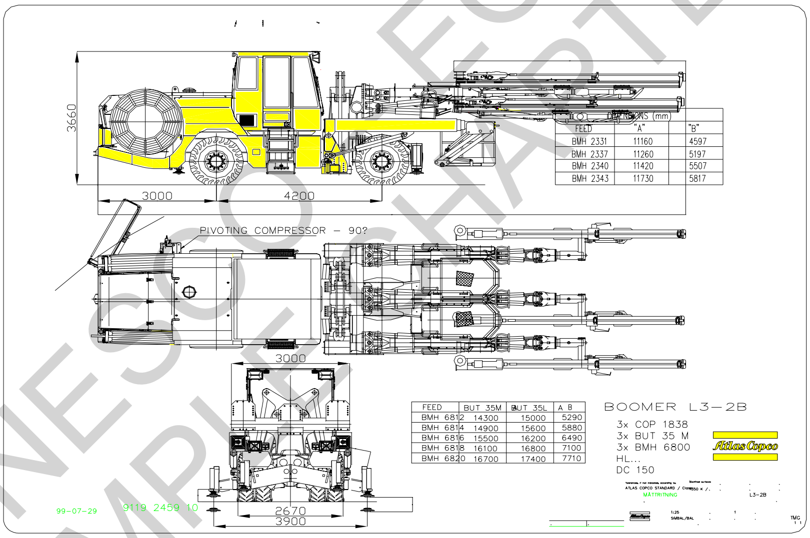
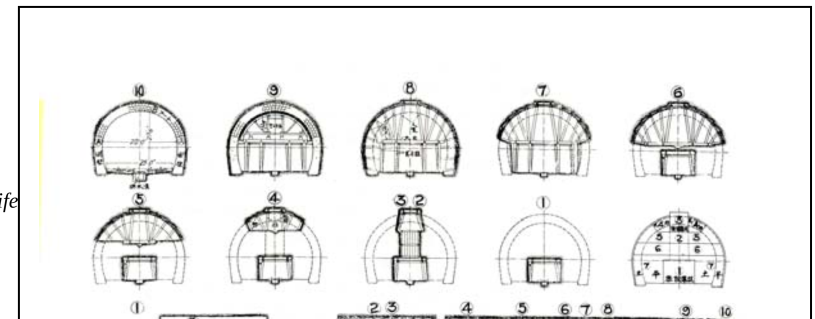
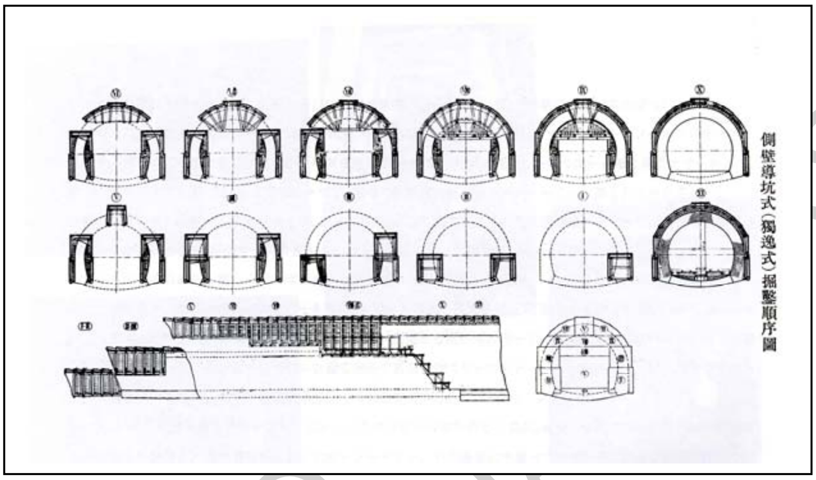


Figure 2. Computer-aided jumbo
courtesy : ATLAS COPCO Corporation (Tokyo, JAPAN)

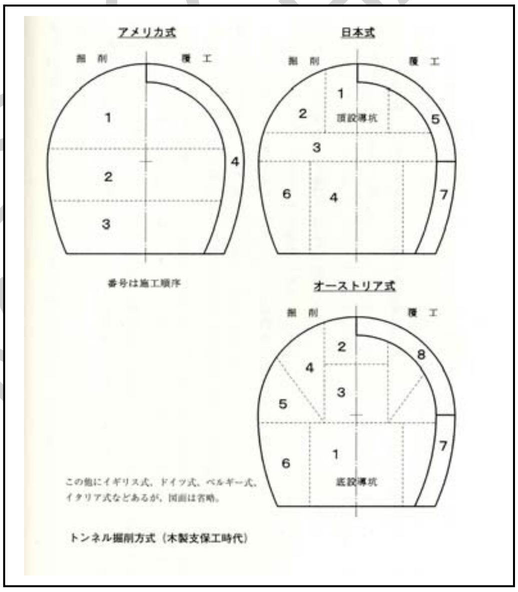
2.2.2. Muck Transport Technique and Space Supporting

Crushed stone, called muck or debris, used to be moved out of a tunnel with manual labor and animal force, such as horses and cows. After the invention of the locomotive, rails were built in tunnels so as to move muck out of them with trolleys in tow by locomotives.





courtesy : RAILWAY TECHNICAL RESEARCH INSTITUTE (Tokyo, JAPAN)



courtesy : SANKAIDO Corporation (Tokyo, JAPAN)

