ADDIS ABABA INSTITUT OF TECHNOLOGY (AAIT) SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

(M.ENG. Degree in Railway Civil Engineering)

Assessment of Railway Tunneling by Cut and Cover Method - Case study of the St. George Church Tunnel in Addis Ababa

By

MAMMO MUMICHA

This Project Submitted to School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirement of the Degree of Masters of Engineering in Railway Engineering

Advisor

Henok Fikire (Dr.Ing)

Mar. 2016

Addis Ababa

ADDIS ABABA INSTITUT OF TECHNOLOGY (AAIT) SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING (M.Eng. Degree in Railway Civil Engineering)

Assessment of Railway Tunneling by Cut and Cover Method - Case study of the St. George Church Tunnel in Addis Ababa

By

MAMMO MUMICHA

Approved by Board of Examiners

Henok Fikire (Dr. Ing)-------------------------	-------------------------	
Advisor	Signature	Date
--------------------------	------------------------	------------------------
Internal Examiner	Signature	Date
-----------------------------	------------------------	------------------------
External Examiner	Signature	Date
-------------------------	------------------------	
Chairman	Signature	Date

Declaration

I hereby declare that the thesis entitled "*Assessment of Railway Tunneling by Cut and Cover Method - Case study of the St. George Church Tunnel in Addis Ababa*" is original and has not been submitted for other degrees orthe like in this university or any other institutes. It does not contain any material, partly orwholly, published or written by others, except those references quoted in the text.

Mammo Mumicha ____________________ ________________________

Name Signature Date

Abstract

The aim of this work is to assess the construction method and used in tunnel -1 construction site for given site soil condition.

It is known that the cut and cover tunnel-1 alignment is under urban street and it needs a serious consideration to provided street for services after excavation; and also the construction method should have to secured the worker and society around the site construction during construction time. In addition, construction method should safe with respect to environmental &socio-economical of Ethiopian.

Finally, the construction method of the tunnel-1constructed by cut and cover is tested and assessed by literatures analysis. The construction method will addressed per global class trend and which applicable for Ethiopia depend on site investigation data.
Moreover, the studies permit assess and present the comparison of the nature, quality of construction method using to construct tunnul-1 around St. George Church site and the method should be used on such like site condition depend on site investigation data and socio-economic condition Ethiopia in case of Addis Ababa city around St. George church.

Acknowledgements

First of all, I would like to thankvery much the almighty God because of his enormous help in my life.

I am truly thankful to my advisor Dr. Ing. Henok Fikire for his best advice and assistance on my paper work and also I am grateful to my co-advisor Engineer Abraha Bezabh for his grate guidance.

I am grateful to EthiopianRailway Corporation (ERC) for accommodating me and sponsored my Masters of Engineering by Railway civil Engineering.

I would also like to show my gratitude to my fellow worker at ERC, Eng. Mokonin Getachew, who made my studies possible and supported me whatever possible.

I want to thank and Dr. Ing. Bikila Tekluhead ofSchool of Civil and Environmental Engineering; and AtoMequanent Mulgeta Railway Civil Engineering Coordinator for their information share and giving supportive letter.

Furthermore I owe my deepest gratitude to Eng. Eyob and Swedish company, Sweroad National Road Consultancy (SWEROAD)forhelping me to access tunnel construction site during my site assessment work.

Lastly but not least I am obliged to all the persons who I met and participated along my way and made me, and also this project, what it is today.

Mammo Mumicha

mumichamammo@gmail.com

March 2016

Contents

LIST OF FIGURES

LIST OF NOTATIONS

Abbreviation   Description

1. E-W East to West
2. N-S North to South
3. BCBefore Christ
4. AD Anno Domini
5. F France
6. GB Great Britain
7. USA United States of America
8. A Austria
9. CH China
10. (AA-LRT) Addis Ababa light railway transport
11. ERC Ethiopian Railway Corporation
12. HDPE High Density Polyethylene
13. PVC-P Polyvinyl Chloride - plasticizer
14. TPOThermoplastic Polyolefin
15. N-C-O Nitrogen –Carbon –Oxgen
16. SPU-301 Brand name of spraying Polyurethane
17. PME-EVA Brandname of Plastic Materia of ethylene–ethylenevinylalchol
18. CRGL China Railway Group Limited

CHAPTER1. INTRODUTION

1.1. Background

Addis Ababa Light Rail Transit Project is Composed of the E-W and N-S lines, and a semi-closed urban rail transit system. For the project, modern trolley car (DC750V power supply type) is used as the passenger train; DC750V diversified power supply system is adopted for the power supply system; most of tracks are constructed on the ground, and some sections are built on overhead bridges or in underground tunnels. The planned line has a total length of about 75 km which is to be constructed in two phases. The N-S (Phase I) Project starts from the east of St. George Church in the north and turns towards the south about 14.012Km is underground tunnel which is constructed as cut and cover tunnel and transition after a section laid along the north of Mercoto Market, then passes through the west of the market to Chad St. and integrates with the E-W line.[5]

Out of this about 659 m of the track is constructing in underground tunnel which is designed as cut and cover tunneling system.[5]

Tunnel construction is characterized as cut and covers construction when the tunnel structure is constructed in a braced or tied-back, trench-type excavation (“cut”) and is subsequently backfilled (“covered”). The tunnel is typically designed as a box-shaped frame, and due to limited space available in areas, it is usually constructed within a braced or anchored excavation.[1]

Where the tunnel alignment is beneath a city street, Cut-and cover construction interferes with traffic and other activities. The cut and cover construction originated in the mid of the 19th century with construction of the London underground train system. At the beginning of the 20th century it was further developed and applied in Berlin(Germany) ,and thereafter used all over the world.[1]

In tunneling, one of the first crucial decisions to be made in planning is the choice of the construction method, i.e. cut-and -cover or mined tunneling. In some cases the local conditions allow just one solution , for example ,if low or shallowoverburden exists due to topography and need to construct the tunnel at shallow, cut-and cover tunneling is may be the only feasible option. Cut and cover tunneling method construction carried out by (1) slope open cut construction method at place where no space limit, (2) bottom-up construction method at place where the space is limited to give enough slope for cut and allow to provide temporary support for soil lateral pressure, (3) top-down construction method at place where the space limited even to provide temporary rather than permanent support.[2]

1.2. Statement of the problem

Ethiopia is not familiar with cut and cover tunnel construction before. As far as cut and cover tunnel construction and design are new and modern of shallow depth tunnel under City Street, it is very interesting to recommend the construction method of cut and cover tunnel after this study.

It is planned to assess on construction method and design of construction method of cut and cover tunnel to analyze and present tunnel-1 to compare with the design of construction method of cut and cover which is reviewing under literature and come up with best output.

1.3. Objective of the study

1.3.1. General objective

The main objective of the study was to assess the construction method of tunnel-1 section which is around st.George Church and recommend the best construction methods relative to global trained.

1.3.2. Specific Objectives

- ✓ To assess and present construction method of cut and cover tunnel and method of waterproofing.
- ✓ To compare and contrast, and identify the gaps between construction method of tunnel-1 and actual trained constructions method for such like situation.
- ✓ To show the direction for future work on design of construction methods of tunneling by cut and cover.

1.4. Methodology

To meet the aforementioned objectives of the study, primary and secondary data collection methods will be employed. Moreover, assessment and determination of design of construction method of tunnel-1 will be conducted in the following manner:

1. Gathering available design of construction method data.
2. Site investigation and visiting.
3. Visiting and follow up the construction method used to construct tunnel-1.
4. Assessing material quality and work metrology to construct tunnel-1 and compare it with standard approach and recommend the gap.

CHAPTER - 2. LITIRATURE REVIEW

2.1. HistoricalDevelopment Time Line of Tunneling

The historical development of tunneling dates back thousands of years to ancient times. The firsttunnels were used to connect caves and later on for irrigating the fields with so called Qanates.[13]

Although the disciplines of tunneling and mining are closely related since ancient times, there aresome important distinctions.Regarding tunneling, the underground construction itself is the purpose of the excavation, and thearising spoil is just a byproduct, often without use. The tube itself needs to be stable, safe andaccessible for the designed use. [13]

Whereas the main purpose of mining is to recover minerals. In this context the construction itself isjust a necessity for the main goal, the recovery of the minerals and used for bringing worker to thematerial and the material out of the mine. That means normally less support and smaller crosssections. Anyway the work-steps needed to be carried out to reach both purposes are quite thesame, just in a different way. [13]

2.1.1. Ancient Times

The first underground constructions are dating back to 5000 BC in Malta and had the purpose toconnect some caves. First mines date back to the 24th century BC in Norfolk / Great Britain. In thisNeolithic mine flint was exploited and used for weapons and tools. [13]

The first historical known pedestrian tunnel dates back to the 22th century BC and was erected by theBabylonians beneath the Euphrates River. It was about 900 m (3000 ft) long. [13]

Salomon, King of Israel started to build tunnels for water transport in Jerusalem about 1000 BC.

About 600 BC Nebuchadnezzar was building the first arched traffic tunnel. Its length was about 1 km(3280 ft) and the dimensions were about 3.6 to 4.7 m (11.8 to 15.4 ft). A historical innovation of thistunnel was the first proofed use of iron made tools. [13]

Also about 600 BC the Eupalinos Tunnel was built in Samos. It had a length of about 1040 m (3400 ft)and it was the second historically proofed tunnel which was dug from two portals.The Pausilippo Tunnel near Naples was constructed in 36 BC. It was 1460 m (4800 ft) long, 7.6 m (25ft) wide and 9.1 m (30 ft) high. The mayor invention regarding this tunnel was the introduction ofproper surveying methods. [13]

At another Roman Tunnel, the Lacus Fucinus built in 41 AD, 30.000 workers were digging about 10years before completing the 6 km (3.5 mi) long tunnel. [13]

A quite common method to crush the stone at this time was the so called Fire-Quenching, where therock gets heated by fire, and suddenly quenched with water. Because of the arising stresses the rockcrushes. [13]

The Egyptians, Greeks and Romans forced slaves, prisoners, prisoners of war and other outcasts to workin their mines and underground constructions. This led to a bad reputation of miners.The middle European countries therefore employed freeman, which were more skilled and also had alot more respect in the society. This is proofed by some historical diggings in Hallstatt, Austria wheresince 2500 BC salt was exploited. In this mines a lot more attention was paid to ventilation and safetymeasures. [13]

2.1.2. Middle Ages

During the Middle Ages from about 600 to 1500 there was nearly no progress in proper tunneling. Atthis time almost all underground constructions were used as mines.

A metal mining industry was arising in the area of South Germany, Austria, Czech, Slovakia andHungary. There were some technical advances but no mayor innovations. The only change was thepicture of the job miner. [13]

2.1.3. Revival of Tunneling

After a period of inactivity in tunneling, the French renewed this profession in the 17th century. Just France was the only politically quite stable and allowed itsengineers and scientists to develop and research without restrictions and political barriers. Out ofthis France began to build and establish a quite good infrastructure. The only nation at this time whocould compete with the France and even had a better infrastructure was the Austrian-HungaryEmpire. [13]

The most important tunnels constructed and inventions at this time have been:

1627 Schemnitz (Slovakia): In the Schemnitz or Selmecbanya mines gunpowder was introduced.Although it was already tested in some German mines, Selmecbanya was the first mine using itproperly to exploit the minerals. [13]

1666 Canal du Midi (France): The Canal du Midi had a length of about 157 m (515 ft) and is supposedto be the first tunnel with mayor use of blasting gunpowder. It was also one of the first tunnels aftercenturies of stagnation. [13]

1678 Malpas Tunnel (F): The Malpas Tunnel is also one of the first tunnels after time of stagnation. Itwas about 157 m (515 ft) long and at first build without lining. The cross-section with more than 8 m(26 ft) was also very impressive. [13]

1761 Bridgewater Canal Tunnel (Great Britain): The Bridgewater Canal Tunnel was part of a canalsystem built for boat traffic shipping coal from the Worsley Mine to Manchester. It was the firstmodern tunnel in Great Britain. [13]

1770 Tunnel de Gier (F): After the Malpas Tunnel was build; it took 90 years till another big andchallenging tunnel project was started. It was the 522 m (1.700 ft) long Tunnel de Gier, part of therailroad track between St. Etienne and Lyon. [13]

2.1.4. Industrial Age

1803 Canal of St. Quentin (F): The Tunnel of Tronquoy as part of the Canal of St. Quentin was a bigstep into modern tunneling. It was one of the first tunnels with a diameter of about eight meter (26ft) in squeezing rock. The engineers decided to excavate the tunnel profile in multiple sections. So aseparate lining in each of the sections was possible which reduced the stresses. Once all lining workswere finished the core of the tunnel was removed safely. [13]

This tunnel was the beginning of a new age in tunneling, because it was the first tunnel using properengineering principles. [13]

1824 Tunnel of Pouilly (F): The Tunnel of Pouilly is another important tunnel in France which was alsobuilt using the above mentioned Core-Method. [13]

1825 Wapping-Rotherhithe Tunnel (GB): The Wapping-Rotherhithe Tunnel was the first tunnel usinga tunnel shield, developed by Bruce, and his son Isambard, Brunel. The tunnel was built under theRiver Thames and became the first subaqueous tunnel. Because of several floorings the work stoppedfor several years. In 1841, after a construction time of nine years, the 365 m (1.200 ft) long tunnelwas finally finished. [13]

1831 Staple Bend Tunnel (USA): The Staple Bend Tunnel was part of the Allegheny Portage RailroadSystem and the first railroad tunnel in the United States. Its length was about 275 m (901 ft) and theheight was about 5,8 m (19 ft). [13]

1836 / 1837 (Germany): The first and second Railroad tunnels in Germany were constructed.

1839 Gumpoldskirchen (Austria): Near Gumpoldskirchen the first railroad tunnel in Austria was builtas a part of the railway line between Vienna and Trieste. [13]

1840 Woodhead Tunnel (GB): The Woodhead Tunnel was part of the railroad line between Sheffieldand Manchester. With its length of about 4.840 m (3 mi) it was one of the longest railroad tunnels atthis time. [13]

1849 Semmering Tunnel (A): It was about 1400 m (4600 ft) long. More than 1200 men were workingat this tunnel, which was part of the first European mountain standard railway. [13]

1855 Hoosac Tunnel (USA): The Hoosac Tunnel was part of the canal system between Boston and Albany and about 7.3 km (4.5 mi) long. It took about 22 years to construct the 6.4 m (21 ft) high and 7.3 m (24 ft) wide bore. It was the first time dynamite and electric firing explosives were used intunneling. Another big impact for the whole construction industry was the invention and use ofpower drills with air, which gave the impulse for the development of the whole compressed airtechnology. [13]

1857 Mount Cenis (F): The Mount Cenis Tunnel near Frejus in the French Alps was the first tunnelforced by a mechanical tunneling machine. It took about 14 years to build this 13.7 km (8.5 mi) longtunnel and it is a milestone in tunneling. Innovations like rail mounted drills; hydraulic ram aircompressors and more advanced boring technology were introduced, and led to much better forcingrates. Furthermore better methods of ventilation and surveying were used. Another novelty was theconstruction of houses and camps for the miners, including housing for their families, schools andhospitals. [13]

1872 St. Gotthard (Swiss): The St. Gotthard is a 15 km (9 mi) long railway tunnel through the SwissAlps. About 3.000 workers needed about seven and a half year to finish the tunnel. The tunnel wasone of the most impressive constructions at his time but also turned the small villages at the portalsinto worker-towns with awful living conditions. The Gotthard is probably one of the most famoustunnels. [13]

1880 Hudson Tunnel (USA): The Hudson Tunnel was the first attempt to force a tunnel with justcompressed air. After mayor fatalities the project was stopped.Second half of 19th century: London Subway (GB): At this time the city of London started to build thefirst underground railway system in the world. The amount of underground tubes continued steadilyduring the second half of the 19th century. [13]

1898 Simplon Tunnel (CH): With its length of 19.3 km (12 mi) the Simplon Tunnel was the longestmountain tunnel for over 70 years. Like at the Gotthard tunnel the working conditions were prettybad and a lot of workers died under the harmful conditions. [13]

1901 Tauern Tunnel (A): Construction of the Tauern Railroad Tunnel with a length of 8550 m (5.3 mi) [13]

1906 Loetschberg Tunnel (CH): The Loetschberg Tunnel is also located in the Swiss Alps. It is 14.6 km (9.1 mi) long and is inglorious famous for the death of 26 workers because of an inflow of water andgravel on a length of 1.500 m (4.900 ft). The surface above this area settled about 3 m (10 ft). [13]

1906 Detroit Tunnel: The central Michigan Railway Tunnel or Detroit Tunnel was the first modernimmersed tunnel. It is about 2.560 m (1.6 mi) long and still connects the American city Detroit withthe Canadian city Windsor under the Detroit River.

1927 Holland Tunnel (USA): The Holland Tunnel is connecting the cities New York and New Jerseybelow the Hudson River. It was named after the chief-engineer Clifford Holland and the firstautomotive tunnel ever built. For its purpose of automotive traffic it was in need of a properventilation system to blow the exhausts out of the tunnel and fresh air into it. [13]

1954 Oahe Dam (USA): At the Oahe Dam in South Dakota the first use of a mechanical rotaryexcavator, named the Mittry Mole, was conducted. [13]

2.2. Types of Tunneling

2.2.1 General

Tunneling is one of the most exciting professions in the field of construction engineering and construction management. Every project is unique, rather be every round length is unique. For almost no other type of construction the predictions and the foreseeing of the advancement is so difficult.[12]

There is a long history in tunneling and mining and it all started thousands of years ago. Engineers and miners developed and used quite impressive methods and technologies at those times. But progress in tunneling didn't continue that way, over a lot of centuries miners only exploited resources but almost no progress in tunneling was made. [12]

Due to the industrial revolution a huge step in technical improvements was made and had led to an increase of knowledge in tunneling. The most inventions in tunneling were made over the last two centuries.[12]

Tunnels became a lifeline of cities and society and are in direct interaction with the rise of the Metropolises and contrariwise. In the year 2000 already 21 cities have grown to so called megacitieswith a population of more than 10000000 people. [12]

When talking about underground construction there are some specific terms and meanings. While insome cases the German language provides exact terms for different underground constructions or itspurposes, the English terms can be used for a broader or different range of meaning. The sameproblem can occur vice versa.Therefore the attempt to work out proper and exact translations for providing a list of words withexactly the same signification failed. [12]

An example is the German word ‘Tunnel’, which is nowadays defined as a horizontal undergroundstructure for the purpose of railroad, automobile or pedestrian traffic with two portals. So this is aquite clear definition. In English the word tunnel just stands for “an essentially horizontalunderground passageway” So that also includes waste water and other non-human traffic or it couldalso be an adit.[12]

At this point is has to be mentioned that the word tunnel was inherited in the 18th century from theEnglish language and over the decades many different definitions emerged, till todays definition, stillnot agreeing with everyone’s opinion, was established. [13]

There are not just only many ways of using a tunnel, but also many ways to construct them as well as todifferentiate them. The following table gives a quick overview. [13]

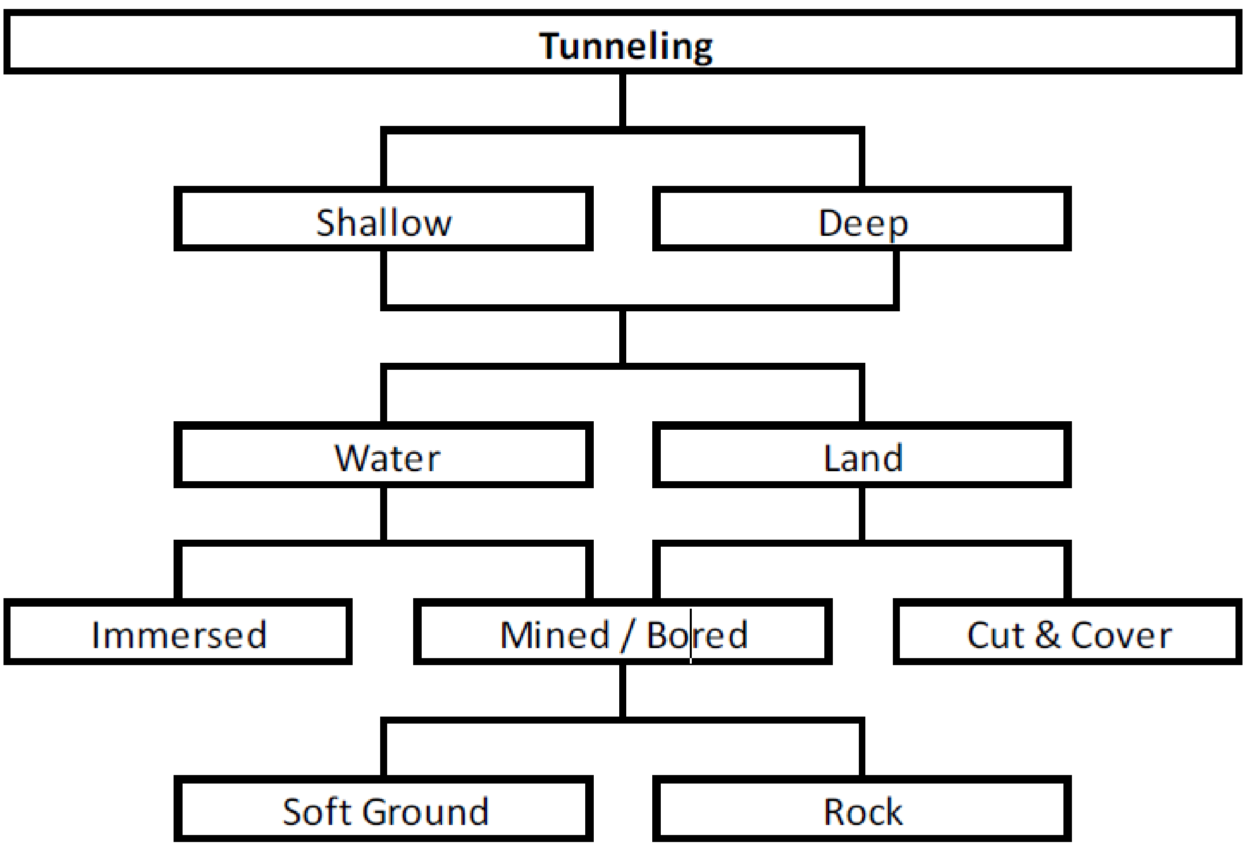


Figure1: Tunnel Classification chart[13]

