Guidelines for the civil engineering work of International Linear Collider (ILC) facilities (Abstract)

Rock Mechanics Committee in Japan Society of Civil Engineers
Subcommittee for the establishment of standard specifications for the civil engineering work of Internal Linear Collider

The subcommittee compiled the result that examined a countermeasure considered at present as guidelines while arranging the subjects and problems about the civil engineering technologies for ILC facilities. Meanwhile, this document was compiled as an abstract for the purpose of public notification of the compiled guidelines and includes important items only extracted from the text. Therefore, the text of guidelines should be referred for the purpose of detailed consideration.

Key Words: *International linear collider, collaboration between particle accelerator science and civil engineering, underground openings, guideline for civil work of ILC*

1. Introduction

Committee on rock mechanics of the Japan Society of Civil Engineering received reports from the special subcommittee on vitalization of rock engineering (Nishiwaki, chairman, April 2004) and established the research subcommittee on linear collider civil engineering technology in the Committee on Rock Mechanics and Tunnel Engineering Committee of the Japan Society of Civil Engineering in 2006 to vitalize rock mechanics and tunnel engineering and started technological support toward the realization of the ILC project and attraction of the project to Japan. The following activities have been implemented to date on consignment with the High Energy Accelerator Research Organization (KEK).

1. Research report on construction sites for long distance collision type accelerator project (in Japan) (2009)
2. Research report on civil engineering technologies for the construction of accelerator (in Japan) (2009)
3. Participation in technical study meetings on ILC project technical study meeting (after 2007)

In 2010, the subcommittee on the formulation of specifications for civil engineering technology for the international linear collider was established by the Japan Society of Civil Engineering and Committee on Rock Mechanics/Tunnel Engineering Committee. In the subcommittee, field surveys of ILC related facilities and planned construction sites and interviews from persons in charge of planning/investigation inside and outside of Japan were implemented. Furthermore, related documents of past construction of the same type (examples of large-scale underground facilities, guidelines, and specifications of the construction) have been collected and analyzed. The guidelines have been established so that rework and overlapping work can be minimized in promoting the ILC project in Japan, and the facility can be constructed economically and with high quality. The document represents the guidelines for civil engineering work (mainly underground space) for the ILC facilities in Japan and is intended to contribute to the ILC project in Japan. However, on the other hand it is expected to be used effectively not only for overseas construction but also large-scale underground space construction in the future.

Table-1 Section meetings of subcommittee and members (February, 2014)

Section Meetings	Secretary, Member
Chairman, Chief of section meeting on project management: Hiroshi Chikahisa (Ground System Laboratory Co., Ltd.)	Adviser: Kiyotoshi Sakaguchi (Tohoku University), Takahumi Seiki (Utsunomiya University), Yasuhiro Mitani (Kyushu University), Secretary General: Masanobu Miyahara (High Energy Accelerator Research Organization), Naoyoshi Kuruyama (Fukken Co., Ltd.), Chief of section meeting
Section meeting on project investigation Chief: Hideto Mashimo (Public Works Research Institute)	Adviser: Yasuaki Ichikawa (Okayama University), Secretary: Kunihumi Takeuchi (Oobayashi Corporation), Members: Kazuhiko Kanai (Yachiyo Engineering Co., Ltd.), Hideaki Kuramochi (Pacific Consultants Co., Ltd.), Takashi Tsuzaki (JP Design Co., Ltd.), Takuro Nishi (Shimizu Corporation), Yoshiaki Hirakawa (Newjec Inc.), Masao Fujiwara (Tohoku Electric Power Co., Ltd.), Norihumi Matsushita (OYO Corporation), Takeshi Matsuda (Oobayashi Corporation), Hideaki Yasuhara (Ehime University)

Section meeting on large cavity Chief: Yoshinobu Nishimoto (Electric Power Development Co., Ltd.)	Adviser: Norikazu Shimizu (Yamaguchi University), Secretary: Tsuyoshi Nishimura(Hazama Ando Corporation), Members: Hirotsugu Ikeda (Kyushu Electric Power Co., Inc.), Ichiro Sekine (Toda Corporation), Kazunobu Matsumoto (Tobishima Corporation)
Section meeting on horizontal pile Chief: Tetsuya Iwao (NEXCO RI)	Adviser: Kazuo Nishimura (Tokyo Metropolitan University), Secretary: Haruo Sasao (Fukada Geological Institute), Members: Makoto Uda (Tekken Corporation), Seiji Hiruko (Okumura Corporation), Takahiko Okai (Nishimatsu Construction Co., Ltd.), Masae Kuji (Maeda Corporation), Michihumi Koyama (Kyoto University), Naoto Matsudo (Takenaka Civil Engineering & Construction Co., Ltd.), Kazuo Miyazawa (East Nippon Expressway Co., Ltd.), Tetsu Teramoto (Taisei Corporation)
Section Meeting on special pile Chief: Katuji Akita (Japan Railway Construction, Transport and Technology Agency)	Adviser: Shinichi Akutagawa (Kobe University), Secretary: Shuichi Sakaguchi (Nishimatsu Construction Co., Ltd.), Members: Masahiro Katayama (Kumagai Gumi Co., Ltd.), Toshinori Sato (Japan Atomic Energy Agency), Satoshi Naganuma (Konoike Construction Co., Ltd.), Kazuhiko Masumoto (Kajima Corporation), Takajin Hunahashi (Tekken Corporation), Hiroshi Yamaji (Sumitomo Mitsui Construction Co., Ltd.)
Section meeting on disaster prevention Chief: Harumasa Okabe (Nikken Sekkei Ltd.)	Adviser: Nobuyoshi Kawabata (Kanazawa University), Makoto Tsujimoto (Tokyo University of Science), Kojiro Horiuchi (Road Engineering Co., Ltd.), Secretary: Kaoru Kobayashi (Kobe City College of Technology), Members: Shinji Sunagane (Public Works Research Institute), Tomoki Kikumoto (Echo Plan Co., Ltd.), Takahumi Shimokoji (Takenaka Corporation), Sachio Nishida (Tokyo University of Sciences)

GDE (Global Design Effort), which is a subsidiary of IUPAP (International Union of Pure & Applied Physics), prepared the Technical Design Report (hereinafter referred to as TDR) in 2013. Then the committee completed the first draft of guidelines. Afterwards, explanatory meetings and symposiums were held widely for interested parties to hear opinions and requests, and the contents of guidelines have been improved to a more realistic level. Furthermore, it is desirable that lively discussions related to the construction of ILC facilities in the underground cavity will be made on various occasions based on guidelines for the future. And, it is expected that ILC facilities will be safely constructed economically and with high quality through such discussions and guidelines.