Figure 3. Block excavation of tunneling

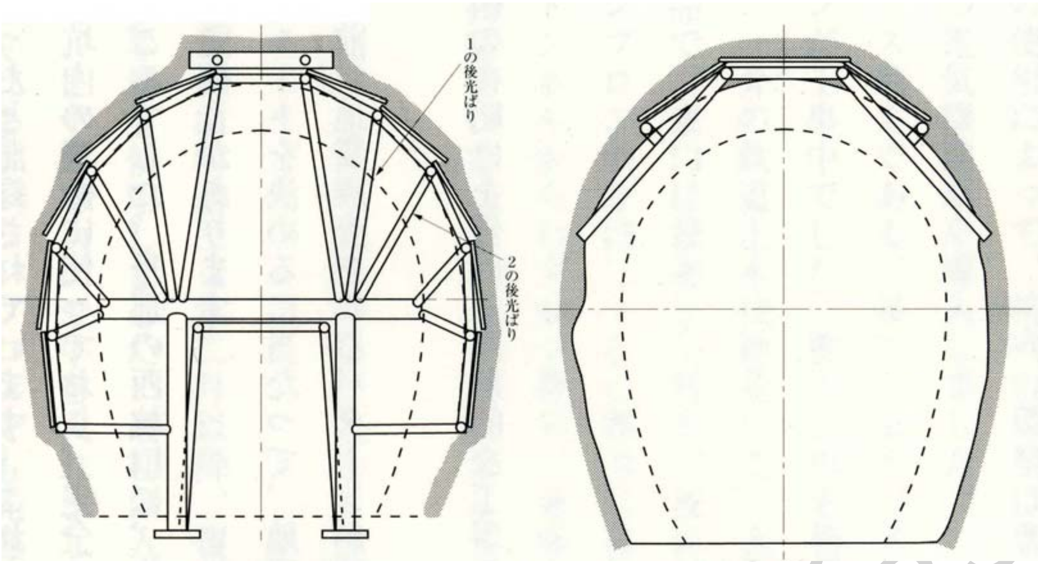


Figure 4. Timber supports of tunneling
courtesy : SANKAIDO Corporation (Tokyo, JAPAN)

After the WW2, steel supports became dominant. As steel supports are stronger than timber ones, they can maintain a larger space and thus allow the use of larger machines for drilling. When tunnels with large cross-section are excavated, muck is moved out by large dump trucks or containers (Figure 5). In long tunnels where blasting is used, the use of belt conveyors (Figure 6) together with crusher equipment for removal of muck has become popular.

courtesy : SHIN CATERPILLAR MITSUBISHI LTD. (Tokyo, JAPAN)

courtesy : TAISEI Corporation (Tokyo, JAPAN)

Figure 5. Large dump trucks or containers

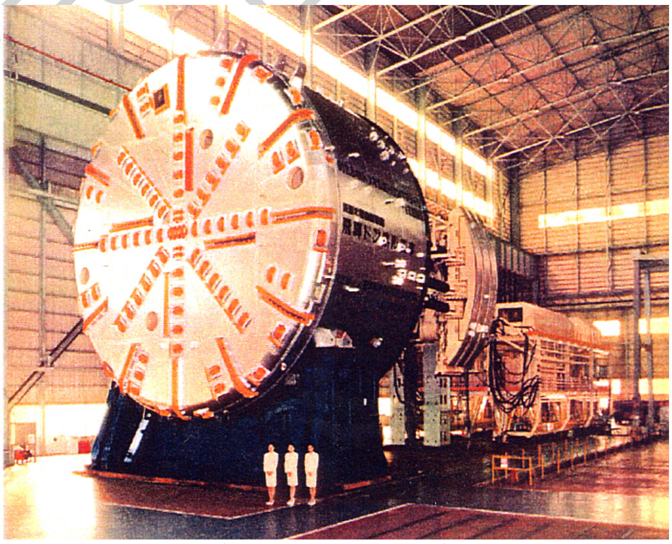
courtesy : TAISEI Corporation (Tokyo, JAPAN)

Figure 6. Belt conveyors

A new concept of tunneling supports, named the New Australian Tunneling Method (NATM), was introduced in the 1960s, in which the natural ground itself is to support the tunnel space through a combined use of sprayed concrete and rock bolts. This new method is based on the ideas that natural ground itself can support the tunnel space and that timely actions (changes) should be made to the tunnel support by measureing and monitoring the behavior of the natural ground.

The idea of excavating the entire cross-section of a rock tunnel with a tunneling machine instead of blasting was born in Italy in the middle of the 19th century. It was in 1952 when a machine close to today's TBM in terms of mechanism was produced and applied to a drainage canal tunneling project for the Oahe Dam, South Dakota, U.S.A. It was in those days that the rock tunneling technique using TBM (Figure 7) started to develop in the USA as well as in Europe. In the USA and Europe, where the ground was suitable for TBM tunneling, application of TBM rapidly increased, and technical standards were upgraded in the fields of excavation speed, applicability to various types of geology, and upsizing. TBM was thus more recognized and appreciated eventually. In the 1990s, an improved version of TBM tuned to softer ground was developed. Incorporating new functions, TBM has gradually increased the applicable range of geology type. Today, TBM is frequently used to drill pilot tunnels for road tunnels, large water channel tunnels and railroad tunnels of over 8m in diameter. The world's largest TBM of 12.8m in diameter, has also been in use for drilling two-lane road tunnels.

(diameter ： 8.3m)



(diameter ： 12.84m)

courtesy : TAISEI Corporation (Tokyo, JAPAN)

Figure 7. TBM (Tunnel Boring Machine)

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