We can divide tunnel to different category depending on depth (site) of tunnel, construction techniques, and ground condition

2.2.2.Depending on Depth (Site) of Tunnel

2.2.2.1. Shallow Tunnel

There is no standardized or official definition, stating where the line between a shallow and a deep-settunnel is.[13]

A few thoughts about shallow tunnels have a quite similar outcome. One of these outcomes is that ashallow tunnel has to carry all the loads from the ground above. This is closely related to the ideathat shallow tunnels are built above bedrock and therefore can't use the ground as a structuralelement. Another thought is that as long as a tunnel is directly influencing the surface and theobjects above the surface it is a shallow tunnel. This brings us back to the statement, which theartificial structure has to carry all the loads from above.[13]

2.2.2.2. Deep-Set Tunnel

Opposed to the shallow tunnels, deep-set tunnels do not directly interfere with the surface. Normallythe rock stresses are just influencing the surroundings of the bore in a proper way. The nearer to thesurface the stresses are measured the more they are decreasing. Since this is a general attempt ofdefining a deep set tunnel, it may not be correct in every case.[13]

2.2.3. Depending on Construction Method (technique)

2.2.3.1. Immersed Tunnel

Immersed tunnels are built beneath water and exist of precast tunnel segments which are mostlymade of reinforced concrete and sometimes steel. These segments are produced in a dry dock whichthen are shipped or floated to their designated location. Once they arrive, every segment getsimmersed and placed in an excavated trench. When placed, they get connected and sealed to thealready immersed segments. These steps continue till all segments are connected to a whole tunnel.[13]

2.2.3.2. Mined / Bored Tunnel

A mined tunnel is a bore or a tube which is totally excavated beneath the surface. There are one ormore portals, shafts or caverns where the excavation starts from. Regarding the excavation there aremany ways of proceeding. Excavation could for example be done by digging, blasting or boring.[13]

2.2.3.3. Cut and Cover Tunnel

Cut and Cover means in a very simple way, that first a trench is excavated from the surface. Whenthe ground is removed the “tunnel” is erected. One possibility is doing that by placing precastelements or by constructing the tunnel-frame in-situ. The in-situ construction can be done using atunnel-form-work or by erecting ordinary concrete walls and slabs. Once the tunnel structure isfinished the remaining trench is refilled with soil, until the whole structure is covered and buried.[13]

2.2.4. Depending on ground conditions

Different ground conditions need different construction methods, geological investigations,surveillance methods and construction sequences. Therefore one of the most important pointsregarding tunneling is a very good knowledge about the ground. In terms of the ground conditions,there can be two mayor distinctions made.[13]

2.2.4.1. Soft Ground Tunnel

Soft ground is defined by its “*mechanical properties, grain size distribution, density, mineralcomposition, parameters of the soil components, matrix parameters, and water content and hydraulic properties*”.[13]

Tunneling in soft ground brings quite different problems and requirements than hard rock tunnelingwith it. In most cases the ground is not able to be structural part, and excavation rounds are need tokept short. Often shields are used to prevent the tunnel from collapsing.[13]

2.2.4.2. Hard Rock Tunnel

Rock is defined by "*mechanical properties (intact rock - rock mass), discontinuity, characteristics andproperties, rock type, rock- and rock mass conditions and hydraulic properties*".[13]

When tunneling in hard rock, the rock is used as a part of the structure. Normally quite less supportmeasures need to be carried out and the open face area can be quite larger than in soft ground.[13]

2.3. Cut and Cover Tunnel

2.3.1. General

The "Cut and Cover" and "Cover and Cut" methods are advanced engineering techniques fortunnel construction in urban and interurban areas. Initially meant for subway tunneling, the "Cutand Cover" method has been lately adopted in motorway projects to deal with small-depth roadtunnels and local environmental constraints. The main concept of the method consists of fulllengthor sequential excavation along the road segment and subsequent construction of the tunnelbore. Following drainage and waterproofing measures, backfilling requires a well-monitoredconstruction process, adequately defined in terms of equipment and quality control. Environmentalissues, such as planting and seeding, constitute the final stage, complemented, eventually, byreconstruction of the secondary road network upslope.

The “Cover and Cut” method for tunnel construction was originally developed for urbansubway structures where the least possible disruption of traffic is required. In motorwayconstruction projects, road designers prescribe the method for underground structures to efficientlyface major issues of instability. At a first stage, a shallow excavation and grading is performed,followed by the construction of a sub-soil concrete “vault”. This vault acting as a retainingstructure provides full protection to the main excavation activities below carried out byconventional drilling and hauling equipment. [**]

And also when cut and cover tunnel structure is constructed in a braced or tied-back, trench-type excavation (“cut”) and is subsequently backfilled (“covered”). The tunnel is typically designed as a box-shaped frame, and due to limited space available in areas, it is usually constructed within a braced or anchored excavation.

Where the tunnel alignment is beneath a city street, Cut-and cover construction interferes with traffic and other activities. The cut and cover construction originated in the mid of the 19th century with construction of the London underground train system. At the beginning of the 20th century it was further developed and applied in Berlin(Germany) ,and thereafter used all over the world.[1]

In a cut and cover tunnel, the structure is built inside an excavation and covered over with backfill material when construction of the structure is complete. Cut and cover construction is used when the tunnel profile is shallow and the excavation from the surface is possible, economical, and acceptable. Cut and cover construction is used for underpasses, the approach sections to mined tunnels and for tunnels in flat terrain or where it is advantageous to construct the tunnel at a shallow depth.[2]

For depths of 30 to 40 feet (about 10 m to 12 m), cut-and-cover is usually more economical and more practical than mined or bored tunneling. The cut-and-cover tunnel is usually designed as a rigid frame box structure. In urban areas, due to the limited available space, the tunnel is usually constructed within a neat excavation line using braced or tied back excavation supporting walls. Wherever construction space permits, in open areas beyond urban development, it may be more economical to employ open cut construction. Where the tunnel alignment is beneath a city street, the cut-and-cover construction will cause interference with traffic and other urban activities. This disruption can be lessened through the use of decking over the excavation to restore traffic. Whilemost cut-and-cover tunnels have a relatively shallow depth to the invert, depths to 60 feet (18 m) are not uncommon; depths rarely exceed 100 feet (30 m). [2]

Because of the under pass of tunnel way should connected to the on pass way and overpass way of light railway (AA-LRT) rout within a limit elevation variation, China Railway Engineering (CRE) used cut and cover method to construct Tunnel -1 of Addis Ababa light railway transport (AA-LRT) which is the best way to solve the scarcity of public transportation.

2.3.2. Cut and Cover Tunnel Construction Method

The "cut and cover" and the "cover and cut" are two techniques for tunnel construction in highway engineering. The "**Cut and Cover**" method has been used for a long time in urban subway construction but also in interurban transportation projects, in the construction of relatively short and shallow highway and railway tunnels. Lately, the method has been adequately adapted to facilitate construction of tunnel portals.[12]

The basic concept of the method is to excavate a trench or a cut which must be roofed over and to concrete a tunnel in situ covered subsequently with fill material.[12]

This technique involves stepped excavation and implementation of support either by means of temporary walls and bracing systems so as to support the slopes of the excavation. In cases of extremely adverse geotechnical conditions, pre-strengthening might be necessary in order to minimize or avoid stability problems during the excavation phase. Therefore, sheet piles or “Berliner walls” have become common practice in “cut and cover” construction.Once the foundation level has been reached, concreting of the tunnel commences, to be followed by waterproofing and placement of backfill.[12]

The “**Cover and Cut**” method was originally developed for construction of shallow underground structures in congested urban areas, where open excavation techniques would cause significant disruption to traffic. The fundamental concept of the method comprises a first stage of constructing the “cover”, an earth retaining concrete shell, followed by the second stage, the “cutting” operation, representing the main excavating activities under the previously constructed “cover”. These retaining effects in road tunnel engineering are established by concrete vaults, providing safe cover to excavating activities underneath.[12]

In urban areas, the traffic disruption criterion is decisive and dictates use of the “Cover and Cut” method, whenever conventional tunneling methods (TBM or other) are not applicable. Conversely, in rural areas, it is mostly the landslide risk that leads to the solution of the “cover and cut” technique. In rare cases, buildings, installations and natural obstacles in the vicinity of the greater area of the intended excavation activities prescribe application of this method instead of the ordinary “non-retained” excavation operations.

The “cut and cover” technique is a simple construction method widely applied in both urban and rural tunneling projects. The main prerequisites for application of the method are the dominance of soft or weak ground conditions and/or low overburden.

The “cut and cover” method consists of excavating an open cut by applying, practically, technical means identical to the traditional excavation process and by constructing a single or twin tunnel lining under ordinary building engineering conditions. Once the cast-in-place concrete structure finished and particular waterproofing and drainage measures taken, fill operations are carried out, usually, up to the initial ground level. Caution at the compaction process during the construction of the first inferior soil layers is necessary, since heavy vibrating rollers risk provoking distress to the tunnel structure. Utilities and local transportation network are subsequently restored and multiple environmental rehabilitation actions are performed.

Tunneling in rural areas, either for highway or railway projects, is expected to involve the use of the “cut and cover” method in cases where a cut along the alignment is to be carried out in weak material and/or in areas with a potential for landslide development no matter whether new or recurring. Therefore, in some cases of poor ground conditions; it is slope instability that calls for application of the method. It can be asserted that modification of the alignment in case of geotechnical instability might be more effective and time savingalternative. There are, however, cases, especially in mountainous terrains with high relief andstability problems, where realigning part or all of a project is not a realistic option.

In rural engineering projects, the “cut and cover” tunnels are constructed using openexcavation methods to form the cut section required. In areas where shaping of a slope to thesoil intrinsic properties tackles to space constraints, additional measures to reduce the area ofoperations must be taken. Moderately unfavorable ground conditions are handled by meansof ground anchors, drilled and stressed in the course of the excavation process.

Cut-and-Cover construction can be subdivided into two methods. For the first method, the shoring walls (support of excavation) are used only during the construction and the tunnel is built independently in the pit. The second method, which is also called "Open-Cut Method", employs the shoring walls as an integral part of the tunnel.[1]

There are two common known excavation in cut and cover construction method.

- Top-down construction method, and
- Bottom-up construction method.

2.3.2.1. Top-down construction method

Apart from Open Cut Excavation Method for construction of the tunnels, Top-down Construction Method was used in part of the South Ingress and Egress Tunnels close toSungaiBesi Old Airfield. The construction method was adopted due to constraints ofexisting site conditions and tight construction schedule. Also, the traffic flow at the stretch of Sungai Besi Old Airfield along Kuala Lumpur-Seremban Highway was very heavy and difficult to be diverted for other construction methods. The top-down construction works began from upper portion toward lower portion of the box tunnel. It was very different and reversed from conventional construction method in the sequence of construction. [4]

In top-down method, side support walls and capping beams are constructed from ground level by such methods as slurry walling, or contiguous bored piling. Then a shallow excavation allows making the tunnel roof of precast beams or in-situ concrete. The surface is then reinstated except for access openings. This allows early reinstatement ofroadways, services and other surface features. Excavation then takes place under the permanent tunnel roof, and the base slab is constructed [6].For wider tunnels, temporary or permanent piles or wall elements are sometimes installed along the center of the proposed tunnel to reduce the span of the roof and floors of the tunnel[2].

Top-down sequence of construction generally consists of the following steps: [2]

Step 1a: Installation of excavation support/tunnel structural walls, such as slurry walls or secant pile walls

Step 1b: Dewatering within the excavation limits if required

Step 2a: Excavation to the level of the bottom of the tunnel top slab

Step 2b: Construction and waterproofing of the tunnel top slab tying it to the support of excavation walls

Step 3a: Backfilling the roof and restoring the ground surface

Step 3b: Excavation of tunnel interior, bracing ofthe support of excavation walls is installed as required during excavation

Step 3c: Construction of the tunnel floor slab and tying it to the support of excavation walls; and

Step 4: Completing the interior finishes including the secondary walls.

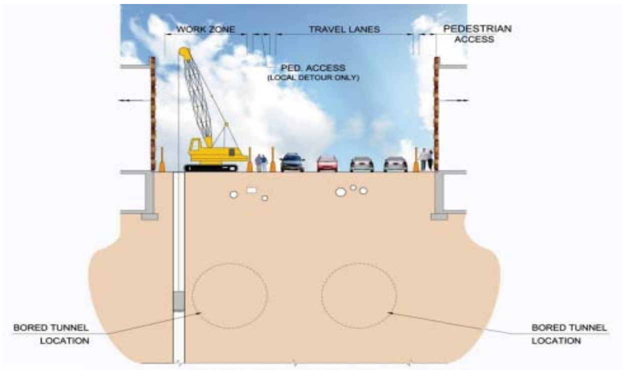


Fig. 2: step 1a[7]

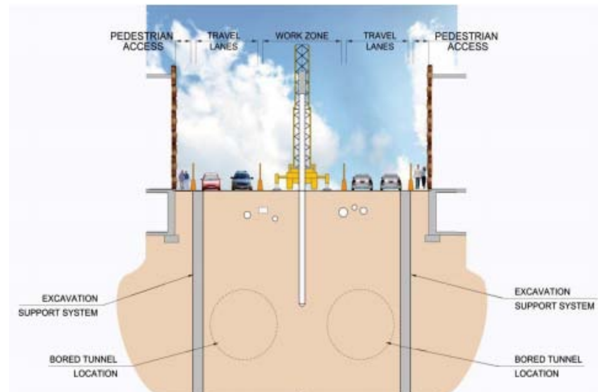


Fig.4: step1c[7]

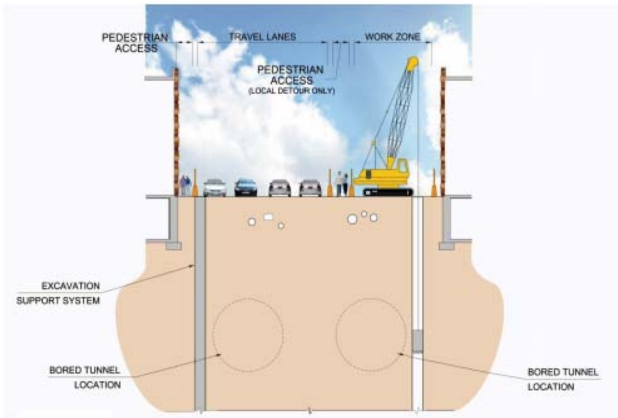


Fig.3: step 1b[7]

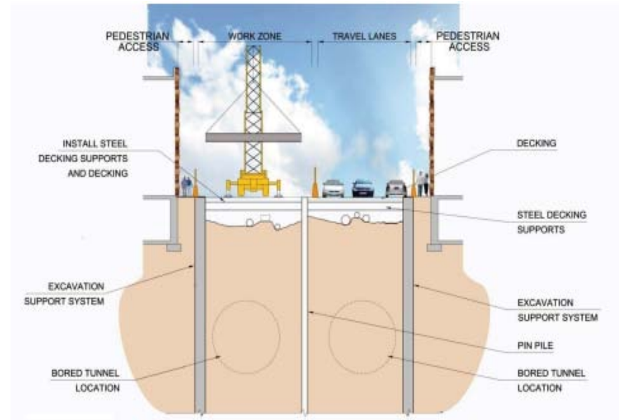


Fig. 7:step 3a[7]

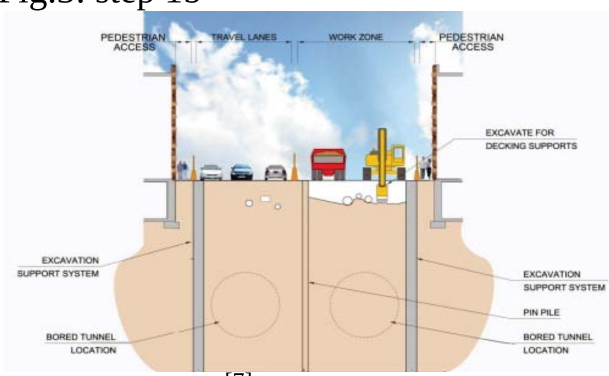


Fig.5: Step 2 a[7]

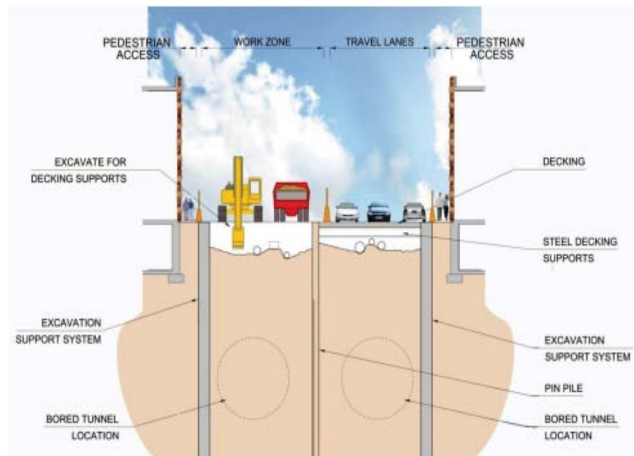


Fig. 8: step 3b[7]

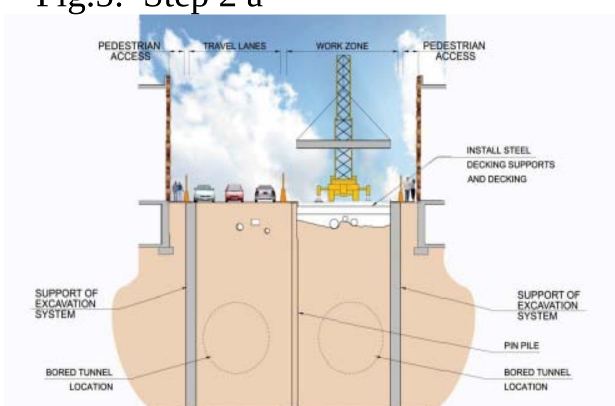


Fig.6: step 2b[7]

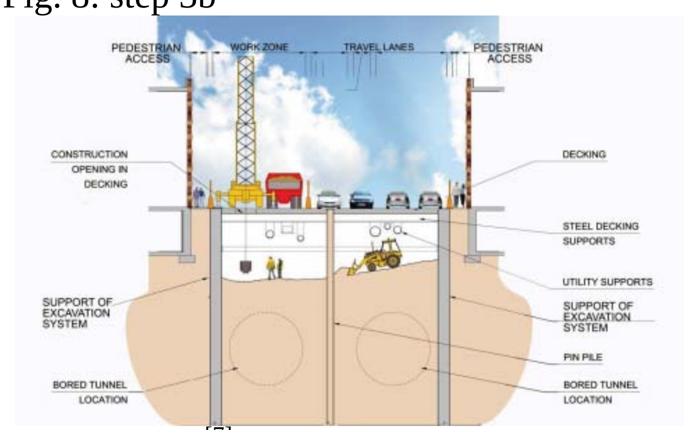


Fig.9: step 3c[7]

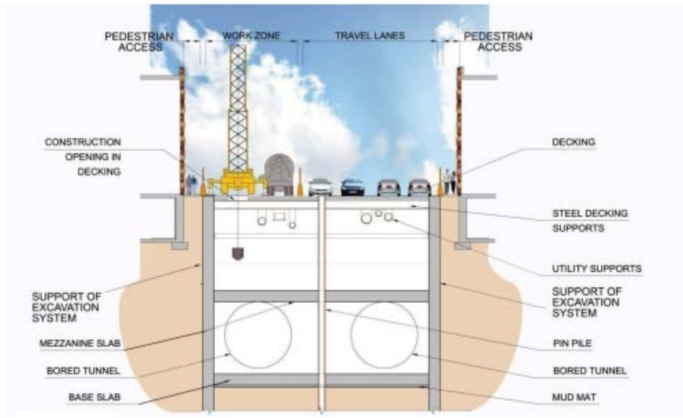


Fig. 10: step 4a[7]

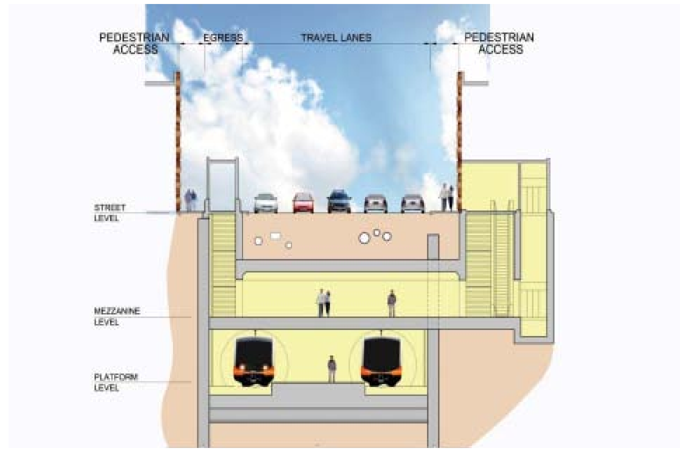


Fig. 11:step 4b[7]

Conditions Favorable to Top-DownConstruction:[2]

• Limited width of right-of-way

• Sidewall deflections must be limited to protect adjacent features

• Surface must be restored to permanent usable condition as soon as possible

2.3.2.2. Bottom-upconstruction method

In the conventional “bottom-up” construction, a trench is excavated from the surface within which the tunnel is constructed and thenthe trench is backfilled and the surface restored afterward. The trench can be formed using open cut (sides sloped back and unsupported), or with vertical faces using an excavation support system. In bottom-up construction, the tunnel is completed before it is covered up and the surface reinstated.[2]

Fig. 12: Bottom –up Construction Method at Limit Space in Urban[12]

In bottom-up construction method bottom floor excavation is easily accessible for equipment and for the delivery, storage and placement of construction materials.[2]

For these reasons, bottom-up construction is perhaps the most economical method for contractors to build large, shallow tunnels, but has the disadvantage of making the site space unusable longer than either of the other methods.