The guidelines were prepared in parallel with preparation work, which is advancing on a daily basis, of TDR by GDE, and new information has been taken into consideration as much as possible. And regardless of the new and old information utilized for preparing the text, the important items in compliance with the purposes and intentions of the text are decided to be left in the sentence. Because of this, please keep in mind that descriptions that do not match the latest project may be left.

2. Committee

(1) Purposed of activities

The committee organizes tasks and problems and prepares guidelines related to the construction of the tunnels and underground cavities at this moment assuming the case that those ILC facilities will be constructed in Japan.

(2) Committee constitution

Constitution of members of the committee is shown in Table 1.

3. Outline of ILC project

(1) Outline and history of ILC project

The International Linear Collider (hereinafter referred to as ILC) project is an extra-large research project that builds a linear accelerator with a total length of approximately 31 km (to be extended to 50 km in the future) and implements experiments involving the collision of electrons and positive electrons. The project implements particle experiments that are the most advanced in the world by building accelerators that utilize the results of advanced research and technologies from a variety of different fields, including superconducting technologies, to find unknown particles and to solve the mysteries of the origin of mass and the creation of the universe. The roadmap for progress of the ILC project and the construction of facilities are shown in Figures 1 and 2. The ILC project is an international project promoted as the only project for an electron-positive electron collision type accelerator in the world at IUPAP held in 2004. GDE was established as the international design team the next year in 2005 in order to make the project happen. Since then, research and development related to ILC and various technical investigations toward construction have been implemented with the participation of over 100 research institutes and universities. As the first significant result, the ILC Reference Design Report (hereinafter referred to as RDR) was issued in 2007. And subsequently to RDR, the new TDR collected more detailed results of technological developments, and designs were issued in the spring of 2013. Taking this opportunity, the LCC (Linear Collider Collaboration) as the subsidiary of ICFA (International Committee for Future Accelerator), which becomes the international design organization replacing the existing GDE, was inaugurated and started operation aiming at the early realization of the ILC.

Just at that moment, the Higgs particle, which has been thought of as the God particle, was discovered by the LHC (Large Hadron Collider) experiments at CERN (European Organization for Nuclear Research) in 2012 in the area of particle physics, and it became global news. From the result of the experiment, the Nobel Prize in Physics for 2013 was awarded to Dr. Higgs who theoretically predicted the existence of the Higgs particle. And the ILC project has attracted attention as the experiments to elucidate the physical properties of the Higgs particle and international expectations for early construction have increased. In addition to the elucidation of the Higgs particle, which is believed to be the origin of mass for all substances, there are a growing number of international voices that desire ILC experiments that have the full possibility of creating entirely new theories on particles and the universe, such as the elucidation of the mysteries of dark matter, which is thought to share the great majority of substances comprising the universe and the creation of the universe, as well as the discovery of new super symmetric particles.

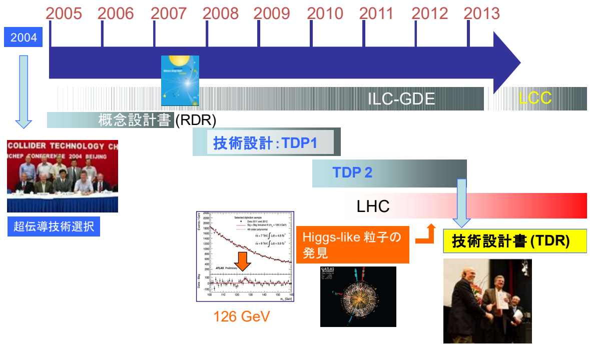


Figure 1 Progress of ILC project

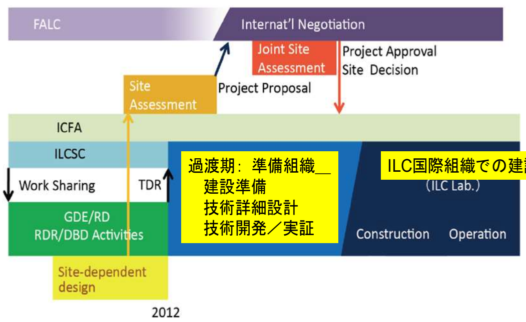


Figure 2 Roadmap for the construction of ILC facilities

On the other hand, besides research and technological developments by international schemes, domestic activities toward the selection of proposed domestic sites are expanding with the aim of the construction of ILC facilities at a mountain site in Japan. Geological surveys have started at two proposed domestic sites as of 2012, and at the same time, consideration of a site survey for the purpose of extraction of tasks for the promotion of the project assuming the location of the ILC is in Japan and the organization of basic requirements necessary to establish the central campus. First, this section summarizes the outline of the underground structure of ILC facilities at the mountain site in Japan for the establishment of guidelines for the civil engineering work of ILC facilities recommitted to the Japan Society of Civil Engineering in order to prepare for the upcoming establishment of the basic plan and the detailed design with the understanding of internal and external circumstances.

(2) Entire layout of ILC facilities

As indicated in Table 2 and Figure 3, the main facilities of the ILC consist of the linear main accelerator tunnel with a total distance of approximately 31 km (to be extended to 50 km in the near future) in the first plan, an experimentation hall in the central part, and a damping ring tunnel. All of them are underground experimentation facilities consisting of long, large tunnels and large caverns at great depth. The facilities for the various experiment supporting facilities to support experiments underground and plants for energy supply are required to be built on the ground. The plan is to locate 10 satellite stations along with the beam line. The access tunnels (inclined shafts) for carrying out/in experimental equipment and other devices from ground stations to underground experimental facilities or maintenance must be constructed. On the other hand, separated from the experimentation site where these experimentation facilities are installed, the construction of facilities on the campus of the International Research Center, where the research buildings are constructed to accommodate approximately 3,000 employees of the International Research Center and guest researchers and engineers, is one of the project tasks. However, the guidelines were established for limited areas centering on the civil engineering work of planning, survey, design, construction, and disaster prevention of underground structures, and these ground facilities are excluded from consideration.

The portion of 11 km from both ends of the main linear accelerator (main linac) installed on both sides of the experimentation hall in the central part is the accelerator called the electron linac and positive electron linac. Superconductive acceleration cavities are continuously installed here, and the beam is accelerated at the required energy level for collision experiments. And tunnel sections of approximately 5 km in total to be located on the left and right side of the experimentation hall are called the Beam Delivery System (hereinafter referred to as “BDS”) and the beam is narrowed toward a collision point at the level of the nanometer. Since accelerator equipment of the final focusing system, which are the most sensitive to vibration, are installed in the BDS section, ensuring the stability and vibration resistance of the tunnel structure (floor surface) in the section becomes the most important task for considerations. Furthermore, the racetrack shaped cavity with the circumference of approximately 3 km called damping ring (hereinafter referred to as DR) tunnel is placed beside the experimentation hall in the central part. The DR is the accelerator that has the important function of adjusting the beam to the extremely high parallelism (low emittance beam) during the process of circulating the beam generated in the linac part. Furthermore, electrons and positive electron beams narrowed to the specified level by DR are transferred to both ends from DR via the beam pipe in the main linac and further transferred to the linac after circled 180 degrees at the small loop portion is then accelerated toward the collision point. The accelerator called RTML (Return to Main Linac) which transfers the beam from DR to the main linac has the total length of approximately 15km and the longest beam line facilities among ILC accelerators together with electron linac and positive electron linac.

In the first construction plan for the ILC facilities, the aim is to gradually realize the collision energy from 250 GeV to 50 0GeV by constructing the accelerator with the total length of 31 km. The project includes collision experiments at super high energy up to the range of 1,000 GeV (1 TeV) by extending the total length to 50 km in the future.

Table 2 Table of main underground structures (The first plan)

Electron linac part	***Central part***	***Positive electron linac part***
Main linac tunnel (approximately 11 km)	Experimentation hall cavern (L=142 m)	Main linac tunnel (approximately 11 km)
RTML loop Tunnel (approximately 2 km)	BDS tunnel (approximately 5 km)	RTML loop Tunnel (approximately 2 km)
Access hall (3 locations)	Damping ring Tunnel (circumference approximately 3 km)	Access hall (3 locations)
Access tunnel (4)	Access tunnel (2)	Access tunnel (4)

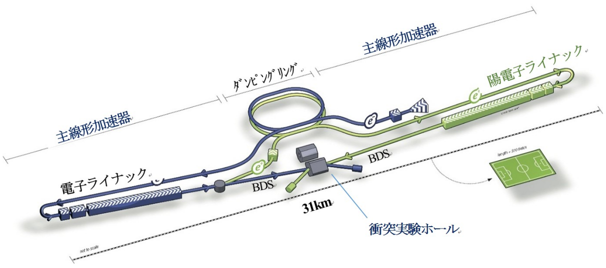


Figure 3 Schematic of main facilities of ILC project (The first plan)

(3) Outline of accelerator tunnel

a) Experimentation hall

The experimentation hall, which is the central facility of ILC facilities, is placed as the beam collision point of electron and positive electron beam lines becomes the center point of it, and so that it becomes orthogonal to the beam line axis. In the hall, two detectors, ILD (International Large Detector, total weight of approximately 1,500 t) and SiD (Silicon Detector, total weight of approximately 10,000 t), are installed based on experience and the results of the past numerous accelerator experiments, and they are alternately transferred onto the beam line by a push/pull system and utilized for experiments. Since these detectors are gigantic and extremely heavy, the experimentation hall where detectors are located becomes a large-scale underground cavern equal to underground electric power plants. Currently, detectors are temporarily assembled in the ground facilities (assembly hall) nearby the entrance of access shaft to the experimentation hall and disassembled into the specified size after the adjustments and are carried into the experimentation hall by special large trailers. And then, the final assembly and adjustments are implemented in the experimentation hall.

Concrete platforms where the detectors are placed maintain ultra-precise alignments of detectors and, at the same time, have the function of decentralizing weights evenly. And the high precision within about ±1 mm of displacement allowance is required for the floor surface (integral structure with bedrock) accompanying the transfer of detectors by the push/pull system. Furthermore, assembly and install procedures of detectors and detailed structural design of the experimentation hall depend upon the geographical and geological conditions of the ILC construction site. However, the document is established here under the basic condition that the experimentation hall is accessed by using an inclined shaft tunnel with the length of approximately 1 km constructed in the mountains area where granite is distributed, which is the common conditions of two proposed sites in Japan. Specifications for the experimentation hall requested by experiment side are indicated in Table 3 and the cross section and layout image and cross section of access tunnel are shown in Figures 4–9.

Table 3 Specifications for experimentation hall and access tunnel

1) Experimentation hall
- Scale of cavern: Width 25.0 m, Height 42.0 m, Length 142 m
- Shape of cavern: Bullet shape (Arch + vertical walls)
- Features of ground: Bedrock with B-Ch class (granite etc.)
- Interior finish: Splayed concrete lining

2) Access tunnel
- Scale of cross section: Width 11.0 m, Height 11.0 m
- Shape of cross section: Horseshoe shape (Mountain tunneling method)
- Interior finish: Splayed concrete lining