Conventional bottom-up sequence of construction generally consists of the following steps: [2]

Step 1a: Installation of temporary excavation support walls, such as soldier pile and lagging, sheet piling, slurry walls, tangent or secant pile walls

Step 1b: Dewatering within the trench if required

Step 1c: Excavation and installation of temporary wall support elements such as struts or tie backs.

Step 2: Construction of the tunnel structure by constructing the floor;

Step 3: Compete construction of the walls and then the roof, apply waterproofing as required;

Step 4: Backfilling to final grade and restoring the ground surface.

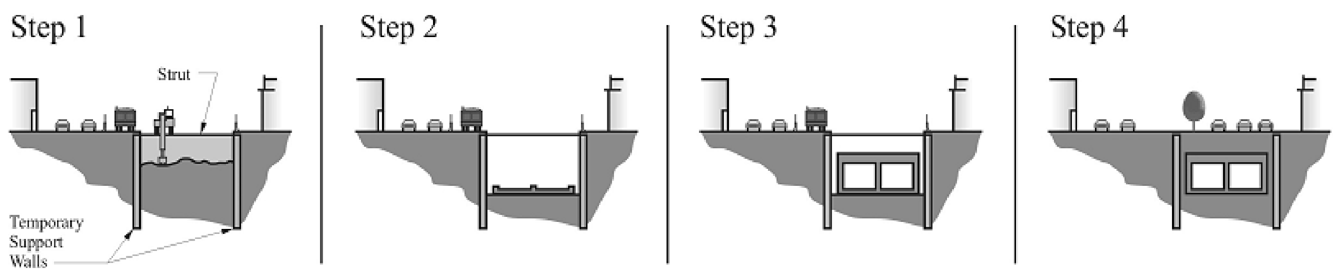


Fig.13Cut-and-Cover Tunnel Bottom-Up Construction Sequence[2]

Conditions Favorable to Bottom-Up Construction:[2]

• No right-of way restrictions

• No requirement to limit sidewall deflections

• No requirement for permanent restoration of surface

2.3.3. Types of Sheeting and Bracing (Supporting) Systems in Cuts

Where the tunnel alignment is beneath a city street, the cut-and-cover construction will cause interferencewith traffic and other urban activities. This disruption can be lessened through the use of decking over the excavation to restore traffic.[2]

Support of excavation is an important aspect of cut and cover construction to avoid slope cut because of the space limit for slope cut in the urban, and the design of support of excavation to keep the trench cut stable.

Now days, there are several types of bracing systems in use which the choice of bracing is closely related to ground wall support, depth of excavation and construction of the permanent structure.[5]

These walls must besupported with internal struts or tiebacks as the excavation is deepened to avoid instability and controlsettlement at the sides of the cut. Depending upon the depth of excavation and the ground conditions thefollowing methods of shoring would be used:[9]

- ***Cased secant piles*** - Cased secant piles are non-driven piles that can be used for ground support in soft ground and hard ground. Secant pile walls are formed by constructing interlocked concrete piles reinforced with either steel rebar or beams. Used extensively in dense population areas due to the minimal disturbance they cause to adjacent structures, secant pile walls are commonly used for shafts and stations in saturated soil conditions. The steel reinforcement in the form of reinforcing bar or wide-flange sections can be dropped or vibrated into place.[9]

- ***Soldier pile and lagging walls*** - Soldier pile wall construction is feasible in unsaturated or dewateredsoils with sufficient stand-up time to allow some soil exposure prior to placement of lagging walls tohold back soils. This method of construction can cause difficulties during excavation in loose sandsthat tend to ravel or soft clays that fast ravel or squeeze. Soldier pile and lagging support is notwatertight and requires dewatering below the groundwater table. This construction method would bemost applicable where compressible materials such as Bay Mud are not present since dewatering cangenerate excessive settlement adjacent to the walls.[9]

- ***Sheet pile walls*** - Sheet pile walls are watertight and do not require dewatering, although they cannotbe driven where obstructions or hard materials are present in the soil profile. Sheet piles can bedriven to depths up to approximately 60 feet in dense sands and up to approximately 85 feet in soft tomedium clays. A disadvantage of this method is that it is not adaptable to utility crossings. Likesoldier pile and lagging walls, sheet pile walls would most likely be employed at the south end of theCentral Subway alignment, where utility crossings do not preclude its use.[9]

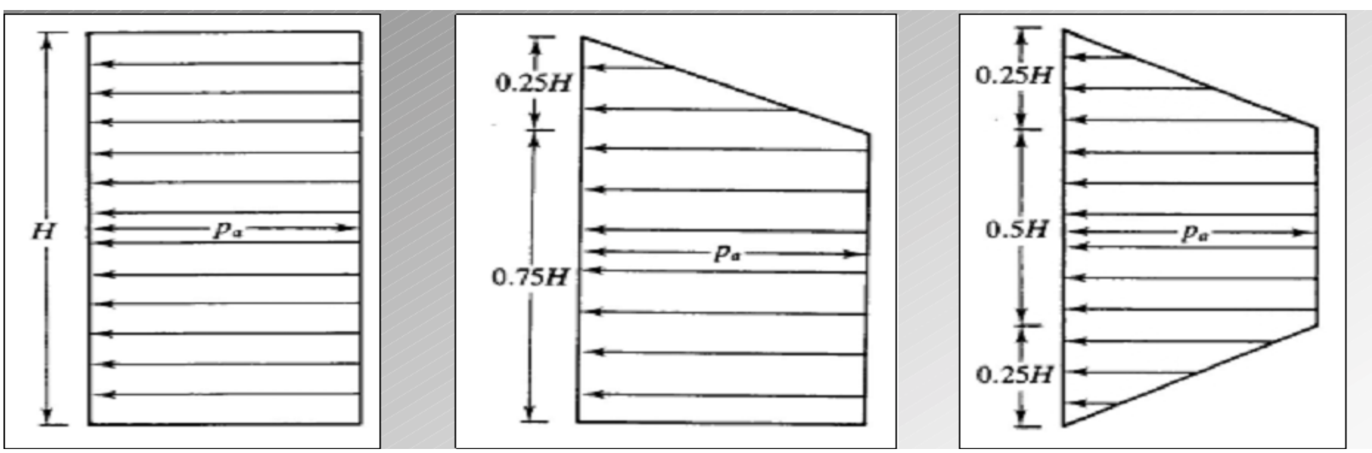
- ***Diaphragm slurry walls*** - Several types of diaphragm slurry walls are applicable to construction of thesubway section of the Project. Diaphragm walls have been constructed in virtually all soil types, butmainly in soft to medium stiff clays, saturated silts, and saturated, loose silty or clayey sands. Thesewalls provide a watertight support system like sheet pile walls and, in addition, provide greater wallstiffness, which helps to control settlement. Construction of diaphragm walls also has the advantageof causing much less noise and vibration than driving sheet pile walls. Diaphragm slurry walls are sometimes used as permanent walls within the cut. As with sheet pile walls, diaphragm walls are not adaptable to utility crossings since all utilities crossed by the wall must be relocated.Diaphragm walls are used in the deep part of the Tunnel. The soil is excavated in trenches using a 'bucket grabs'. The trenches are supported as they are excavated with 'Bentonite' suspension, as a temporary measure to secure its sides. Readymix concrete is later pumped into the trench displacing the 'Bentonite', which is recycled. Once the excavation to the required depth is complete, base slab of reinforced concrete is poured. The waterproofed base acts as an additional support to the sides of the excavation. The long travelling shutter is positioned and steel reinforcing is fixed around the shutter. Ready-mix concrete is then poured to a thickness of tunnel wall in the form of a tunnel designed shape, which was adapted for better structural performance.[9]

- ***Soil-cement-mixed walls*** – Continuous soil-cement walls are installed underground using mechanicalsoil-mixing technology for the purposes of excavation support, ground water control and containmentof contaminated soil. The equipment for this purpose usually has multiple shaft augers to install apanel element consisting of multiple overlapped soil-cement columns. The panels overlap each otherto form continuous soil-cement walls. A recent development uses large trench cutting equipmentequipped with the chainsaw-like cutter, which moves horizontally while cutting and mixing in-situsoil with cement grout to form seamless soil-cement walls. A narrow trench is excavated underbentonite slurry. The excavation is completed to the final trench depth with the slurry acting as astabilizing agent to keep the walls of the trench from collapsing. Once the excavation of the trenchhas progressed to some point clear of the starting point, it is backfilled with a blended mixture of soil,bentonite slurry, dry bentonite and cement. Backfill is placed in the trench after the excavation iscompleted by forming a slope of the mixed material that slumps down and displaces the liquid slurryforward. The excavation proceeds at the same rate as backfilling, so that the distance between theexcavator and the backfill placement point remains relatively constant.[9]

An alternative to use of sheeting and bracing system, which is being increasingly used these days, is the construction of slurry trenches around the area to be excavated. The slurry stabilizes the walls of the trench, and thus the excavation can be done without sheeting and bracing. The concrete and reinforcement (if required) is placed in the trench, and concrete displaced the slurry.[5]

Some form of internal bracing or tiebacks is required with some of the wall types discussed above. Internalbracing is the most commonly used support for narrow cut-and-cover excavations. An alternative tointernal bracing support is the use of tiebacks. Tiebacks may be feasible for some elements of cut-andcoverconstruction on the Central Subway, but have several disadvantages. Tiebacks may requireadditional right-of-way to extend anchors beyond the excavation line, which may not be possible wherebasements exist, and they generally are not economical for excavations less than 60 feet wide. [9]

Design of earth pressure on braced cutwhich suggestedPeck (1969) using design pressure envelopes for braced cuts in sand and clay.



Sand **Soft-Medium Clay** **Stiff Clay**

$P_a = 0.65\gamma H K_a$ $P_a = \gamma H\left[1-\left(4C/\gamma H\right)\right]$ $P_a = 0.2\gamma H$ to $0.4\gamma H$

Fig.14Earth Pressure Distribution on Trench Excavation Bracing Support[5]

2.4. Waterproofing and Waterproofing Materials

2.4.1. General

The existence of a high groundwater table or water percolating down from above requires that tunnels be waterproof. Durability is improved when the tunnel is waterproof. Good waterproofing design is alsoimperative to keep the tunnel dry and reduce future maintenance. Leaking tunnels are unsightly and can give rise to concern by users.[2]

There are a large number of qualities waterproofing productsavailable which provide tunnel engineers with the capacityto achieve any number of waterproofing goals.

Waterproofing materials range greatly in the tunnelingindustry. From fast-setting micro-cements and highlypenetrating colloidal silica gels for soil/rock per-injection, toflexible polymeric sheet and spray applied membranes, to self-adhered membrane and sodium betoniessystems that form a continuous mechanical bond to theexterior of the tunnel lining. Additionally, many tunneldesigns still incorporate interior water collection troughsand discharge pits to dispose of water seepage of apredetermined “allowable” ingress flow rate.Leading engineering firms are incorporating joint sealingsystems for tunnel waterproofing applications. An exampleof this expanding hydrophilic rubber or bentoniteconcrete joint waterstops, which are installed in theconcrete construction joints and around penetrations. And also markets a complete range of PVC-P, PE or PP geomembranes in response to a wide variety of applications.

Experience has shown that the PVC-P geomembrane is the most suitable for waterproofing of cut and covers buildings due to its excellentmechanical properties, handling and durability.Its high resistance to puncture allows it to withstand the mechanical aggression caused by the implementation of backfill and to resist highpressure carried out on the geomembrane by the weight of the building

Another system is an injection hose systems that can be make beautify after construction by injecting polyurethane resinsor microfine cements, to seal any voids or cracks. Onseveral tunnel projects, the joint design specified both a bentonite strip waterstop and a PVC dumbbellwaterstop in the concrete joints.[10]

Waterproofing of tunnels is done for three main reasons: structural preservation; guarantee functional service; and for preventing a lowering of the groundwater level around the tunnel. Some tunnels are designed without an exterior waterproofing system and only an interior drainage of ingress water. What must be evaluated is the cost of continual water discharge fees and maintenance of the drainage system, as well as the cost of future structural maintenance and repairs. [10]

Over the past two decades tunneling technology hasmade great strides, advancing the state-of-the-art indesign and construction methods. The waterproofingsolution is, in most cases, determined by the followingdesign criteria: tunneling construction method,prevailing soil/rock conditions, level of water table, andthe design of the tunnel lining.[10]

Most tunnel work relies upon the public sector infrastructure improvements, including vehicular, pedestrian and light rail tunnels. For example, the multibillion dollar western ring route project in Auckland.[10]

The waterproofing system should be selected based on the required performance and its compatibility with the structural system.Depending on the appearance of the water (humidity, temporary water pressure, and permanent water pressure) the lining system has to be adapted accordingly. This is done through the thickness of the geo-membrane and a system of control and repair. Under the influence of permanent water pressure a minimum thickness of 2.0 mm of the geo-membrane has to be taken into account.[3]

The quality of the waterproofing depends on:

- Choice of geo-membrane
- Waterproofing system including the preparation of the underground
- Work methodology (underground, drainage, waterproofing system, protection).

2.4.2. Requirement of Waterproofing

2.4.2.1. Water tightness

Water tightness depends on the typeof geo-membrane (product group, thickness) in order to beable to withstand all influences (e.g. pressure, condition of the underground).[3]

2.4.2.2. Flexibility

This point has to be taken into consideration during projecting. Depending on the form, angles and settlements of the construction the type of membrane has to be chosen. [3]

2.4.2.3. Chemical resistance

The waterproofing member should free from pollution of the ground and of the ground water and it should be have good resistance chemicals. [3]

2.4.3. Cut and Cover Tunnel Waterprofing

Depending on the situation and construction methods used; there are many different method and type of waterproofing construction to fit that particular project and the expected site conditions. To determine the best waterproof solution, any one must consider how the tunnel will be constructed.[15]

In generallyasauthor discused on this pape above, there are two broad categories construction method used to build cut and cover tunnels and each of them requires an entirely different approach to waterproofing.[15]

2.4.3.1. Bottom – up Construction Method Waterproofing

The mostcomman techinque is the bottom up construction wich done by excavating the trench from the suface downward to the final depth reached, the tunnel floor is built, then the wall and roof casted in- situ or from pre- cast. Walls are typically cast in place, and the waterproofing can be applied to the outside face of the concrete with minimal constrution problems.[15]

Usually, though, there’s not enough room for positive side waterproofing. Especially in urban settings, where most cut- and –cover tunnels are built, land is at a premium, so the excavation is cut vertically and reinforced with soldier piles or soil nails. In this case, the waterproofing is done “blindside”. With this construction method, the walls are poured after the waterproofing is finished.[15]

Roofs can be poured in place or formed with precast planks. The roof waterproofing is then tied into the wall waterproofing and drainage , and then structure.[15]

2.4.3.2. Top Down Construction Method Waterproofing

As discused on above topic, top down contruction method calls for the wall and roof of the tunnel to be put into place before the actual excavation takes place.

Top down cut and cover tunnels use blind-side waterproofing techniques. The waterproofing membrane is typically applied between the temporary shoring wall and the permanent tunnel lining.[15]

2.4.4. Type of Waterproofng in cut and cover tunneling

In recent years, there has been a significant increase in thechoice of concrete additives and waterprofing and manufacturers continue toenhance waterproofing systems, waterstops andexpansion joint sealing systems to simplify application andfacilitate demanding installation requirements.

Waterproofing can be diveded into two:

- ✓ Membrane Systems (Thermoplastic membranes PVC, TPO, or polyethylene (HDPE))
- ✓ Liquid Systems (*polyurethane or modified bitumen*) by *painting or spraying*

2.4.4.1. Membrane Systems waterproofing

2.4.4.1.1. HDPE

High Density Polyethylene Self-Adhesive Film Waterproofing Sheet Material (Briefly,HDPE Self-Adhesive Film Waterproofing Sheet Material),this is a waterproofing sheet material which is specially designed for underground engineerings with international advanced technology, it can bind the later cast concrete form a firm structure. It takes the specially-made high density thermoplastic polyethylene (HDPE) film as waterproof base material, on one side of HDPE film we cover with macromolecule self-adhesive film and on the exposed surface of composite adhesive phase we apply weather-resistant protecting layer and insulating layer, it belongs to macromolecule self-adhesive film waterproof sheet material. There is 70mm wide composite adhesive band for overlapping joint along longitudinal direction of the sheet material. There are self-healing function for its self-adhesive layer and weather-resistant layer, it reacts with liquid concrete and cures to be a waterproof layer, this layer binds with concrete firmly and gaplessly, stopping water fleeing, therefore this material is able to increase the liability of waterproofing system. [11]

2.4.4.1.2. PME-EVA Plastic Waterproofing

PME-EVA Plastic Waterproofing Board is a flake waterproofing material with certain thickness, which is made out of the base materials of ethylene-EVA, together with dedicated auxiliary and inhibitor, it is extruded and press-polished .The appearance of product is semi-transparent white color, it is also called plastic waterproofing board in "Underground Engineering Technical Regulation". [11]

Advantages[11]

High tensile strength:

- Over 16Mpa at room temperature; Large elongation: Can reach up to 550% and above at room temperature; Exellent fracture resistance by stress, being very adaptive to water-swelling and fracture of structures.

Perfect low temperature bending performance:

- there will be good flexibility even at -35 ℃ ; being very adaptive to surrounding temperature changes.

Soft texture:

- easy to attach to base, convenient paving.

Resistant to acid:

- to alkali,to salt and resistant to mould too, good stability against infection of the acid and alkali or other chemicals in concrete or in the sand, being adaptive to tunnel engineering and civil engineering.

Good application property:

- Sweat soldering can be used for overlapping of sheet material, in order to have ideal construction effect.

2.4.4.1.3. Geomembrane and its compartment

- ✓ Geomembrane

The choice of the geomembrane should be done following the taskthe geomembrane has to fulfil PVC-P, PP or PE).PVC-P Geomembranes are the most suitable material for thewaterproofing of tunnels and foundations due to their excellentmechanical performance and their good chemical resistance.Its also high resistance to puncture allows it to withstand the mechanical aggression caused by the implementation of backfill and to resist high pressure carried out on the geomembrane by the backfill of tunnel cover.[16]

- ✓ Geotextile

The geotextile has to be of Polypropylene fibers, short fibersmechanically fixed or long fibers. Polyester geotextile has to beavoided because of hydrolysis of polyester due to the alkalinity ofconcrete. The freshly applied concrete attacks the Polyester geotextileand after a certain time the geotextile dissolves completely.[16]

- ✓ Injection tube

Alternative injection device: injection tubes spot welded to thegeomembrane that open when the resin is injected under pressure.