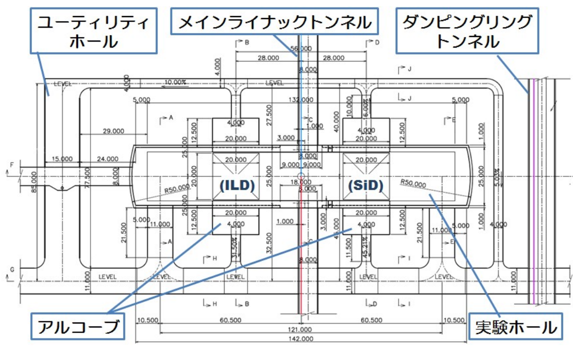


Figure 4 Floor plan of experimentation hall

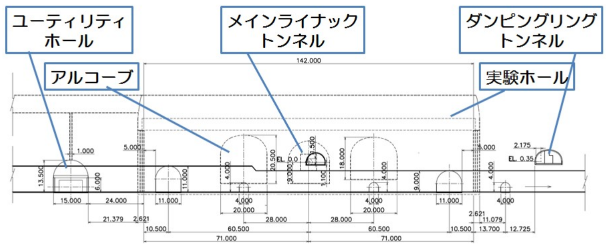


Figure 5 Cross sectional drawing of experimentation hall

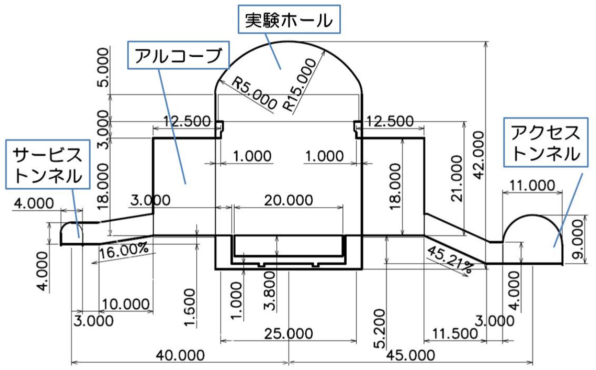


Figure 6 Cross sectional drawing of experimentation hall

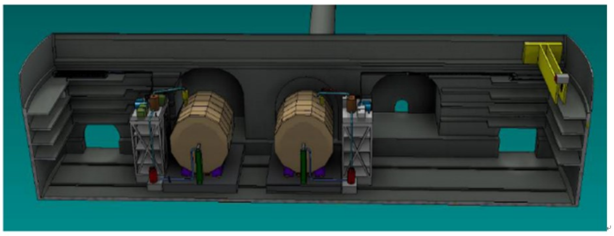


Figure 7 Vertical cross sectional image of experimentation hall

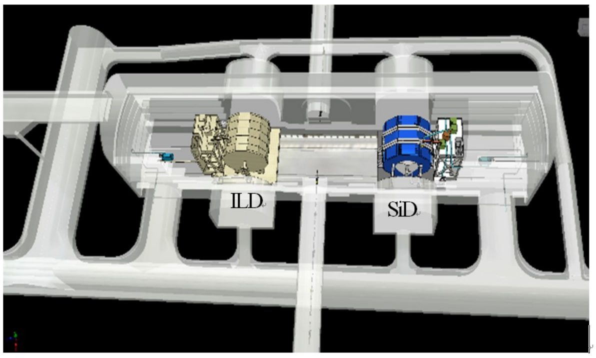


Figure 8 Bird's eye view image of experimentation hall area

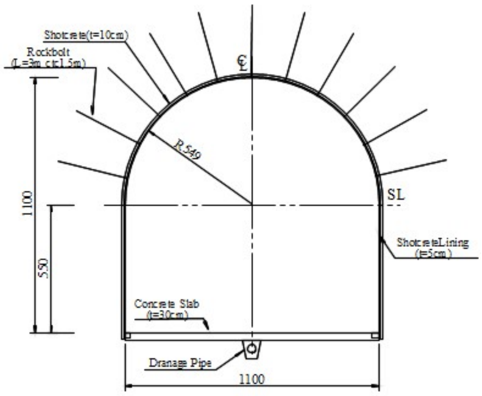


Figure 9 Cross sectional drawing of access tunnel to experimentation hall

b) Main linac tunnel

The entire layout of planned beam line is shown in Figure 10.

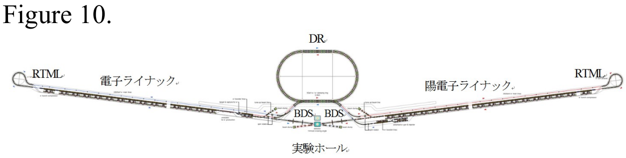


Figure 10 Layout image of ILC beam line

The greatest feature of the main linac tunnel is the strict requirement of linearity along with the direction of axis. As shown in Figure 10, 2 beam lines of electron linac and positive electron linac bend at the minute angle (14 mmrad) at the collision point but the strict linearity should be kept for the horizontal alignment over the span of 15 km. Longitudinally, the linearity of laser straight is required for the BDS section in the central part. On the other hand, two linacs located at both sides require the strict horizontal nature along with the geoids surface. These are the required conditions from accelerator equipment in order to ensure the horizontal nature of liquid surface of helium coolant inside of the piping installed to the linac for the span of its total length. However, in case there are large benefits in construction cost and construction period of the main linac tunnel, the incline of the tunnel of up to 0.5%, which can ensure the horizontal nature of liquid surface of helium within the specified cross sectional size of piping, can be allowed as exceptional measures.

The specifications for tunnels, cross sectional drawing of the main linac tunnel (the same cross section for both electron and positive electron linac), image drawing, and cross sectional drawing of the access tunnel are shown in Table 4 and Figures 11–14.

Table 4 Specifications for main linac tunnel and access tunnel

1) Main linac tunnel -Scale of cross section: Width 11.0 m, Height 5.5 m -Shape of cross section: Semi-cylindrical shape (Mountain tunneling method) -Interior finish: Concrete lining (water introduction measures behind the concrete to prevent internal flow) -Supplementary structure: Central partition wall, drainage trench 2) Access tunnel - Scale of cross section: Width 8 m, Height 7.5 m - Shape of cross section: Horse shoe (Mountain tunneling method) -Interior finish: Splayed concrete lining

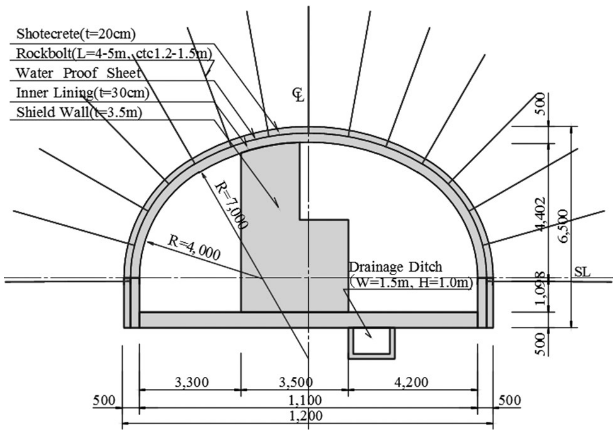


Figure 11 Cross sectional drawing of main linac tunnel

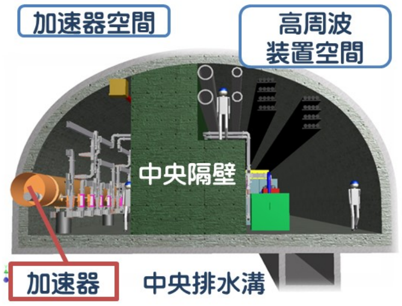


Figure 12 Conceptual drawing of main linac tunnel

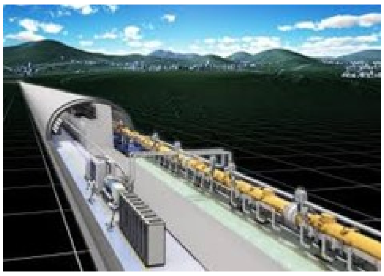


Figure 13 Image of main linac tunnel

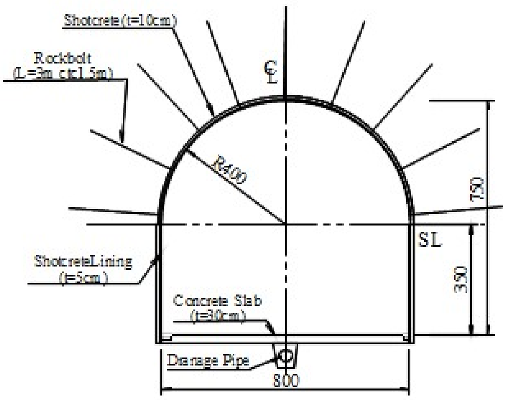


Figure 14 Cross sectional drawing of access tunnel to Main Linac

The main linac tunnel proposed by Japan is separated into the following two spaces by the partition wall made of 3.5 m thick concrete and installed at the center of the cross section.