- ✓ Injection devices

In addition to the water stops, injection devices are welded at specificspots to the geomembrane. The task of the injection devices is toprovide the possibility of injecting liquid waterproofing materialsin order to close the leakage of the geomembrane. These liquids orresins are based mainly on two components acrylate or polyurethane.[16]

The injection devices go through the concrete shell and are alwaysreachable in case of a failure of the waterproofing system.The injection work is a difficult task and has to be carried out byexperts. The injection resin has to be pressed through the injectionpipes between geomembrane and inside concrete. The mixuter of thetwo resin components is very important as on the one hand it has tostay liquid long enough to be able to spread over the whole surface ofthe compartment and on the other hand it has to harden quickly so itdoes not leak out by the infiltrating water.[16]

Two different injection systems are available:

- injection pipe
- injection tube

✓ Injection pipe

The injection pipe is a hose on which a PVC-P tube will be weldedthrough the wall reinforced steel. One has to ensure that the tube can resist a pressureof at least 6 to 8 bars. No metallic device will be used to avoid the danger of perforating the geomembranes.The exit piece of the injection pipe has to be integrated into a safedevice of the surface of the concrete.[16]

✓ Injection tube

Alternative injection device: injection tubes spot welded to thegeomembrane that open when the resin is injected under pressure.[16]

2.4.4.1.3.1. Conception of geomembrane waterproofing system

Foundation Slab

✓ Lean concrete

- ✓ Geotextile of 500 g/m²
- ✓ PVC-P geomembrane of 2,0 mm (1,5 mm)
- ✓ Geotextile of 500 g/m²
- ✓ PE sheet of 0.25 mm as gliding layer
- ✓ Protective concrete

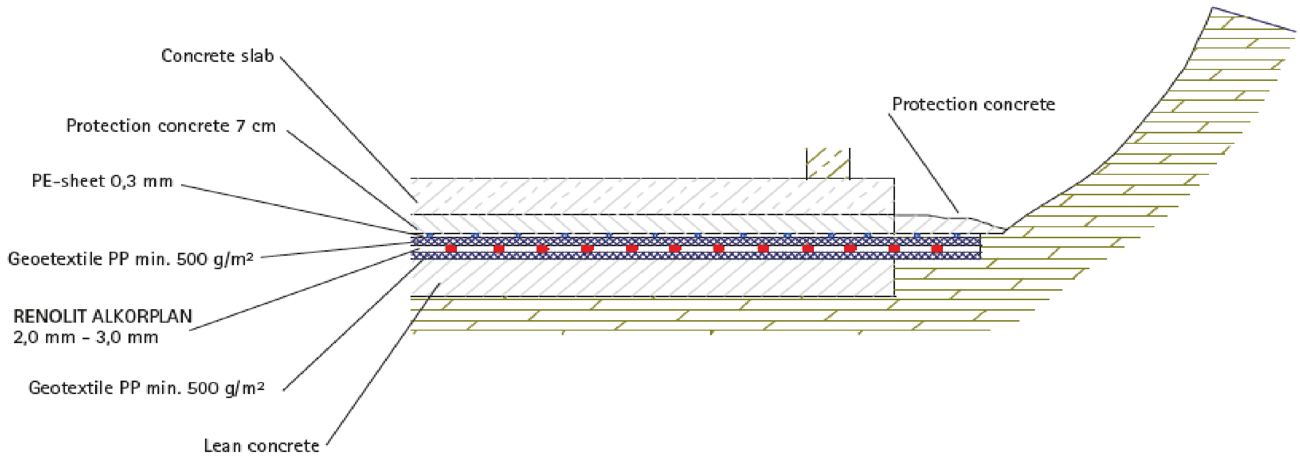


Fig.15: Waterproofing of bottom slab with working space[16]

In order to control and use as repair systems, water stops and injection pipes are installed.The surface of control areas should not overpass 100 m² of the foundation slab. The foundation slab has to be separated through water stops from the wall section.[16]

- ➢ Vertical faces with working space
    - ❖ Geotextile 500 g/m²
    - ❖ PVC-P geomembrane 2,0 mm (1,5 mm)
    - ❖ Geotextile 500 g/m²
    - ❖ Protection layer (card board, concrete blocks)
    - ❖ Backfill

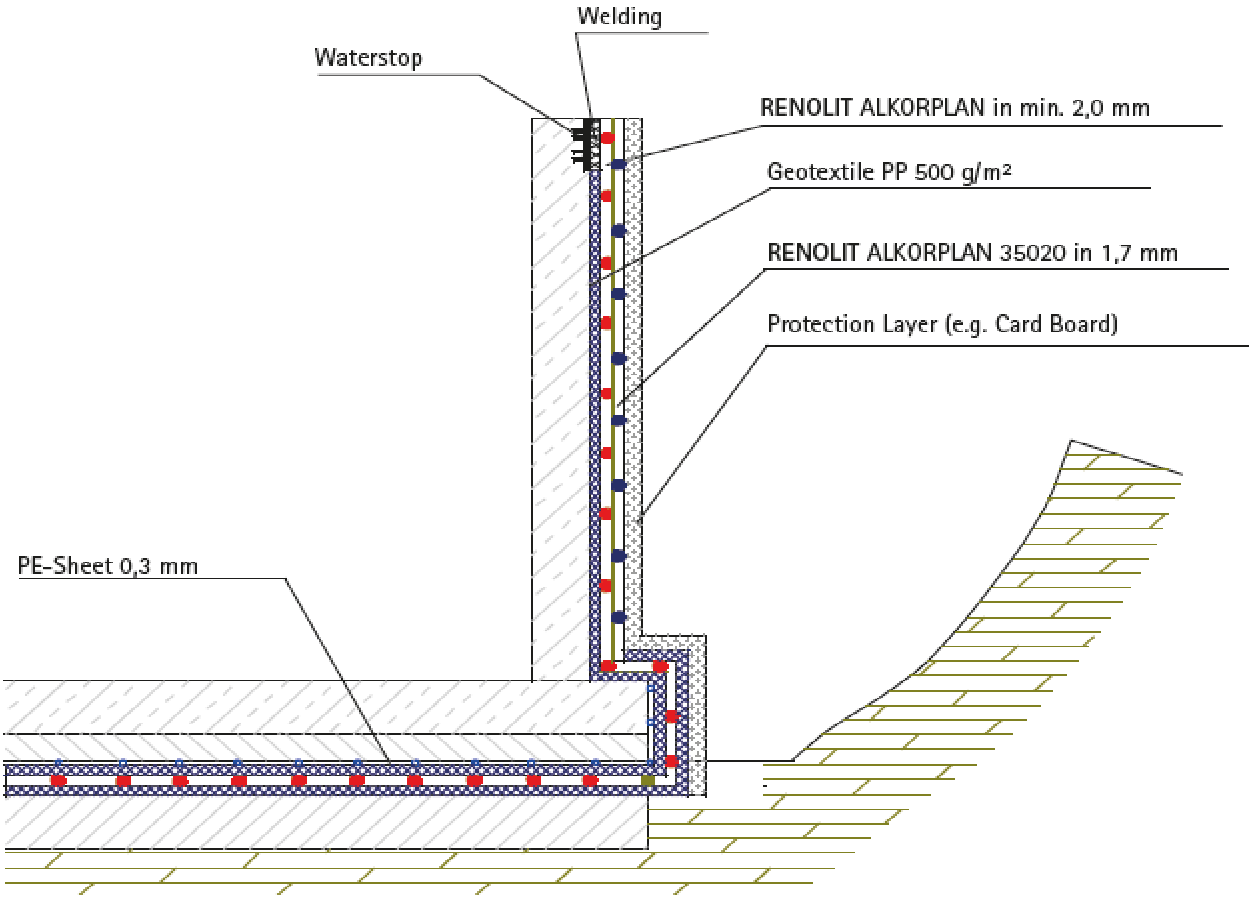


Fig. 16: Waterproofing of the vertical wallwith working space[16]

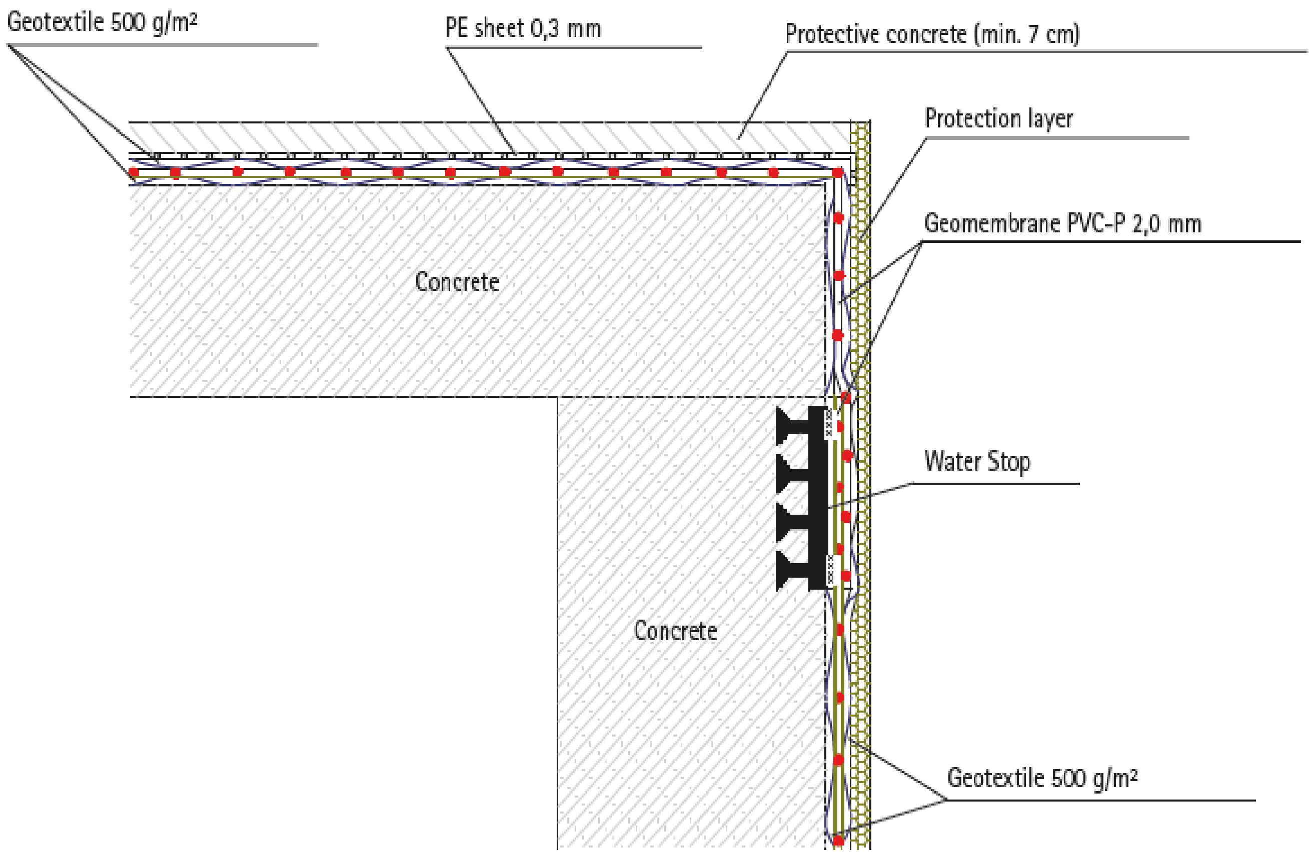


Fig. 17: Waterproofing of the top slab with working space[16]

- Vertical faces without working space
    - Retaining wall
    - Separation layer (e.g. Styrofoam 4 cm or similar)
    - Geotextile 500 g/m²
    - PVC-P geomembrane 2,0 mm (1,5 mm)
    - Geotextile 500 g/m²
    - Concrete wall

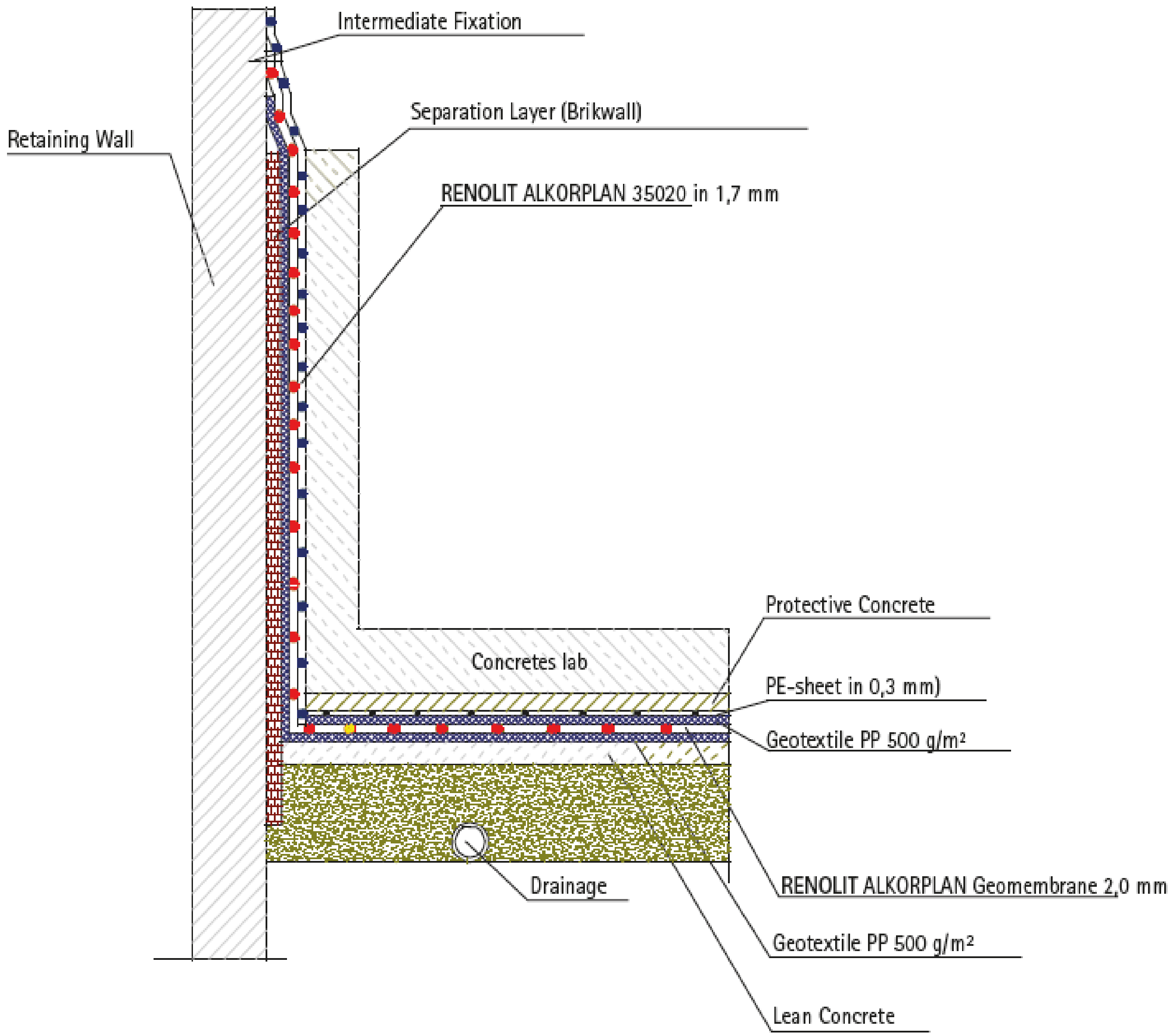


Fig. 18: Waterproofing of the vertical wallwithout working space[16]

The same control and repair system is used as for the slab. The waterstops are placed in the joint or just near the joint between the slaband the wall. The surface area control has to be determined followingthe situation on site.[16]

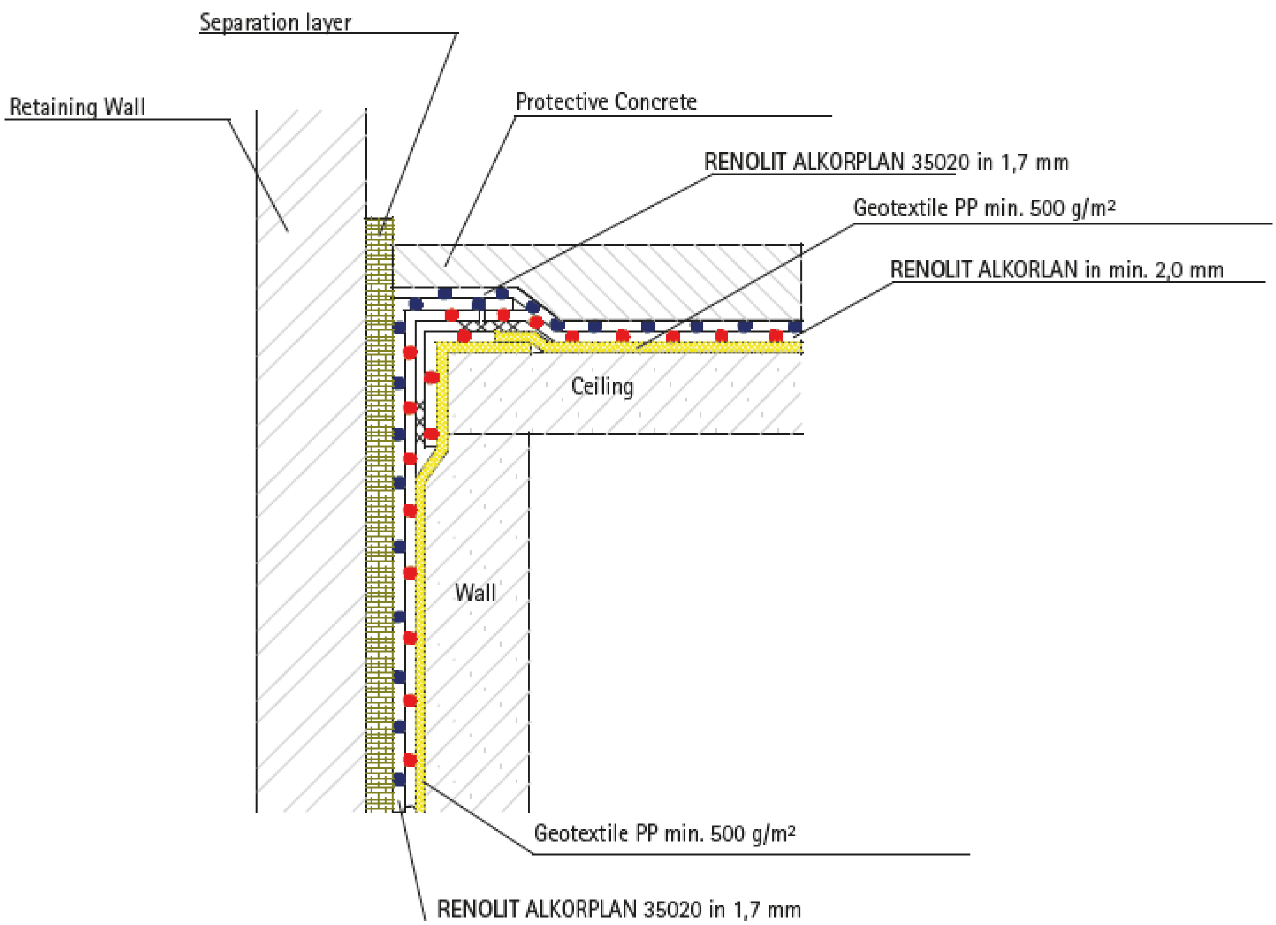


Fig. 19: Waterproofing of the top slab without working space[16]

2.4.4.2. Paintable Systems Waterproofing

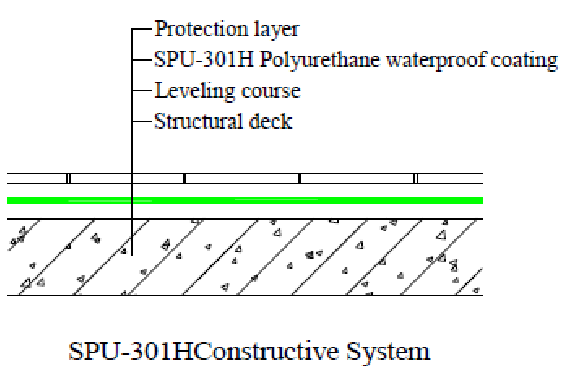
2.4.4.2.1. SPU 301 Single-Component Polyurethane Waterproofing Paint

"YUHONG" brand SPU301 Single-Component Polyurethane Waterproofing Paint is made out of the main materials of isocyanate and polyether polyol, together with various auxiliaries and fillers by polyreaction ,we coat it on the waterproofing base, after chemical reaction of N-C-O terminal group of polyurethane prepolymer and moisture in air, it forms a jointless , flexible and strong rubber waterproofing film.[11]

SPU-301 is a one component moisture-curing polyurethane waterproof coating especially used for horizontal plane. When this coating is applied on surface substrate, it has chemical reaction with the moisture in the air, and then it will form a seamless elastomeric rubber waterproof membrane.[11]

SPU(spraying polyurethane) have high tensile strength, large elongation, good elasticity, perfect low and high temperature resistance, and being adaptive to shrinkage, fracture and deformation of base. It also have strong bonding strength, no need to apply brushing coat of base treating agent on various qualified base surfaces. Large single time coating thickness, compact film, no pinhole, no bubble. Film is formed by chemical reaction, long term resistance of water erosion, corrosion resistance, mould resistance and fatigue resistance. [11]

Adaptive to basement (basement of building, basement parking lot, open-cut subway and passageway). [11]



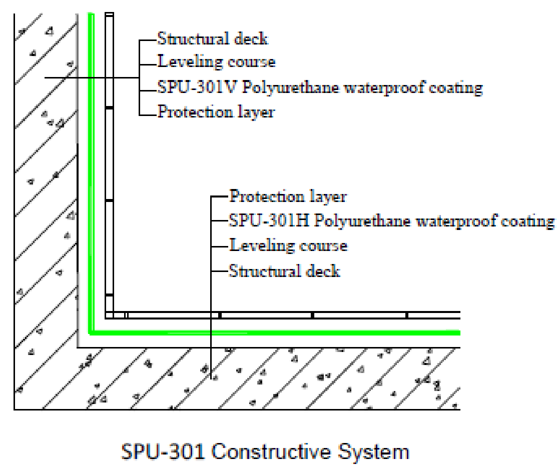


Fig. 20: SPU 301 Waterproofing of wall& slab with working space[11]

The system is basically consisted of substrate, additional layer, waterproof coated membrane and protection layer. To apply it,the surfaces should be dry, stable, clean, smooth, without pockmarks or honeycombs and free from any dusts, oil or loose particles. Cracks and surface irregularities need to be filled by sealants and do additional waterproofing. For smooth and stable surfaces, this step can be skipped.[11]

It can use rubber scrapers or spray equipments to paint 2 or 3 times. After fully dry, it can be painted again. The normal time between each painting is 24 hour. The direction of second time painting needs to be perpendicular to the first time painting.[11]

After waterproof coated membrane is fully dry and meets quality requirements, it can begin application of protection layer.[11]