(i) Accelerator space...superconductive accelerator (cryo module) is installed

(ii) High frequency equipment space...Klystron, which supplies high frequency to the accelerator, and power supply equipment are installed

The main purpose of the partition wall located at the center and made of concrete is to shield radiation generated by the beam operations. It has the large benefit that humans can enter for maintenance of the high frequency equipment even during beam operation. Furthermore, in case of disasters, such as fire and helium leakages, it is possible to ensure the redundancy of facilities since the other space of the wall can be used as an evacuation route due to the partition wall. The tunnel structure is regarded to greatly contribute to the improvement of disaster prevention function, which would be a fateful for ILC facilities as a large underground space.

In the tunnel, reclaimed surfaces are covered by water resistant sheets, and water introduction measures are implemented so that spring water from surrounding natural ground will not flow into the inner space of the tunnel. After that, about 30 cm thick lining concrete will be poured. Spring water flowing in the rear side of the cover will be collected into a drain located at the backside of the leg part of the concrete lining and then drained to the outside of the shaft through the central drainage located underneath the batholithic concrete of the tunnel. By adopting the drain introduction system, spring water coming from surrounding natural ground will be directly drained to the outside of the shaft, through drains and drainages located at the back of the lining and batholith without flowing into the tunnel, and spring water flowing into the tunnel will be decreased significantly. All of the decreased spring water flowing into the tunnel will be stored in the drain tank as the controlled drain, strictly monitored, and then treated. On the other hand, since most of the spring water will be drained to the outside of the shaft as a state that it is shielded by the concrete of the lining or the batholith, it can be treated as natural water. Furthermore, if the characteristics of the geographical features of the mountains can be utilized effectively, depending on the local geographical conditions, since spring water (assumed average amount of spring water 0.6 t/min/km) introduced in the backside of the lining concrete of the tunnel will become possible to be discharged naturally without pump-up to the existing rivers, and searches for the possible points of natural drain at proposed sites for the project are implemented in parallel with the site survey.

c) Damping ring tunnel

Specifications, floor plan, cross sectional drawing of the damping ring tunnel are shown in Table 5, Figure 15, and Figure 16, respectively. Figure 16 is for the curved section and the linear part has the same cross section as the main linac tunnel. The access tunnel to damping ring has the same cross section (Figure 14) as the access of the main linac.

Table 5 Specifications for damping ring Tunnel and access tunnel

1) Damping ring Tunnel -Scale of cross section: Width 5.5 m, Height 4.7 m -Shape of cross section: Horse shoe shape (mountain tunneling method) - Interior finish: Concrete lining (water introduction measures behind the concrete to prevent internal flow) 2) Access tunnel -Scale of cross section: Width 8 m, Height 7.5 m -Shape of cross section: Horse shoe shape (mountain tunneling method) - Interior finish: Splayed concrete lining

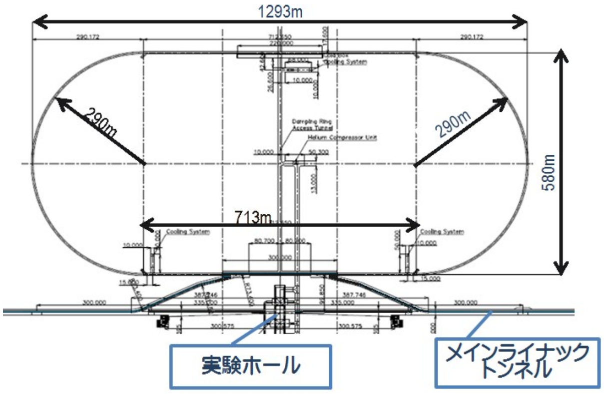


Figure 15 Floor plan of damping ring tunnel

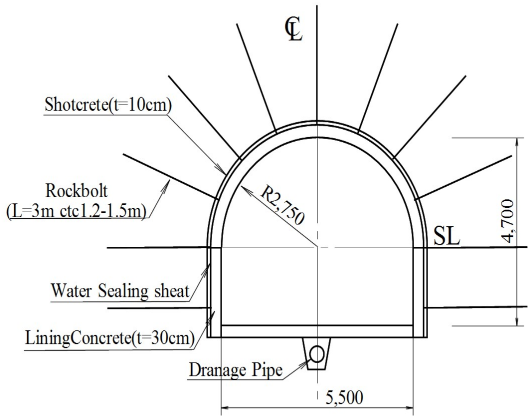


Figure 16 Cross sectional drawing damping ring tunnel

The damping ring is the essential accelerator to obtain high luminosity required for ILC. The damping ring has a very important function to feed the low emittance beam formed by narrowing electrons and positive electrons entered from the generator to the utmost limit into each linac for electrons and positive electrons. The damping ring has the planar shape of a racetrack as shown in Figure 15 and is a system where the electron ring and positive electron ring are installed in 2 tiers in one tunnel with the beams circulating in opposite directions.

d) RTML (Ring to Main Linac)

RTML is the system to transport the electron beam and positive electron beam from the damping ring to the main linac and the longest beam transportation line of 15 km among the ILC facilities. Electron and positive electron beams extracted from the damping ring are transported to the end of upstream of the linac by the beam pipe inside the electron linac and positive electron linac and used as the beam for collision experiments after circling 180 degrees. RTML is the beam pipe that the most part is located inside the main linac tunnel and only circulation part at the end becomes the proprietary tunnel structure (loop tunnel). The guidelines shall treat RTML in proportion to the main linac tunnel.

e) Beam Delivery System (BDS)

BDS is the last stage and important accelerator that narrows down the electron and positive electron beams inherited from the end part of the main linac to the beam size required by the luminosity objective of the ILC project and feeds into the collision point. And other than the function of beam transportation, it has a wide range of important functions, such as to minimize the background noise of detectors by eliminating beam halos from linac and to measure beam parameters before and after the collisions precisely. Currently, testing and developments of experiment equipment in the BDS section are vigorously implemented, and although it is possible that new requirement tasks on tunnel scale and structure will be presented in the future, considerations on TDR is to be promoted based on the standard design plan, which is internationally proposed at this point.

f) Outline of construction schedule of ILC facilities

As a milestone of TDR, approximately nine years is assumed for the required period from the start of civil engineering work to the commencement of beam operation after the completion of the installation and adjustments of experiment equipment as the result of considerations on the construction schedule based on the construction plan at mountains sites. It is confirmed internationally as the basic scheme that the initial approximately six years is allocated as the construction period of access tunnels and accelerator tunnels, experimentation hall, main underground structures, and incidental-facilities (electrical facilities, mechanical facilities and disaster prevention facilities) and to start full-scale installation work of experiment equipment and experiment incidental facilities from the seventh year.