2.5. Construction Safety Issue

In a high-hazard industry like construction, safety is an investment that provides real benefits. A safe work environment helps to keep skilled employees on the job and projects on track by reducing accidents that result in injuries and schedule delays, while also reducing the risks of litigation and regulatory action. A strong safety record enhances a company's reputation, makes it more competitive and helps to manage insurance costs over time.Today more construction companies are retaining a larger portion of the risk through higher deductibles, and can expect to bear significant costs for any accident involving bodily injury. To be competitive, companies need to control all costs, including insurance. Safer companies tend to be more appealing to potential clients and to insurers. A proactive safety culture helps to save lives, retain workers, reduce claims and delays, and enhance productivity and profitability while strengthening the company's reputation.[13]

Because every project is built on paper first, safety begins with pre-planning. The means and methods that will be used to build the project should be identified, along with the exposures they will entail. All exposures should be identified and addressed in pre-planning, from excavation to foundation, and superstructure to fit out. Controls to mitigate the exposures must then be identified and incorporated into the safety plan. Successful performed pre-planning allows the project to run un-impeded by minimizing the potential for accidents that can hamper productivity and cause schedule delays. Proactive companies make safety pre-planning an integral part of every project. Before work starts, a project specific safety plan should be developed to provide an overview of the scope of the work and the names, roles and responsibilities of key personnel. It should include a list of local emergency responders and medical facilities; emergency procedures and evacuation plans; fall management and retrieval procedures; substance abuse testing and new employee orientation.[8]

Safety is not simply common sense. Workers need to be trained to properly use a variety ofsafety equipment, such as fall arrest systems, and they need to know the appropriate regulations. Orientation shouldn't be limited to new hires. The company should provide orientation specific to each project. The orientation should include an overview of the project, an in-depth review of the safety requirements and expectations, evacuation plans and procedures, disciplinary actions, substance abuse testing policy and fall management procedures and requirements. Communicating to a diverse workforce whose primary language or commonly understood language, construction firms need to address the issue of effectively communicating safety and job expectations.[8]

In every tunnel or rather at every construction site a proper safety management needs to be installed. Because of more critical issues in shallow and urban tunneling it is even more important, and a good quality absolutely necessary. [13]

There should be a safety management plan for the whole project as well as for specific (ground) conditions, because uncertainties in geological conditions can occur even if the investigation was done in an excellent way. [13]

The Safety Management should consider: [13]

- ✓ *Basic elements and structure of the Safety Management Plan*
- ✓ *Parties and stakeholders involved and their responsibilities*

- ✓ *Determination/Definition of the expected behavior; definition of warning and alarm levels/criteria*
- ✓ *Monitoring program; layout and frequency of monitoring in accordance with expected behavior and boundary conditions*
- ✓ *Information and communication flow*
- ✓ *Action plan; organization, and mitigation measures in case observed behavior deviates from the expected*
- ✓ *Management of a crisis*

A proper assessment of hazards is important to set the right monitoring criterions and responsibilities as well as warning levels and a target-aimed information flow. Regarding information flow, it should be mentioned that information need to be at the right time at the right person, and in case of an emergency the information flow must be clearly defined, so that no deterioration is caused.[13]

There are many legal aspects regarding tunneling in urban areas. This paragraph is not giving aninsight of actual standards, laws or restrictions but tries to point out some problems which occur orcan occur in future urban tunneling.[13]

When pushing forward underground constructions another problem occurs: Who owns thesubsurface?!Landahl was addressing this problem in his paper “Planning and mapping of underground space - anoverview”85. The following paragraphs are summarizing the outcomes of this paper.[13]

There are four attempts of clarifying who owns the underground:

- ✓ *The owner owns the ground from the surface to the center of the earth*
- ✓ *The owner owns the ground as far as reasonable interest exists*

- ✓ *The owner owns the ground until a limited depth (up to 6m) and right to access freely his/her own ground*
- ✓ *Private land ownership doesn't exist*

But even if the ownership is clarified, that doesn't automatically give a right to use the underground.So there are two attempts of establishing a legal framework to use the underground. One attempt isthe more or less simple establishment of easements. These easements need to be worked out byappropriate departments and rights must be obtained. The second attempt is to establish 3D realestate with a clear definition of responsibilities for the owner of the surface and the owner of theunderground.[13]

Related to the legal issues are the strategic issues, also addressed by Landahl86. Proper undergrounddevelopment needs an intelligent strategic planning. Nowadays there are just a few tunnels, whichare not interrupting each other, but if you regulate the underground use and open it to the public,further development could result in an overcrowded underground and therefore a loss of valuable space. The subsurface planning today is carried out in an insufficient way by most countries and there are no strategic objectives.[13]

Governments need to work out strategic underground plans and create an underground mapping, so that underground corridors and spaces maybe turning important in the future are reserved and not destroyed by impetuous structures nowadays. The most important thing is to remember that proper usable underground space is not infinite and therefore must be managed carefully andprofessionally. This requires guidelines for the use of underground space and governments shouldconsider elaborating them soon.[13]

CHAPTER -3. CASE STUDY OF TUNNEL -1 AROUND St. GEORGE

3.1. General

As mentioned earlier, the "Cut and Cover" method can be applied in major motorway projects urban/city areas. The tunnel-1 of the Addis Ababa railway in Ethiopia is a typical case illustrating use ofthe technique.

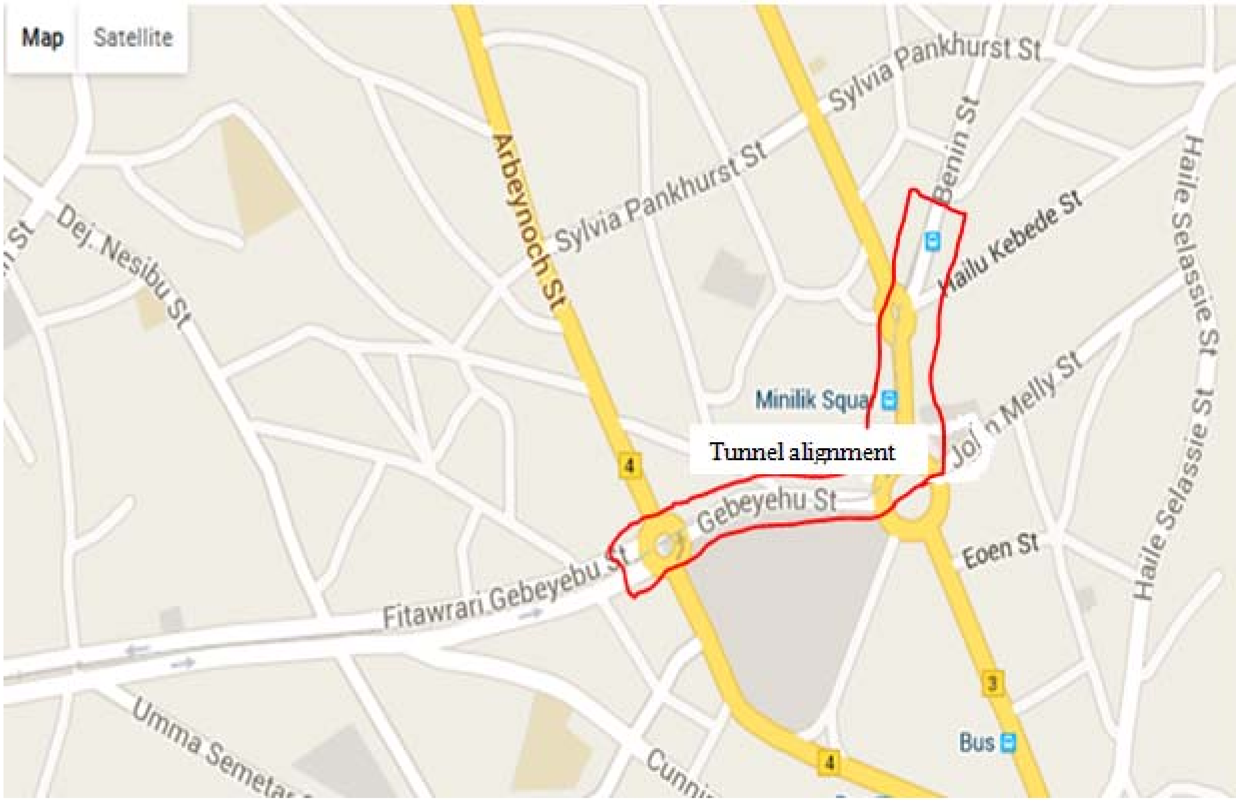


Fig. 21: Tunnel-1 alignment map.[14]

Tunnel twin tube alignment shown on the map by red color line which crosses two road intersections.

The tunnel was constructed as a twin-tube tunnel having a length of 659m. This part of the Addis Ababa Light railway crosses an extensive high traffic zone which considered as city businesses center and geographicalcenter of Addis Ababa city; and soil characterized by good material and stable conditions. Thematerials consist of lateritic red clay up to 8m, and almost blow that the ground containsweathered rock which can contribute to the overall stability of the ground. The alignment runs along a main road from Atekilt Tera (Fitawrari Gebeyebu St.) to Sidist Killo (Benin St.) by crossingmain road from G/Wingate TVT and Addisu Gebey as shown on satellite map (fig.21) which have huge vehicle and pedestrian traffic. To solve this problem Ethiopia Railway Corporation (ERC) proposed and constructed tunnel rather than crossing at level.

Along the tunnel corridor there is serious pedestrian traffic because of different public service like market, offices, hotels, church and privet homes, shops and etc. and also the junction is center to distribute to other sub-city.

3.2. Tunnel-1 Excavation method and Excavation support

Excavation is common in tunneling systems and also excavation of tunnel-1 was being started on May 2013 and it was going under construction until middle 2015. Excavation started from junction of Fitawrari Gebeyebu St. to Miniliki II Square. The excavation done as open cut with side slope to increase slope stability of the trench cut and also on some location on the trench cut secant pile used to support surcharge from G+4 St. George Church building seriously near to tunnel-1 alignment and Soil Nailing and Shotcreting was used on the slope show weakness as shown on fig. 22. Slope tunnel trench excavation required more space than other open cut tunnel excavation and the contractor used this method. The excavation was done without giving any space even for foot movement and society on the periphery of trench excavated they faced difficulty to use their homes even for shelter and lost their businesses.Duringsite visit, some people living on periphery of the tunnel told me no one get any composition except the owner of G+4 building for their business losses. Normally slope tunnel trench excavation done on free land where there is no space limit. But in case of like tunnel-1 which constructed under City Street it need more consideration to use the space effectively. The tunnel constructed as two box tunnelon long trench.During tunnel-1 trench excavation, even at local dry seasons, there high ground water leak (seepage) on the cut surface and also high inflow to the trench from utility lines. The contractor (CREC) used pump to dewater percolated inflow from construction space.

Fig. 22: Tunnel-1 Excavation and Supporting System [from source]

3.3. Tunnel-1 Waterproof Material and Its Application

3.3.1. Waterproofing Material for Tunnel-1

During design stage engineer select material type of waterproof, application method which is applicable for selected waterproof material and method of tunnel construction, additional resource required to finish that work. Incase of Tunnel-1 waterproofing, as I assessed during site visit there is no official design for waterproofing material. Since design also done by contractor, theconsultantenforced the contractor to provide waterproof but the selection of waterproofing material and the way to applying not seriously considered.

Fig. 23 Ground water level seen on bottom of Tunnel-1 cut level [from source]

SPU 301(spraying polyurethane) is the waterproofing material used to cover Tunnel-1 tube .

SPU-301 is a one component moisture-curing polyurethane waterproof coating especially used for horizontal plane. When this coating is applied on surface substrate, it has chemical reaction with the moisture in the air, and then it will form a seamless elastomeric rubber waterproof membrane and further material property is covered in Appendix: A of this paper.

3.3.2. Tunnel-1 Waterproofing Application Method

In construction of underground structure there is expected existence of groundwater or water percolating down from surface discharge is required that the structure to be protected with waterproofing. Also since cut and cover tunnel is one of underground structure, durability and service lifeis improved when the tunnel is covered with waterproofing. Good waterproofing design is alsoimperative to keep the tunnel dry and reduce future maintenance and increase users safety and comfort.

As author discussed above when Tunnel-1 was constructed there seepage on the surface of trench cut from water table and utility lines even at dry season but there was no waterproofing for bottom slab tunnel. As mentioned above on literature review when we construct waterproofing for tunnels we are saving three main things, which are: structural preservation; guarantee functional service; and for preventing a lowering of the groundwater level around the tunnel to avoid settlement of ground around tunnel. In case of Tunnel-1 waterproofing was constructed.

Some tunnels are designed without an exterior waterproofing system and only an interior drainage of ingress water. What must be evaluated is the cost of continual water discharge fees and maintenance of the drainage system, as well as the cost of future structural maintenance and repairs. [10]

Fig. 24. Tunnel-1 Wall Waterproof Application and its Cover [from source]

On tunnel-1 waterproofing, the SPU 301 produced company put the minimum requirement and direction of application of the material as follows:

"Surfaces should be dry, stable, clean, smooth, without pockmarks or honeycombs and free from any dusts, oil or loose particles. Cracks and surface irregularities need to be filled by sealants and do additional waterproofing. For smooth and stable surfaces, this step can be skipped.Paint SPU-301 as additional layer to enhance at internal and external corners, drain pipes, floor drains or embedded parts.

It can use rubber scrapers or spray equipments to paint 2 or 3 time. Per one cycle of painting or spraying 1.7kg per m^2 gives different 1mm minimum. Coverage may vary with the substrate condition during application. After fully dry, it can be painted again.

The normal time between each painting is 24 hour. The direction of second time painting needs to be perpendicular to the first time painting. After waterproof coated membrane is fully dry and meets quality requirements, it can begin application of protection layer."

By considering information discussed aboveon Tunnel-1 the contractor used SPU 301 painting for only one cycle without smoothing roughness of side walls and top slab, cleaning dust,oil or loose particles, cracks and surface irregularities of constructed tunnel-1 tube.

During application of SPU 301 the factory manual order 2 up 3 times painting or spraying the product at perpendicular of previous application direction and fully dry with 24 hour difference. Also the manual specify after painting or spraying the product and get dry, it should covered with protecting layer like concrete, but on Tunnel-1 waterproofing system the only protection covered was top slab as shown on Fig.25 and other surface was buried barely without protection as shown on Fig. 24

Fig. 25.Tunnel-1 Top Slab Waterproofcovers Application and itscrack [from source]

CHAPTER 4. CONCLUSION AND RECOMMENDATION

4.1. Conclusions

The main objective of the study was to assess the design of construction method of tunnel-1 section and, to conclude and recommend the best construction methods relative to global trained forfuture cut and cover tunnel design of construction method considerations based on the rebuke learnedfrom Tunnel-1construction method.

In this study the author assessed different construction approach problem of Tunnel-1 and, to conclude this study the lessons gained from problems are as follow.

- ❖ As reviewed on literature, the most common cut and cover tunnel construction method under city streets are bottom-up and top-down. Since space is premium in urban the most safe and economical relative to public safety is top down cut and cover tunnel construction approach, but it might be add cost of constructing permanent excavation support rather than constructing without excavation support as slope tunnel trench cut and wherever bottom-up method is used, it will be with space limit construction approach by providing temporary excavation support fornon sloped trench cut.
- ❖ When consider Tunne-1, the contractor used slope tunnel trench excavationwithout excavation support except secant pile permanent excavation support at high surcharge of G+4 building and side of St, George Church.
- ❖ The space accommodated to satisfy the stability cut slope can serve not only for pedestrian walkway but also it was enough for taxies. Actually contractor construction approach saves cost of excavation support because of being used slope cut approach to excavate Tunnel-1 trench.
- ❖ On periphery of Tunnel-1 cafes, restaurants, shops and other public service were partially or totally locked almost for year because absence of access to their

serving place. Even though, contractor construction approach saves cost of excavation support because of being used slope cut approach to excavate Tunnel-1 trench; the client (government) should analysis cost of public safety and service lose to compare with cost of excavation support.

- ❖ Tunnel-1 bottom slab casted without any waterproofing and some of the wall part was not being painted waterproofing because of roughness and some parts waterproofing were dismantled because of unclean dust on the wall surface.
- ❖ Thickness of applied waterproofing material even not satisfies the company requirement.

4.2. Recommendation

By considering problems encountered on Tunnel-1 construction the author recommend following points for future cut and cover tunnel construction.

- ✓ At stage of contract agreement the client should put enforcing condition to meet the required construction method and also put as contractor selection criteria.
- ✓ In case of Tunnel-1 or AA-LRT project, eventhoughit have budget implication, the client should have awareness of construction method to make such thing as per condition for negotiation and also design review should have to done before project start.
- ✓ Since Tunnel-1 waterproofing was not good enough, it might leak as service life will increase and it is better to design and construct internal waterproofing.
- ✓ At initial stage of the project public safety implication should have to consider with relative to construction methodoptions.

Finally, the author suggests for any researcher, he/she can conduct his /her studies on thefollowing:

1. Assessment of poor application effect of waterproofing on cut and cover tunnel. Case study on Tunnel-1 around St. George Church.
2. Analyzing andverifying an effect and remedy of surcharge on cut and cover tunnel structures by PLAXIS software modeling.

REFERENCES

1. Ahmet Saglamer, "*Cut and cover tunnels in metropolitan areas*" ITA/AITES – Training Course TUNNEL ENGINEERING, Istanbul -2005 [6]
2. Carretera del Montnegre, "*Waterproofing of Cut and Cover Tunnels*", s/n - 08470 San Celoni – España 2013[3]
3. Dr.K.R. Arora, "*Soil Mechanics and Foundation Engineering*", 6th Edition, Lomus Offset Press,Delhi, Jan.2003 [5]
4. Environmental Project Report, "*Eglinton Cross-town Light Rail Transit Project Assesment*", March.2010 [7]
5. Ir. Vince Tan Pik Sing, Ir. Chin Yew Thai, "*Design Challenges to Cut-and-Cover Tunnels*", Stormwater Managementand Road Tunnel (SMART), Sepakat Setia Perunding (Sdn.) Bhd. [4]
6. Kurzfassung Eva Greifeneder, "*Master's Thesis onComparison of Cut-and-Cover Tunneling Method vs.New Austrian Tunneling Method (NATM) for Urban Tunnels with Shallow Overburden* ", October 2003 [1]
7. U.S. Department of Transportation Federal Highway Administration, "*Technical Manual for Design and Construction of Road Tunnels – Civil Elements*", Publication No. FHWA-NHI-10-034, December 2009 [2]
8. George Cesarini, Geoffrey Hall and Matthew Kupiec, "*Building a Proactive Safety Culture in the Construction Industry*" April 2013[8]
9. Christoph Sturm, "*Master's Thesis on*Shallow tunnels and caverns in urban areas" Austria,Graz / February 14, 2011 [13]
10. A. Mouratidis**:** Professor of Highway Engineering, Aristotle University of Thessaloniki, "*The "Cut-and-Cover" and "Cover and- Cut" Techniques in Highway Engineering,*Vol. 13, Bund. F 2, 2008 [12]
11. VOLCLAY, "*Watertite advice - tunnel waterproofing*"Cut and cover tunnels, Volume 2, Issue 4, Part 1 [10]
12. Http://www.yuhong.com.cn/yuhong product manuals/[11]
13. http://www.newstrackindia.com/ Cut and Cover [14]
14. Central Subway Project Final SEIS/SEIR, "Central Subway Construction Methods, Impacts, And Mitigation Measures" Cut and cover tunnels, Volume 1,[9]
15. http://www.rhinoliningsindustrial.com/Cut and Cover Tunnels/PDF[15]
16. http://www.alkorgeo.com/Waterpoorfing_cut_and_covertunnels-ENbrPDF[16]

APPENDICES

Appendix A: SPU 301 Waterproofing Material Specification Attached on Product

Appendix B: SPU 301 Waterproofing Material Manual Specification

北京东方雨虹防水技术股份有限公司
BEIJING ORIENTAL YUHONG WATERPROOF TECHNOLOGY CO.,LTD.

雨虹 YUHONG

SPU-301

One Component Polyurethane Waterproof Coating

Description

SPU-301 is a one component moisture-curing polyurethane waterproof coating especially used for horizontal plane. When this coating is applied on surface substrate, it has chemical reaction with the moisture in the air, and then it will form a seamless elastomeric rubber waterproof membrane.

Where to use

- Undergrounds;
- Parking garages;
- Subways in open cut method;
- Channels;
- Kitchen or bathroom;
- Floors, balcony and unexposed roofs;
- Swimming pools, man-made fountain and other pools;
- Top plate at plazas.

Advantages

- Good tensile strength and elongation;
- Both high and low temperature resistance;
- Strong adhesive;
- Seamless, no pinholes and bubbles;
- Resistance to long-term water erosion;
- Corrosion-resisting and mould-resisting;
- Convenient to apply.

Standards

ASTM C 836

Typical properties

Item	Requirement	Test Method
Hardness	≥50	ASTM D 2240
Weight Loss	≤20%	ASTM C 1250
Low temperature crack bridging	No cracking	ASTM C 1305
Film thickness(vertical surface)	1.5mm±0.1mm	ASTM C 836
Adhesion-in-peel after water immersion	175N/m	ASTM C 794
Optional test after adhesion in peel	No separation at surface	ASTM C 836
Extensibility after hear aging	6.4mm (note 1) no cracking	ASTM C 1522
Stability	≥6 months	ASTM C 836

北京东方雨虹防水技术股份有限公司
BEIJING ORIENTAL YUHONG WATERPROOF TECHNOLOGY CO.,LTD.
雨虹 YUHONG

Packaging

SPU-301 is sealed in 20kg pails and transported in wooden cases. Each wooden case can be contained 36 pails of SPU-301.

Storage

SPU-301 material should be stored by sealed pails at dry and well-ventilated places and protected from sun or rain. The temperature in stored places can not be higher than 40° C. It can not be closed to fire sources. The normal shelf life is 6 months.

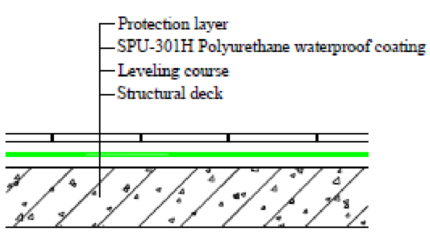
Transportation

SPU-301 is needed to be avoided sunshine and rain. Fire sources are forbidden during transportation.

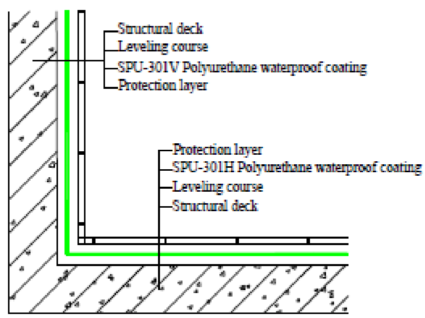
Application System

- Constructive System

The system is basically consisted of substrate, additional layer, waterproof coated membrane and protection layer.



SPU-301HConstructive System



SPU-301 Constructive System

- Coverage

1.7kg per m^2 gives dft 1mm minimum. Coverage may vary with the substrate condition during application.

- Application Method

Surface preparation

Surfaces should be dry, stable, clean, smooth, without pockmarks or honeycombs and free from any dusts, oil or loose particles. Cracks and surface irregularities need to be filled by sealants and do additional waterproofing. For smooth and stable surfaces, this step can be skipped.

Additional layer

Paint SPU-301 as additional layer to enhance at internal and external corners, drain pipes, floor drains or embedded parts.

北京东方雨虹防水技术股份有限公司
BEIJING ORIENTAL YUHONG WATERPROOF TECHNOLOGY CO.,LTD.

雨虹 YUHONG

Application of waterproof coated membrane

It can use rubber scrapers or spray equipments to paint 2 or 3 times. After fully dry, it can be painted again. The normal time between each painting is 24 hour. The direction of second time painting needs to be perpendicular to the first time painting.

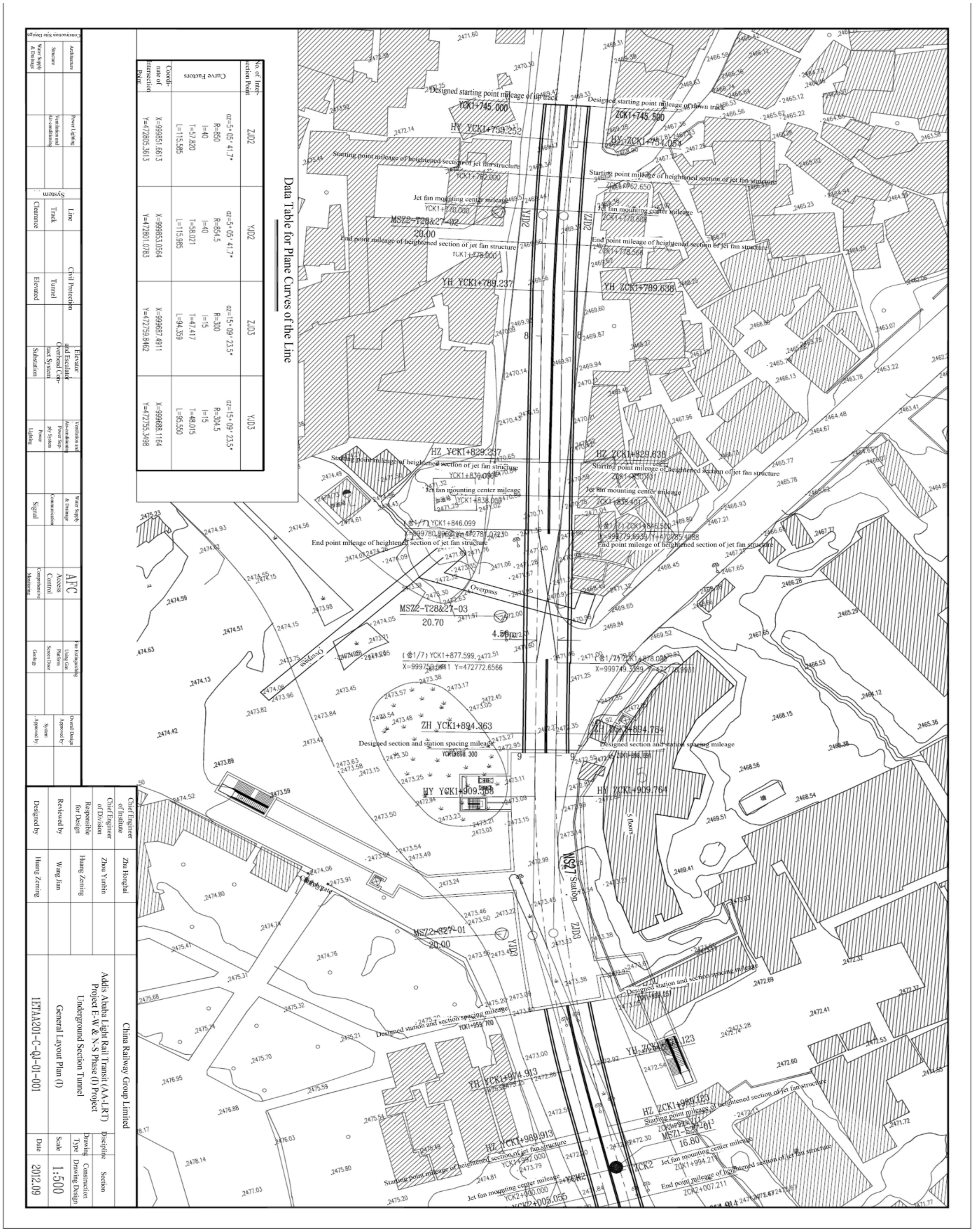
Application of protection layer

After waterproof coated membrane is fully dry and meets quality requirements, it can begin application of protection layer.

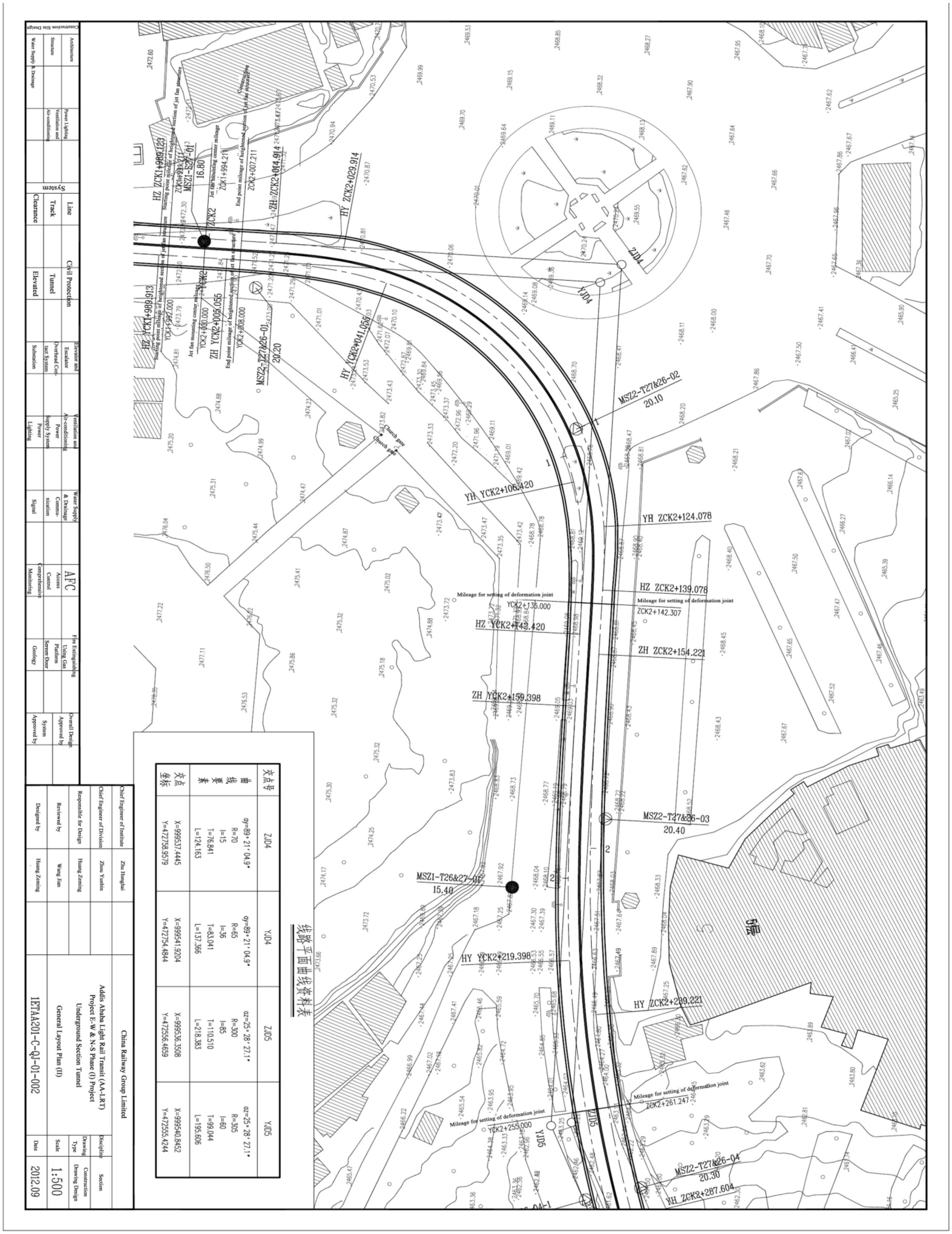
Notice

- The temperature for application of SPU-301 should be above 5℃.
- SPU-301 needs to be consumed instantly and can not be diluted with solvent.
- The storage and application places should be well-ventilated and no fire.

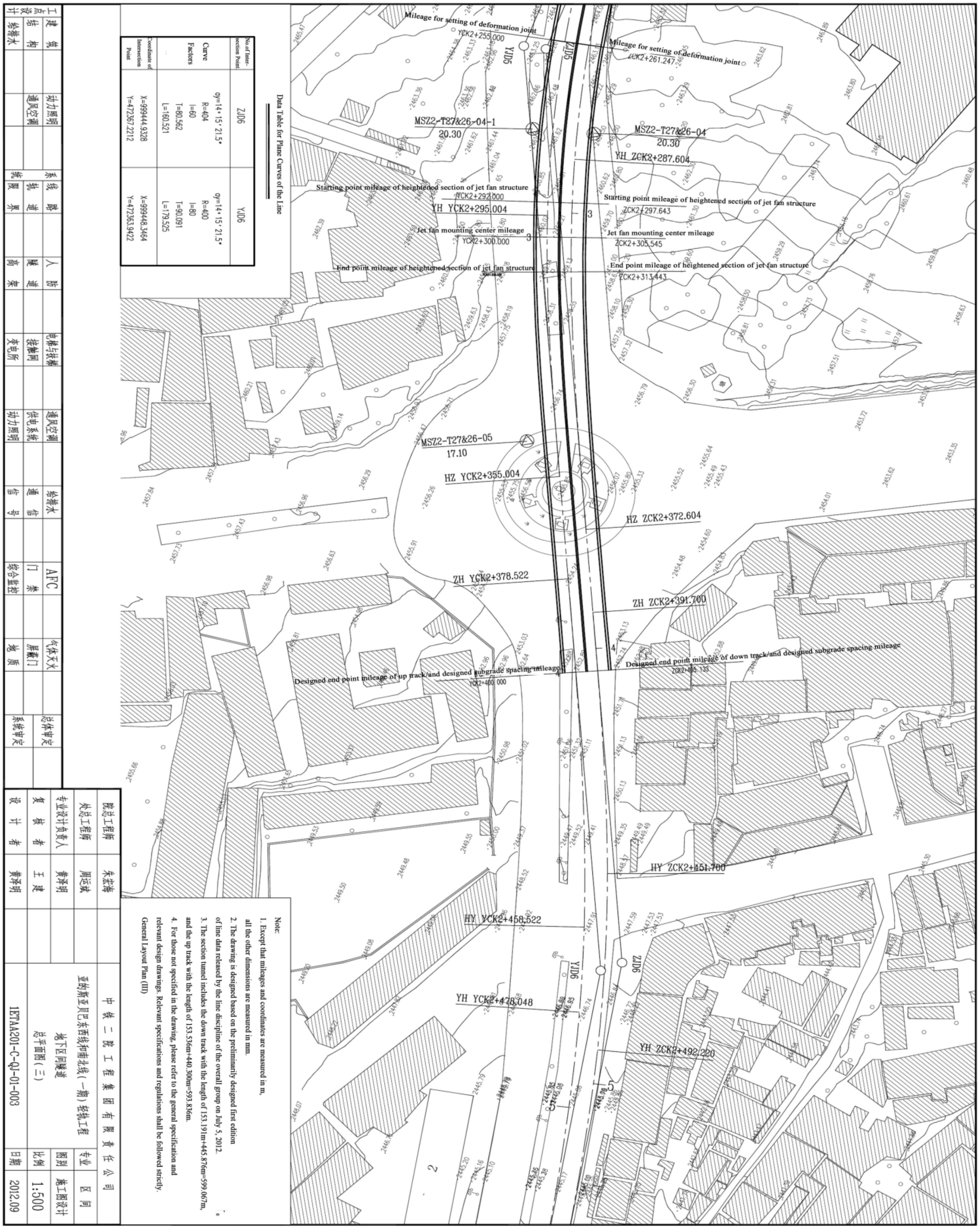
Appendix C: General Layout Plan (I)



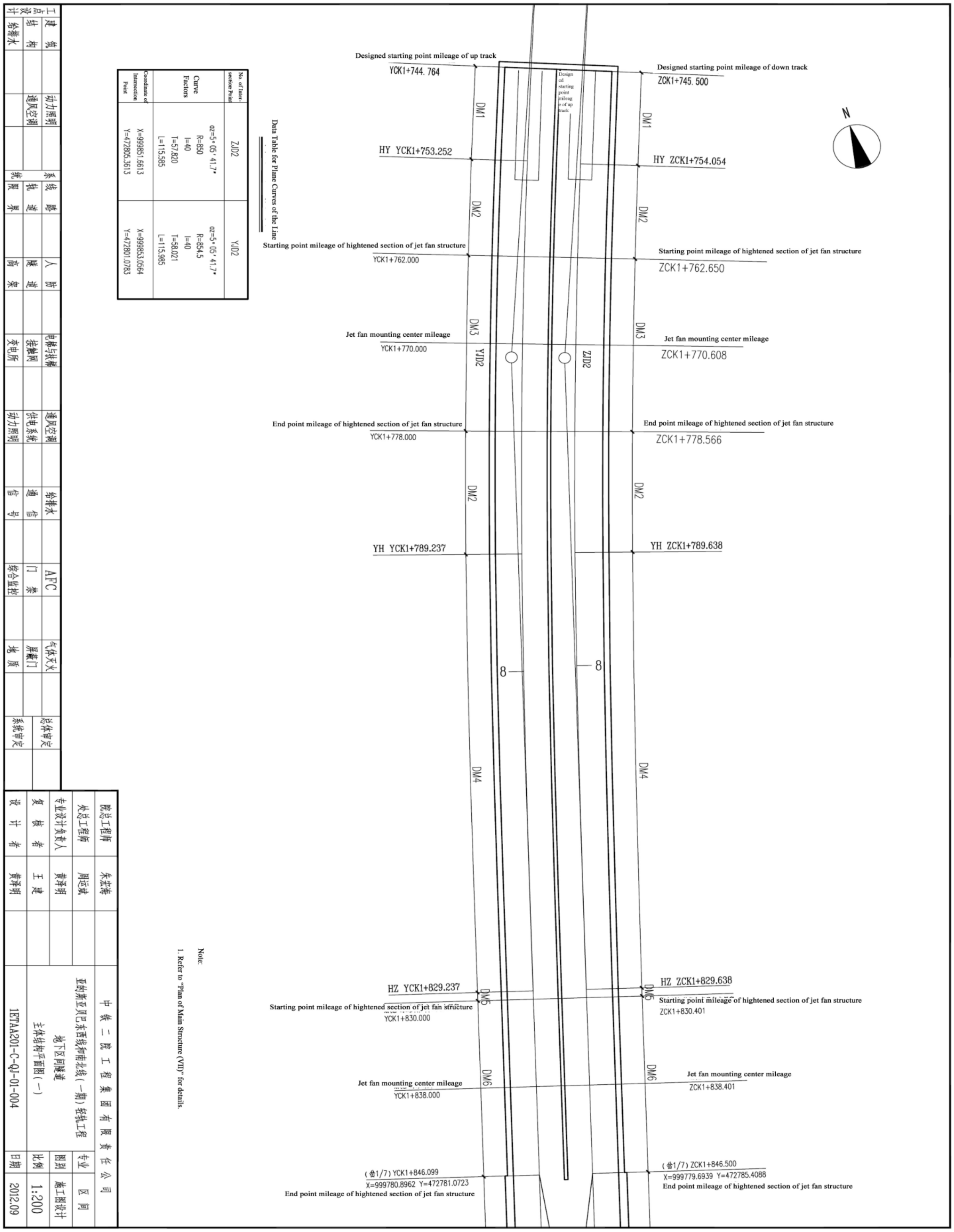
Appendix D: General Layout Plan (II)



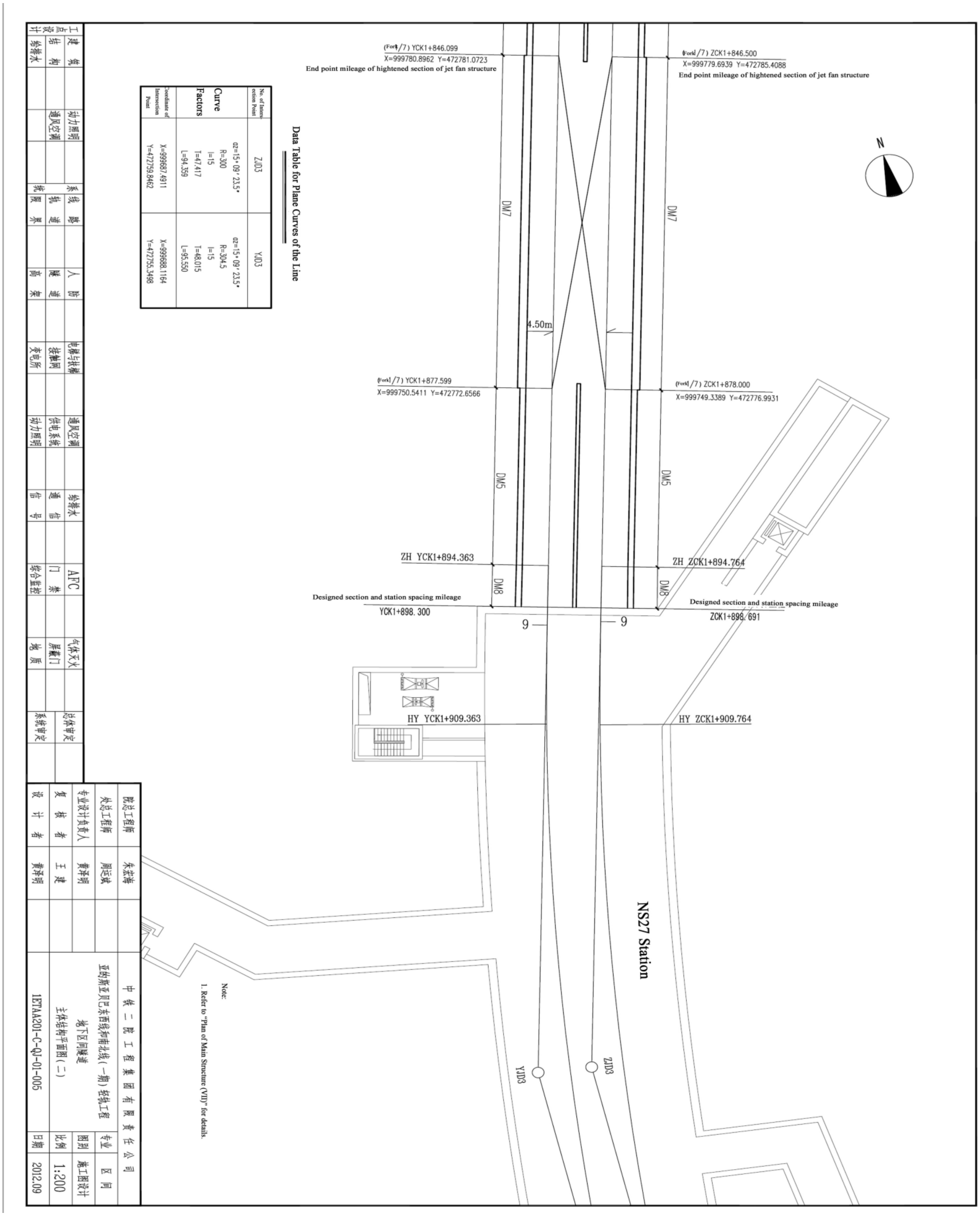
Appendix E: General Layout Plan (III)