In establishing the guidelines, drafting of the construction plan and consideration of the construction period are not included, but the above-mentioned construction schedule is used as the preconditions assuming the use as the guidelines of design and construction.

4. Outline of guidelines

4.1 Planning and survey

In order to establish the basic plan for the ILC facilities, the basic policy must be decided at first to reasonably promote planning, survey, design, and construction of large-scale underground cavities for the long distance tunnel in which accelerators are installed and the experimentation hall in which detectors are installed. Next, the basic linear and cross sections and specifications of the tunnels of the main linac tunnel, damping ring tunnel, access hall, and access tunnel composing ILC facilities and experimentation hall must be determined by satisfying the required performance from the side of the experiment equipment regarding plane and vertical alignment in consideration of conveyance of heavy machinery and materials, spring water treatment, ventilation, and the disaster prevention plan. Furthermore, earthquake-proof performance for underground structures, such as accelerator tunnel and experimentation hall, must be determined as the facility design for earthquakes.

Surveys on underground cavities for the tunnels and experimentation hall are roughly divided into 2 areas which are natural ground conditions and site conditions. Natural ground condition survey will be implemented for each stage of survey and planning, design, construction, and maintenance. As natural ground condition surveys implemented at the planning and survey stage, there are divided into general survey (existing materials survey, reading of aerial photographs, ground surface geological features survey, hydrological survey, active fault survey etc.) and proprietary surveys (diastrophism, micro tremor survey etc.) of ILC facilities. Natural ground condition surveys implemented at design and construction stage are required to gradually improve the precision for the purpose of acquiring required basic materials for design and construction planning by grasping whole natural ground conditions of underground cavities of the tunnels and experimentation hall. And, since spring water generated in association with the excavation of the tunnels and experimentation hall significantly affects not only the difficulty of construction but also surrounding environments, the predictions and evaluations of the amount of spring water and effects to surroundings shall be implemented by conducting hydrological survey at appropriate time and as necessary. On the other hand, site condition surveys consist of environmental survey (natural environment, social environment and living environment), survey on laws that regulate construction, survey on subjects of compensation and surveys on connections to existing infrastructures.

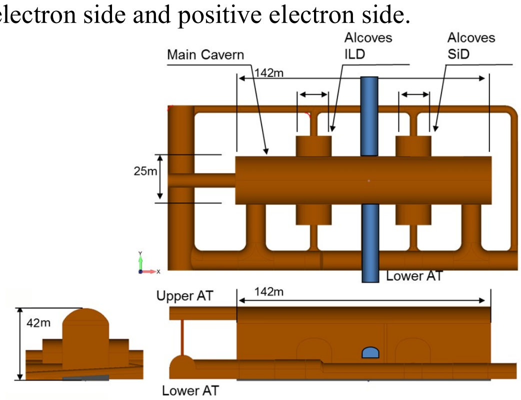
4.2 Large cavern

(1) Large cavern in ILC

There are experimentation hall and access hall as large caverns in ILC facilities. The shape of experimentation hall is shown in Figure 17.

The experimentation hall is the large cavern to where detectors are installed to acquire data when accelerated particles are collided. The main cavern has the shape of Width 25 m × height 42 m × length 142 m and the large cavern called alcove is attached. The scale of main cavern equals to the large-scale underground electric power plant.

Access hall is the cavern to where electric facilities, ventilation cooling facilities and helium production facilities for superconductivity required to operate accelerator are installed. The hall becomes the cavern of width 20 m × height 20 m × length 180 m and is planned to be placed as orthogonal to the main linac tunnel. And access halls are placed one each at the distance of little under 5 km in the main linac tunnel and each 3 locations at electron side and positive electron side.



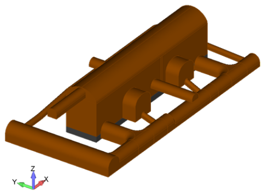


Figure 17 Outline shape of experimentation hall

(2) Technological tasks

The experimentation hall becomes the large-scale underground cavern. And the following 5 items are listed as the technological tasks taking into consideration that precise experiments of particle physics are implemented inside:

(i) Static stability of large cavern
(ii) Dynamic stability of large cavern at the time of earthquake
(iii) Evaluation on displacement of surrounding
(iv) grounds nearby the cavern in association with transfer of detectors
(v) Suppression of the effects of vibration
(vi) Maintenance of the environments in experimentation hall

(3) Stability design of cavern

Since extremely large cavern are excavated, it is important to implement considerations on layout plan and selections of cavern shape in order to minimize inhibiting factors in stability design of the cavern. And after the layout and cavern shape were finalized it shall be designed so that the stability of cavern is maintained by appropriate timbering members for short and long terms.

a) Layout plan and cavern shape

Large cavern such as experimentation hall shall be placed to the location with as good geological features as possible. And, in case that there is anisotropy in initial ground stress, it is desirable to direct the cavern to the direction that the stability increases as much as possible. However, limitations in the layout of extremely long main linac tunnel are also important since degree of freedom for each facility is small and also the location and direction of axis for the cavern of experimentation hall are determined in the layout for the entire facilities, and it is desirable to attempt the optimization to the extent possible.

Cavern shapes excavated are roughly classified into the shapes shown in Figure 18 from the cases of underground electric power plants in Japan. For early underground electric power plants, mushroom type cross section which supports arch part by concrete was mostly used, however, recently shapes of egg type cross section and bullet head type cross section are often used by applying the theory of sprayed concrete and lock bolts method. In case the geological features of bedrock itself are good, the bullet head type cross section that the useless space becomes small is economical, it would be also necessary to consider the application of egg type cross section that can suppress the expansion of loosened area of side wall depending on the geological features.

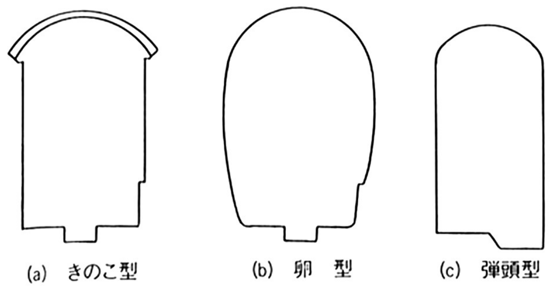


Figure 18 Shapes of cross section for large cavern represented by underground electric power plants

b) Design for timbering of cavern

Since ILC facilities are the facilities used for long period of time, the long term stability shall be ensured.

Construction records for large caverns include many underground electric power plants and underground storage caverns inside and outside of Japan. And these caverns are designed to maintain the dynamical stability in consideration of characteristics of timbering materials such as sprayed concrete, lock bolts, and PS anchor. As a result, these underground caverns have been safely operated for long period of time. Judging from these design results, design techniques of existing underground cavities are very useful to the stability designs for large caverns such as experimentation hall etc. And, it is important to implement continuous monitoring of stability by continuing the monitoring of cavern stability not only for the period of construction but also for long period of time. The results of long term monitoring of displacement at underground electric power plants are shown in Figure 19.

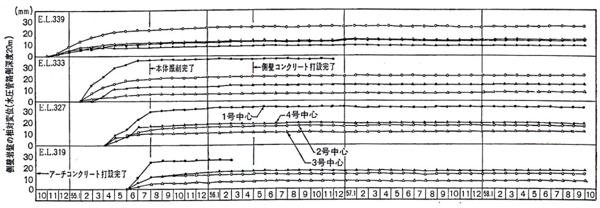


Figure 19 Examples for the monitoring of displacement of underground electric power plants

(4) Stability of cavern at the time of earthquake

Since ILC experimentation hall to where many researchers and engineers will visit and precision devices and equipment are installed, will be used for a long period of time, it is desirable to implement appropriate earthquake–proof design.

It is generally regarded that there are less effects of earthquake to underground space, in spite that there are few cases that the earthquake-proof design for underground cavern design, earthquake-proof designs prescribed by laws are introduced for Takayama Festival Museum (Building Standard Act), Underground Crude Oil Stockpiling Base (Fire Services Act), Underground Petroleum Gas Stockpiling Base (High Pressure Gas Safety Law) and there has been no problem in terms of earthquake-proof design even several large earthquakes already occurred.

General techniques of earthquake-proof design are (i) static seismic intensity method, (ii) seismic deformation method, (iii) response seismic intensity method, (iv) dynamic analysis method. The propagation velocity of earthquake wave becomes high and the wavelength becomes long for the structures installed in hard bedrock. And, the cavern vibrates in almost the same direction without phase differences for the size of experimentation hall at the time of earthquake. Therefore, the earthquake-proof design is implemented for the cases such as underground crude oil stockpiling cavern etc. by the method that static seismic intensity is applied and it is conceivable to be the reasonable design technique.

Seismic deformation method, response seismic intensity method, and dynamic analysis method are more advanced design techniques, but it is conceivable that big differences will not occur in evaluating stability of caverns which are deep in depth and located inside hard bedrock. By evaluating properties and depth of bedrock in which the cavern is located, the reasonable design technique should be applied.

(5) Transfer of detectors and displacement of bedrock

Detectors installed in the experimentation hall are 2 types, which are ILD and SiD, and are regularly replaced by push/pull method on to the beam line and then used for experiments. Each detector is placed on the approximately 20 m square pallet made of concrete shown in Figure 20. Generally, these transfer causes displacements to supporting bedrock. In case that displacement of bedrock occurs, it is possible to affect not only the bottom of detectors but also the beam line and even surroundings of the damping ring. Since the experiment facility like the beam line requires beam controls with nano level, occurrence of displacements which are malign to experiments should be eliminated. An example of the result of elastic deformation analysis by finite element method is shown in Figure 21. The deformation of bedrock cannot be avoided to some extent, elastic deformation and creep deformation should be grasped in advance and countermeasures should be taken not to affect experiments by transferring detectors.

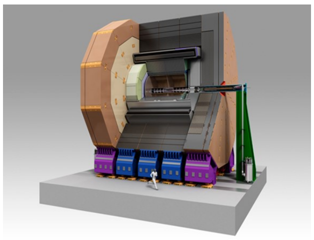


Figure 20 ILD detectors and pallet

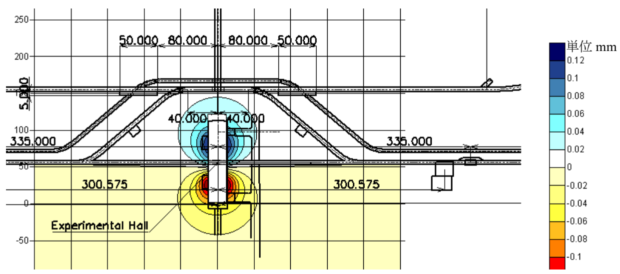


Figure 21 An example of result of finite elastic deformation analysis of displacement behavior of surrounding natural grounds in association with transfer of detector

(6) Effects of vibration

Not only should the displacement of bedrock in the previous section but also the effects to beam line caused by ground vibration be eliminated. In the current plan, the following vibrations are predicted.

(i) Vibrations generated by equipment installed in the experimentation hall and surroundings
(ii) Vibrations generated by vehicle traffic, factories, and plant equipment in biosphere on the ground
(iii) Earthquake vibration generated from the nature world
(iv) Vibrations such as micro tremor

For example, the final convergence magnet part (QD0: refer to Figure 22) which introduces the beam into the detectors is the most sensitive to vibrations among equipment installed in the experimentation hall, and it is regarded that 5 Hz / 50 nm is the target allowance level. For these equipments, vibrations should be lowered to below than the allowance level by investigating the effects of vibrations conducted from surroundings.

As the specific countermeasures, at first facilities and equipment that become the source of vibrations which can cause problems are surveyed. And for the experiment equipment which are sensitive to vibrations, in case that those vibrations may cause problems, it should be considered whether the vibration of the target equipment can be lowered to below than the allowance level by separating the distance between the source and equipment. In case that the vibration level cannot be lowered enough with equipment separated from the source of vibration and the changes in layout plan only, anti vibration measures should be taken to the source of vibration and target equipment.