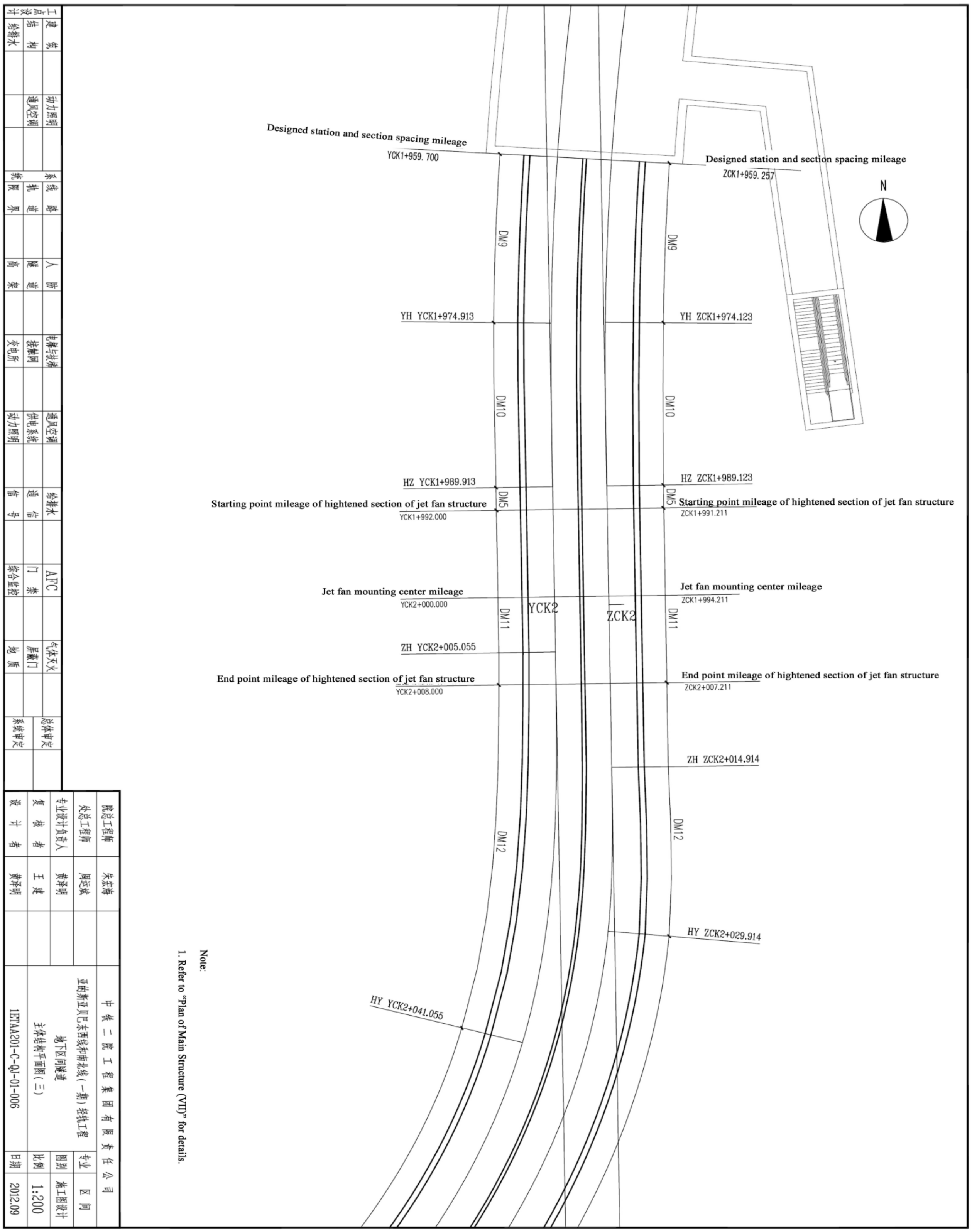
Appendix F: Plan of Main Structure (I)



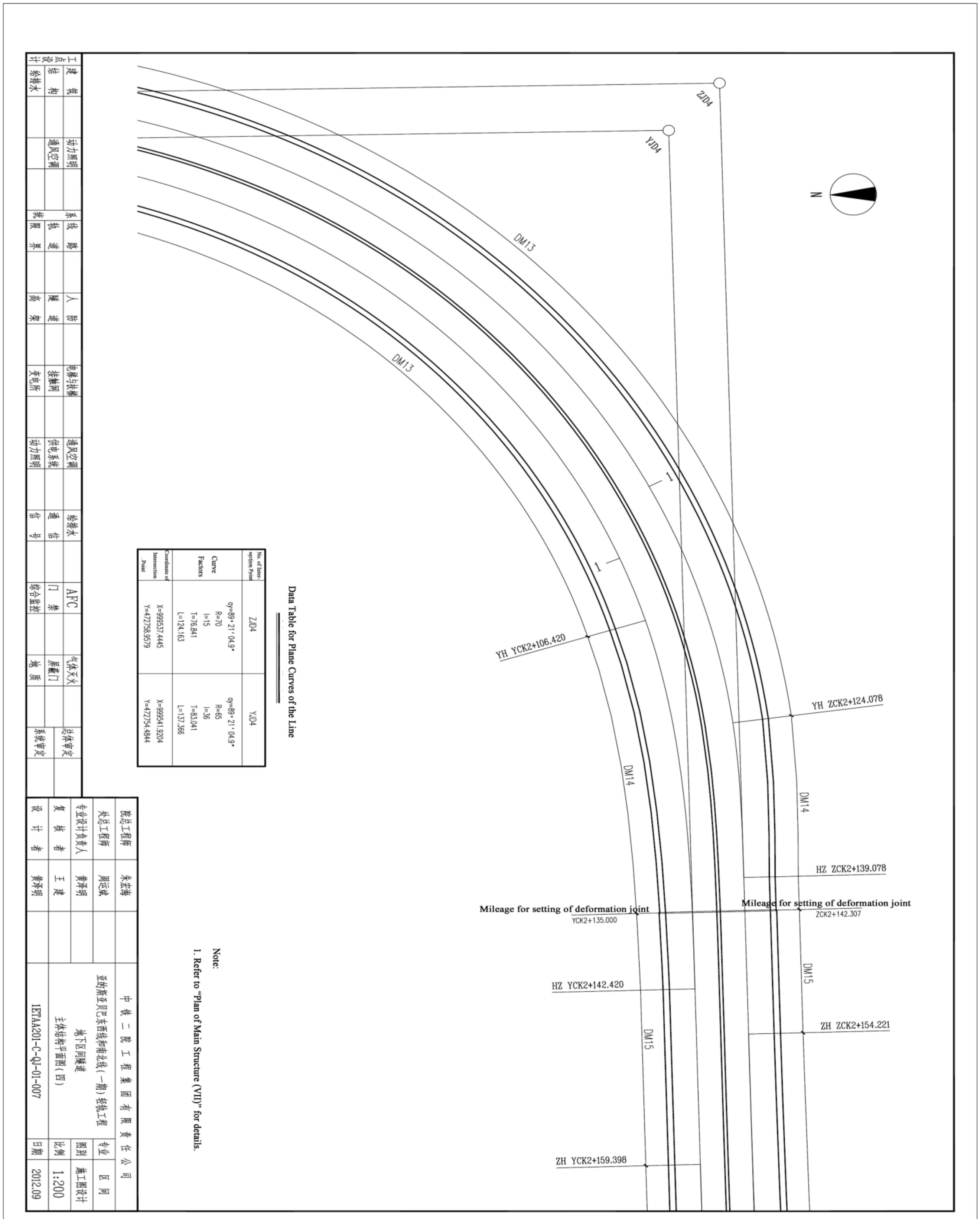
Appendix G: Plan of Main Structure (II)



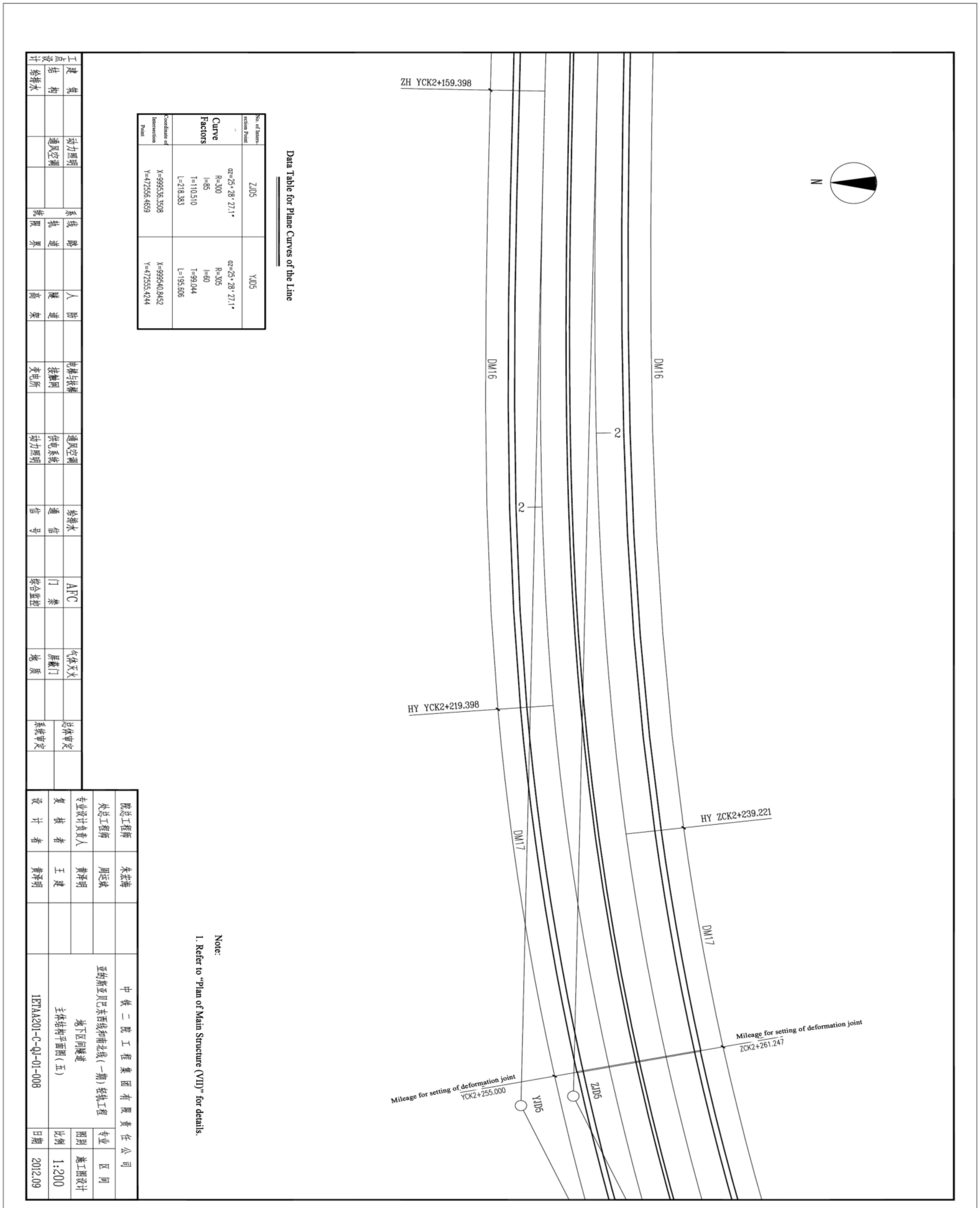
Appendix H: Plan of Main Structure (III)



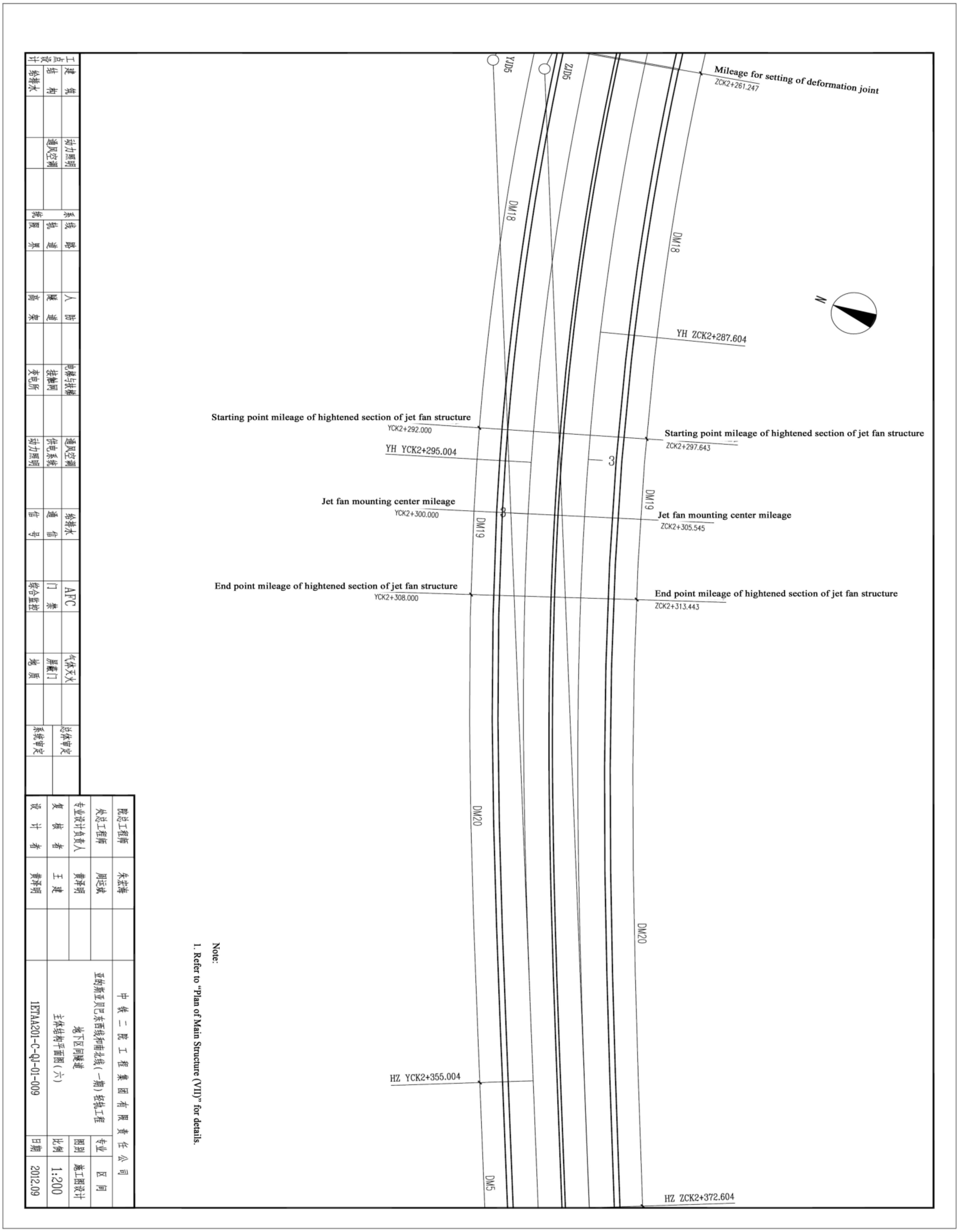
Appendix I: Plan of Main Structure (IV)



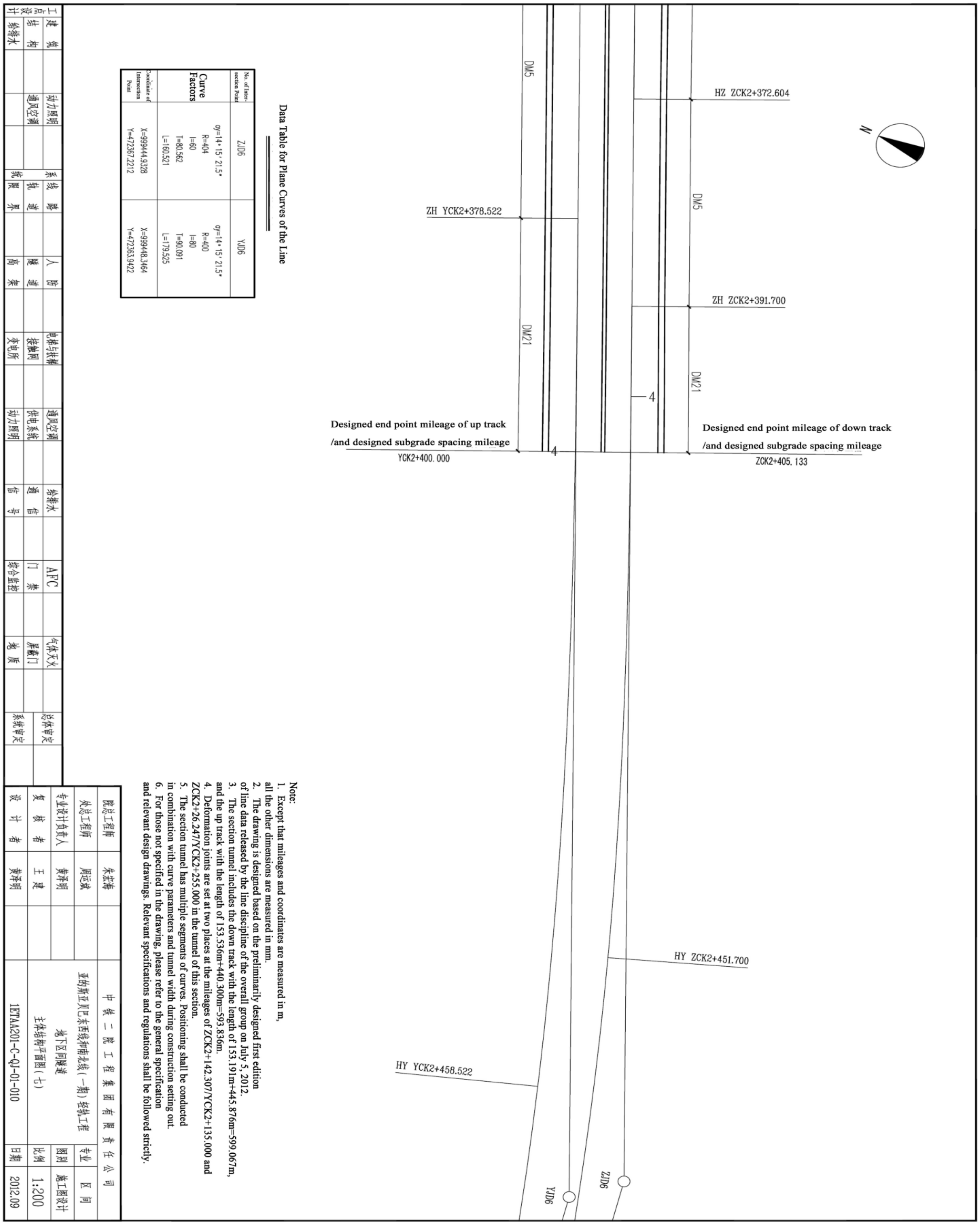
Appendix J: Plan of Main Structure (V)



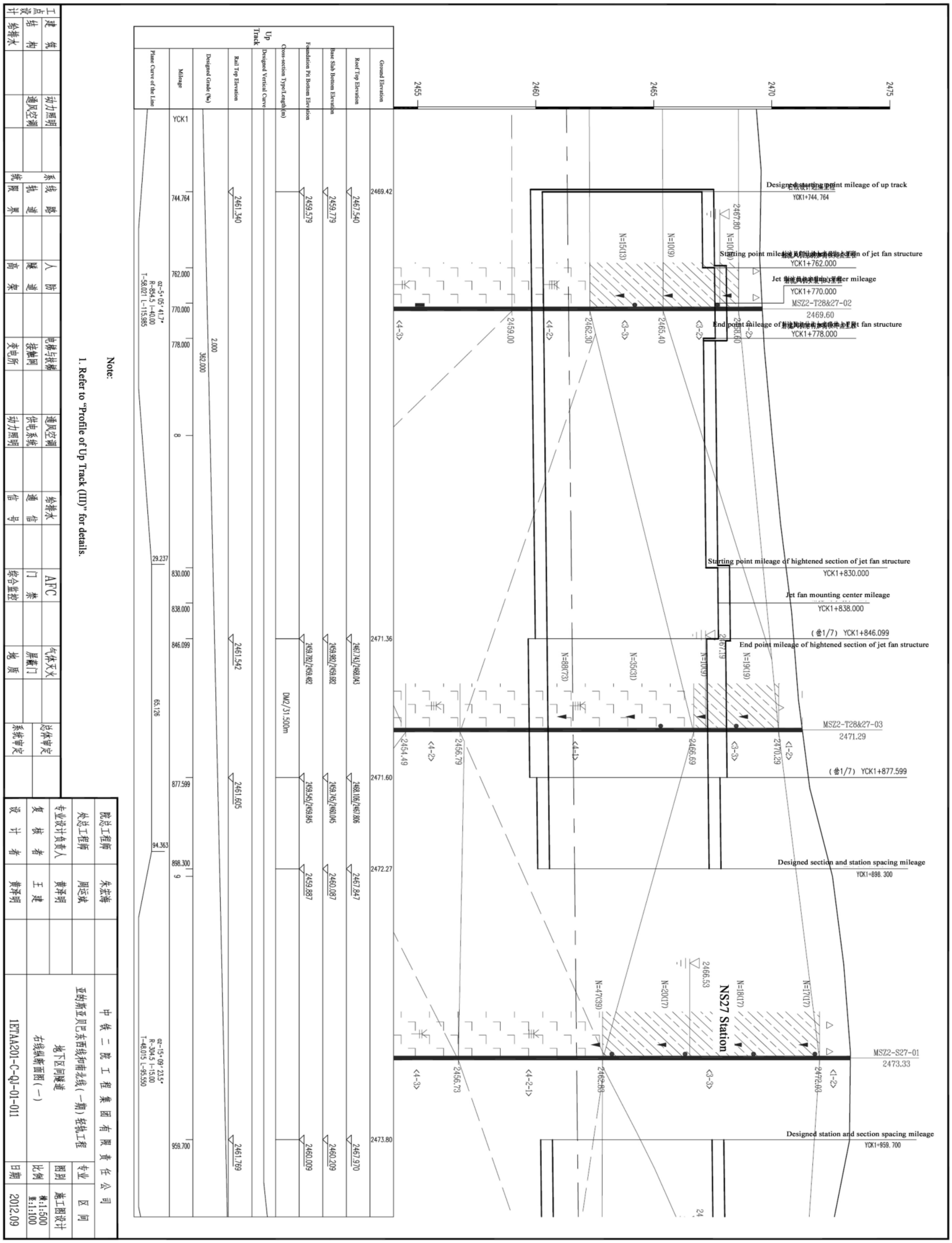
Appendix K: Plan of Main Structure (VI)



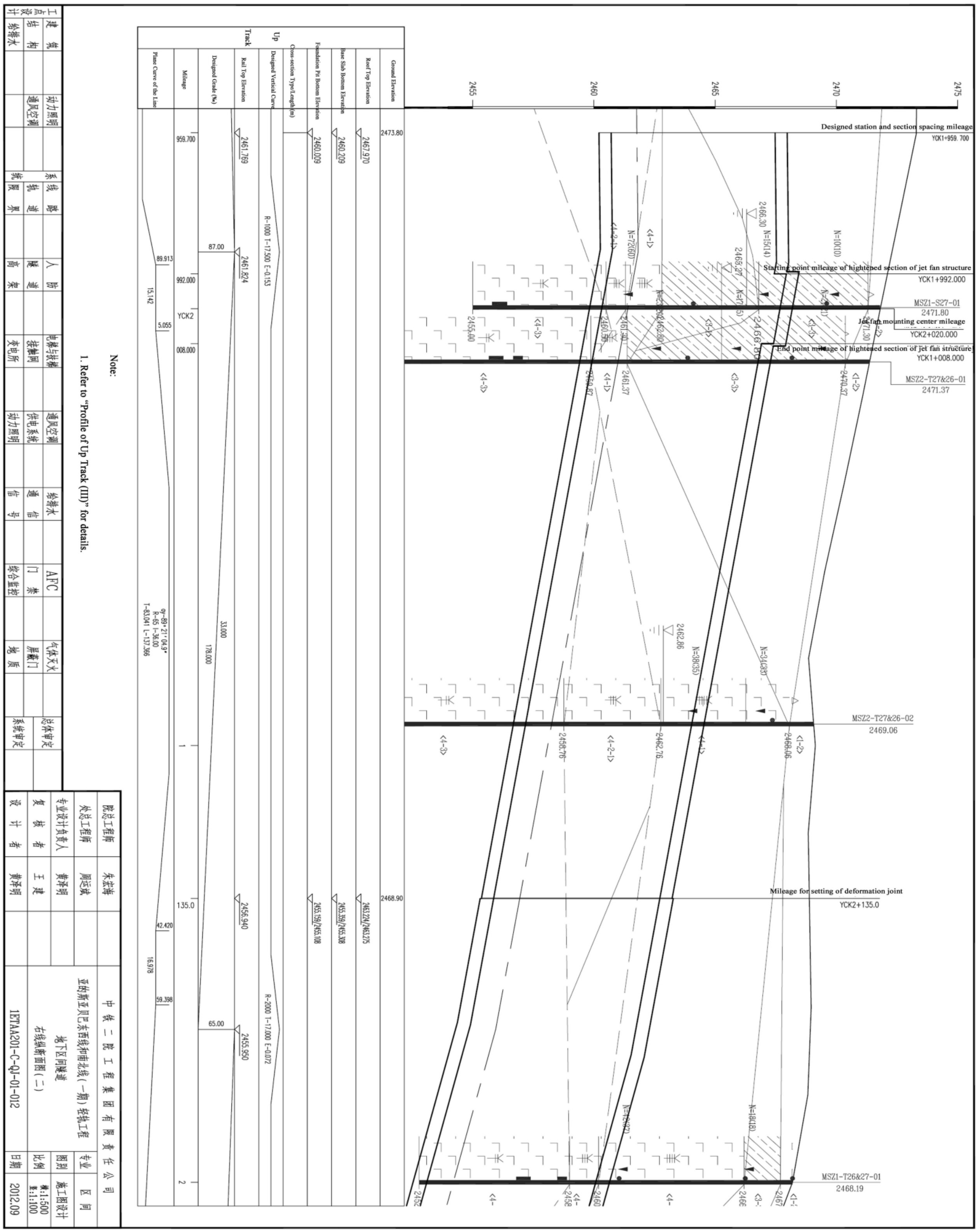
Appendix L: Plan of Main Structure (VII)


Data Table for Plane Curves of the Line
ZJD6
YJD6
HZ ZCK2+372.604
ZH YCK2+378.522
ZH ZCK2+391.700
Designed end point mileage of up track
/and designed subgrade spacing mileage
YCK2+400.000
Designed end point mileage of down track
/and designed subgrade spacing mileage
ZCK2+405.133
HY ZCK2+451.700
HY YCK2+458.522
DM5
DM21
Note:
1. Except that mileages and coordinates are measured in m, all the other dimensions are measured in mm.
2. The drawing is designed based on the preliminarily designed first edition of line data released by the line discipline of the overall group on July 5, 2012.
3. The section tunnel includes the down track with the length of 153.191m+445.876m=599.067m, and the up track with the length of 153.536m+440.300m=593.836m.
4. Deformation joints are set at two places at the mileages of ZCK2+142.307/YCK2+135.000 and ZCK2+26.247/YCK2+255.000 in the tunnel of this section.
5. The section tunnel has multiple segments of curves. Positioning shall be conducted in combination with curve parameters and tunnel width during construction setting out.
6. For those not specified in the drawing, please refer to the general specification and relevant design drawings. Relevant specifications and regulations shall be followed strictly.
AFC
1ETAA201-C-QJ-01-010
1:200
2012.09

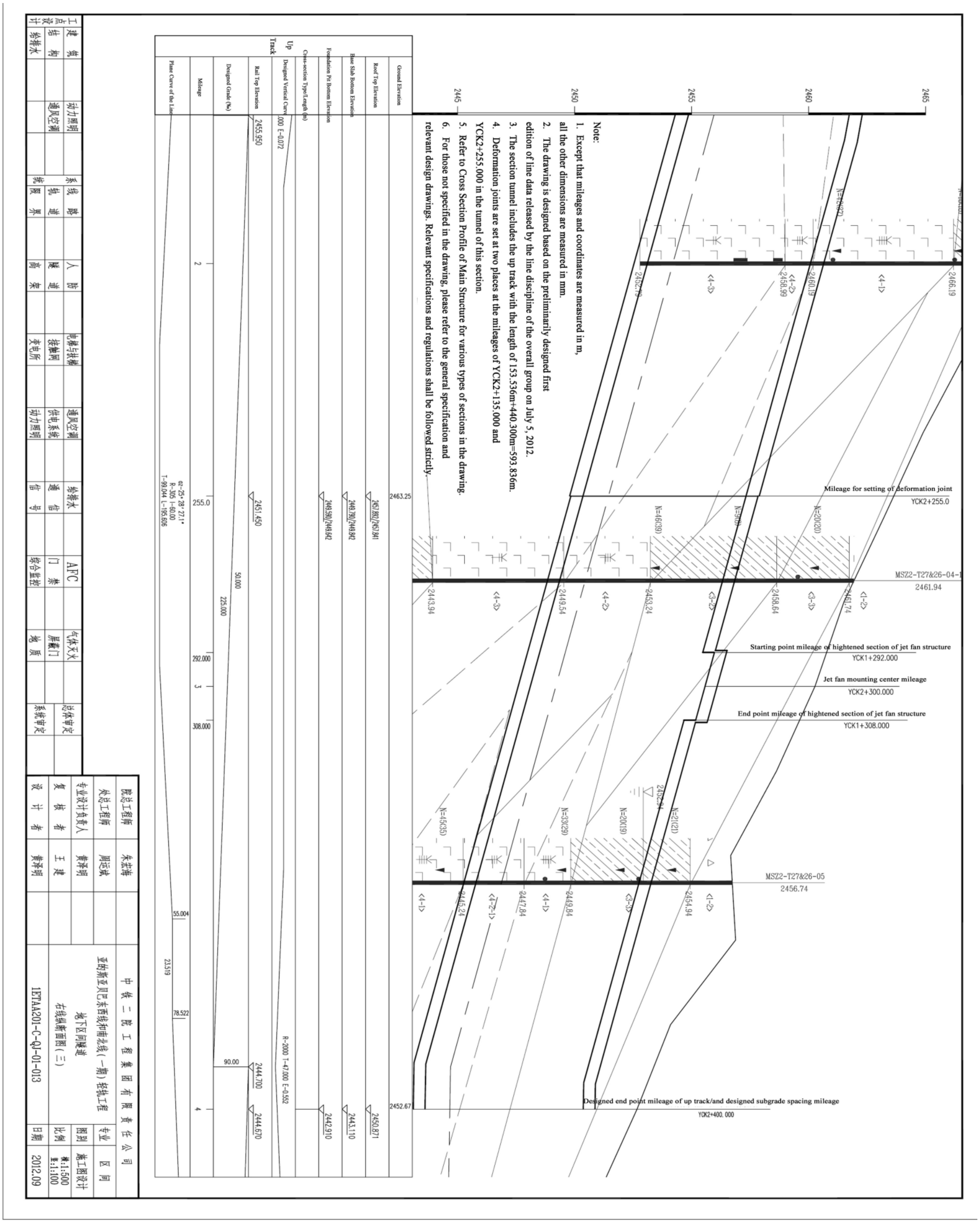
Appendix M: Profile of Up Track (I)



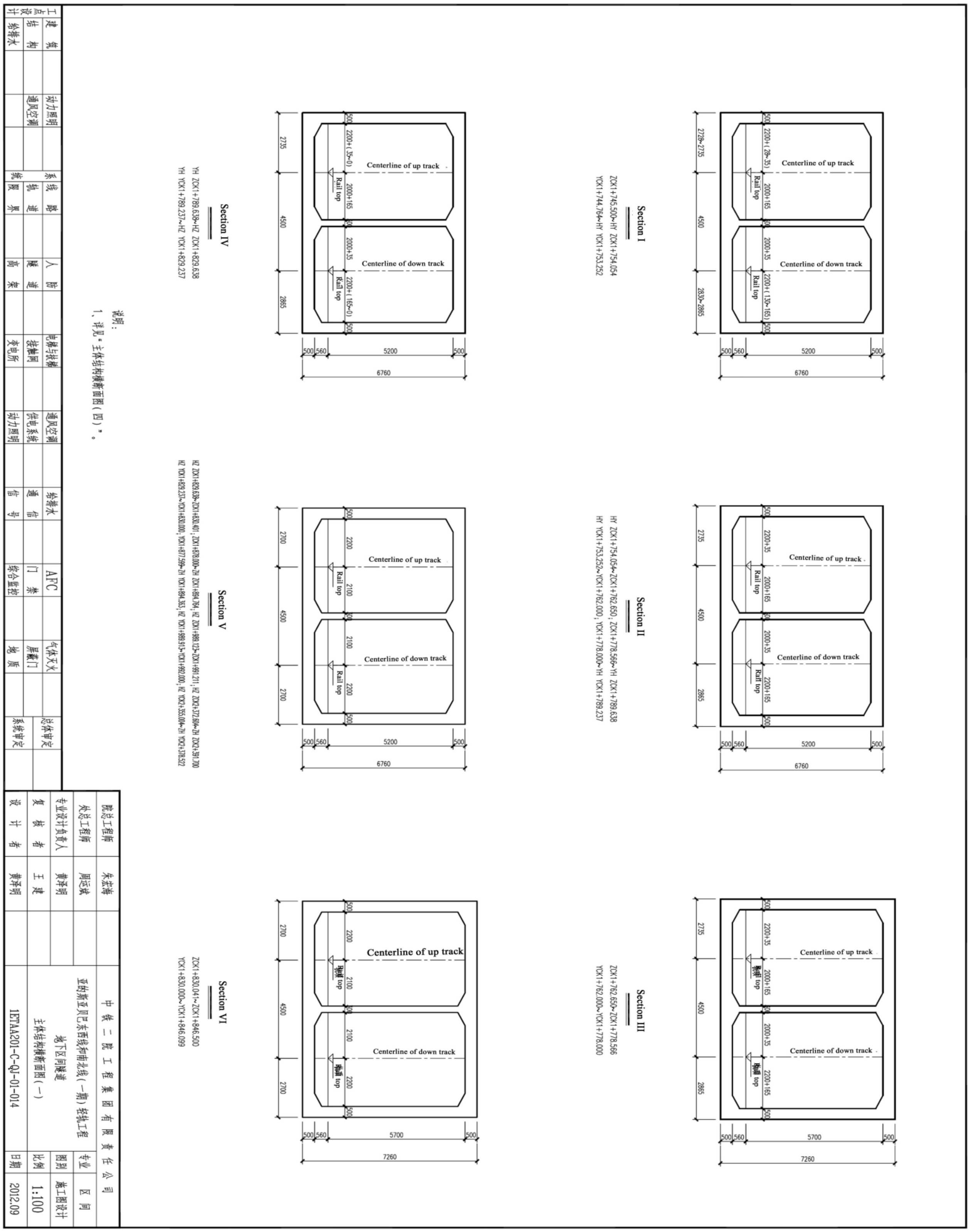
Appendix N: Profile of Up Track (II)



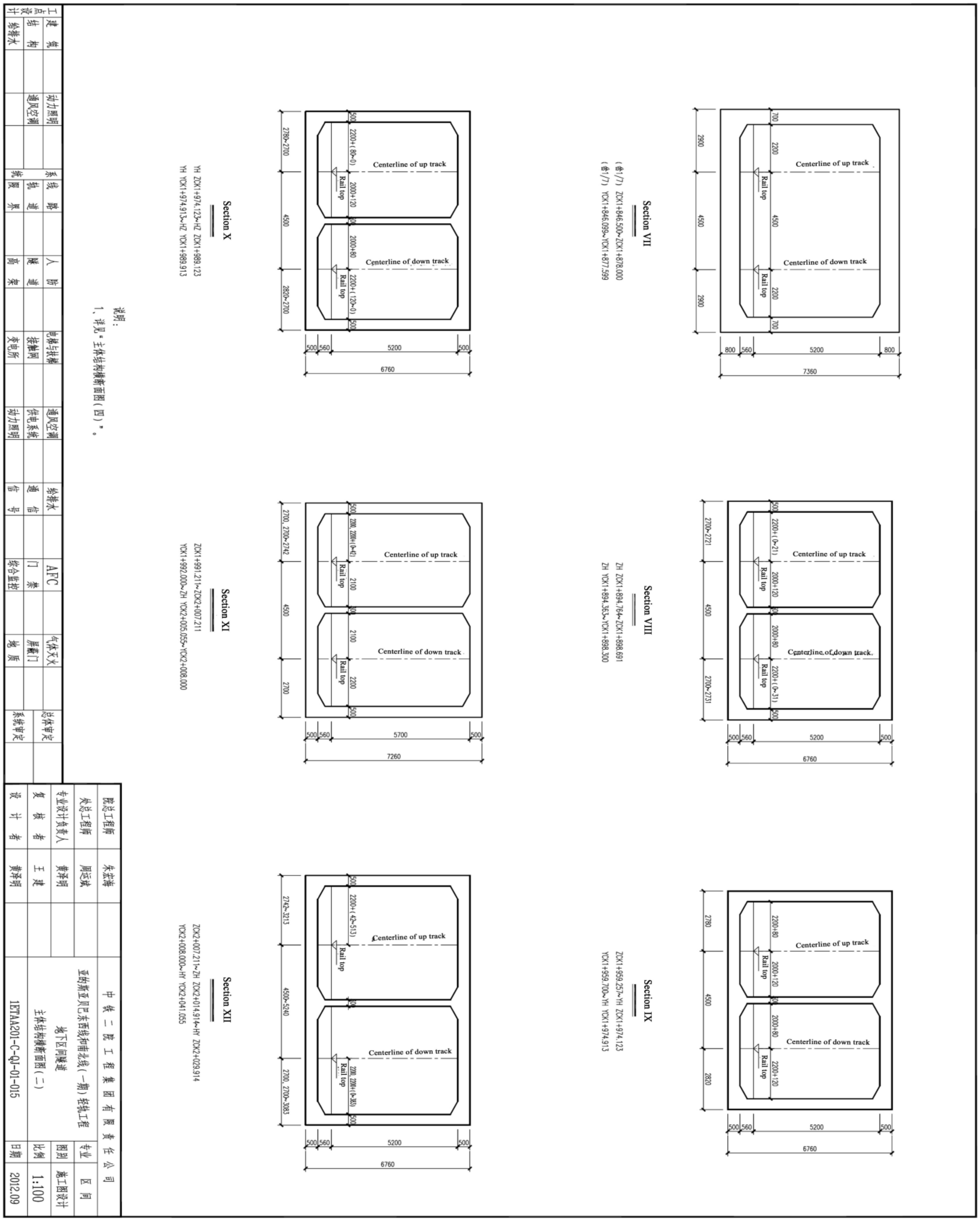
Appendix O: Profile of Up Track (III)



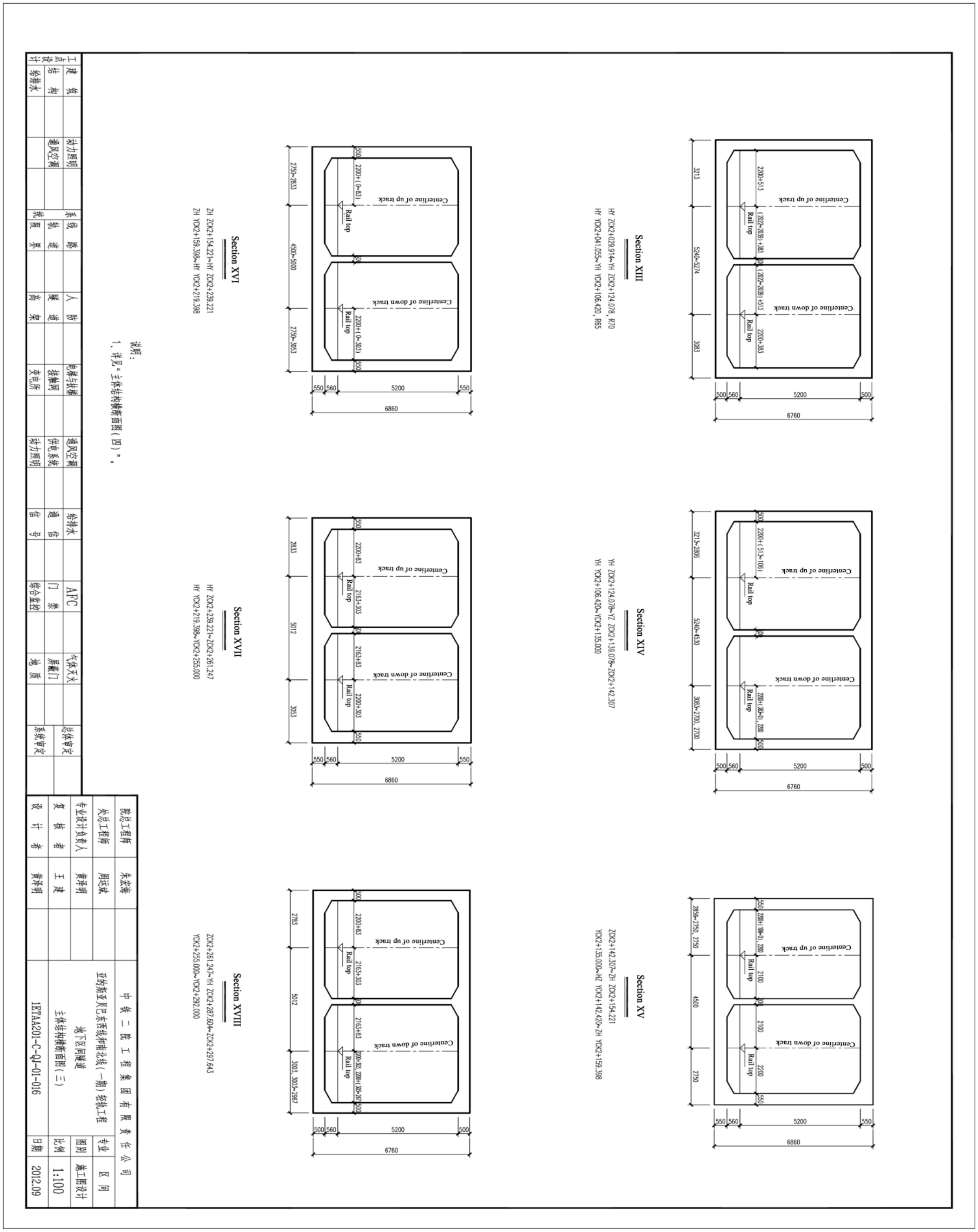
Appendix P: Cross Section Profile of Main Structure (I)



Appendix Q: Cross Section Profile of Main Structure (II)



Appendix S: Cross Section Profile of Main Structure (III)



Appendix T: Cross Section Profile of Main Structure (IV)