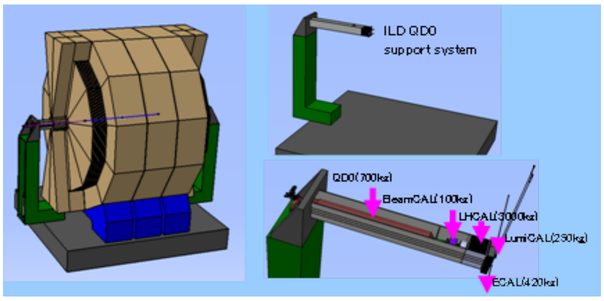


Figure 22 QD0 part of detector

(7) Environment in cavern

Since precision experiment equipment are placed in the experimentation hall, the temperature and humidity should be maintained properly so that they do not adversely affect to experiment equipment etc. Tunnel temperature is around 25-30°C humidity is less than around 50% and dust should be controlled to the extent that it does not affect human body and equipment, but there is no special requirements. The temperature and humidity can be controlled by the ventilation system, direct water dropping and spring water into the cavity should be eliminated as much as possible. Since the experimentation hall will be constructed below than the surface of underground water, it will be impossible to completely prevent underground water from gushing up. Therefore, infiltration of spring water into the experimentation hall should be reduced and especially experiment equipment should be protected from water dripping. Currently, three measures are being considered as indicated in Figure 23, but spring water treatment should be implemented by applying either measure properly depending on the state of spring water.

(i) Draining off treatment which collects underground water flowing toward the experimentation hall at peripheral part and drain it
(ii) Spring water suppression treatment to convert high water permeability region of bedrock around the experimentation hall to low water permeability by grout injection
(iii) Water leakage treatment by backside drainage which prevents spring water from flowing into the experimentation hall

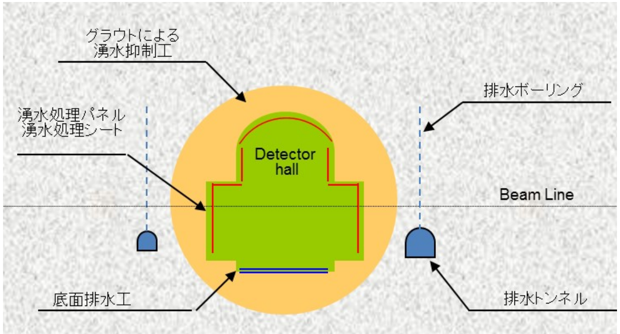


Figure 23 Concept of spring water treatment around experimentation hall

4.3 Horizontal shaft

Tasks in design and construction of accelerator tunnels are mainly considered here.

(1) Design

a) Design technique

In designing horizontal shafts, the timbering function possessed by natural ground should be utilized effectively by fully examining the survey results of natural ground in which the shaft is constructed. At that time, timbering materials, which satisfy required conditions such as purpose and form of usage and others, should be designed in consideration of conditions required for the maintenance work comprehensively such as economics, safety, degree of the influences to the surroundings, constructiveness, furthermore, economic efficiency after the use and maintainability.

There are the following design techniques for mountain tunnel in Japan.

(i) Application of standard design
(ii) Application of design in similar conditions
(iii) Application of analytical technique

b) Comparisons with overseas classification of bedrock and timbering pattern

In 2003, ISO 14689-1:2003 “Geotechnical engineering – Identification and classification of rock – Part 1 Identification and description” was established as one of international standards for the survey and testing technology of bedrock and geological features. Intended for boring core sample and outcrops of bedrock, basic factors of classification of bedrock were extracted and the standards of division are indicated in association with distinction and description of rocks such as geological features structure, causes, state of discontinuity surface, state of weathering, mineral composition, grain diameter, bedrock strength etc. And it is conceivable that bedrock classification in the world moves in the direction to conform to ISO in the future.

In such a movement, it is vital to implement the adoption of survey items and testing methods and data coordination which conform to ISO14689-1:2003 in order to obtain the common perceptions and understanding with overseas engineers easily with respect to the advance geological features survey of ILC facilities. However, the current natural ground classification which has been used at home and abroad does not conform to the above mentioned ISO. And the natural ground classification for roads and railways in Japan adopts elastic wave velocity as a main indicator. However, since almost none of overseas natural ground classifications adopt elastic wave velocity as an indicator it is in a difficult situation that both cannot be simply compared. On the other hand, RMR(Rock Mass Rating, Bieniawski, 1973) and Q-system (Barton, 1974) are the widely adopted international bedrock classifications overseas. Based on such present circumstances, parameters of RMR and allotment table, RMR values and tunnel construction methods and table for timbering selection are included in the guidelines so that domestic and overseas bedrock classifications can be compared. And classification parameters, allotment table, and table for timbering division selection by Q-system are indicated.

c) Partition

It is thought that the construction of partition to be installed at the central part of main linac tunnel is generally done by the method that installs molds and then places concrete. However, when the cross sectional shape and size of the tunnel were considered, the concrete placing work should be implemented after the completion of excavation and the process gets longer. Furthermore, construction and curing method for large quantity of concrete and separate construction of the upper part of the partition that contacts the arch part of the lining concrete must be considered.

In order to shorten the process, precast concrete can be considered. At this time, the size and weight of components should be investigated considering manufacturing yard of precast concrete, transportation method on public roads, conveyance method in the shaft, assembling method etc. By adopting a simple joint structure such as mortise joint, reasonable precision in assembly and slip stopping effect can be expected.

As an example, the precast type construction method is introduced here. In case that the dimensions for one precast block are set as width 1.75 m × height 1.75 m × Depth 1.3 m, the weight of the block becomes 10 tons and the lower part of the partition should be divided into 4 sections in terms of transportation weight. Arrangement of bars for precast components should be determined in consideration of the distribution of weight that is suitable for the handling in production, transportation, and assembly. And on the other hand, cast-in-place concrete finish is desirable for the following locations.

(i) It is difficult to install the upper side of partition that contacts to the arch part of the lining by precast components. Therefore, in case that partition concrete and lining concrete are required be adhered, the placement of concrete is stopped with some space left at the top part of partition and the shrinkage-compensating-mortar is filled in a state that air vents are installed.

(ii) It is required to install through holes with the diameter of around φ300 mm at the intervals of 10-15 m to the partition for waveguides and electric cables. Since the electric power source pipes with high frequency and high voltage and cables pass through here, inside the pipes should be kept dry and leakage, dropping and condensation of water should not be allowed. Therefore, in order to form the through pipes it is desirable that pipes should be placed at specified positions before concrete placement.

(iii) For walk-through (located at around 500 m intervals), construction methods by using precast shape of the walk through or cast-in-place concrete to the permanent mold installed in advance can be considered.

d) Construction of drainages

The ILC facilities are constructed so that the longitudinal slope of the main linac tunnel becomes laser straight at the central section (around 5km section centered on the experimentation hall) and others in principal are planned to be constructed along with geoids surface. Furthermore, since there are no pit heads directly connected to the outside for the accelerator tunnel, it is planned to access from the ground surface through the vertical shafts and inclined shafts. Therefore, spring water inside the accelerator tunnel (mine water) is collected to the access hall (installed at the intersection point of accelerator tunnel and access tunnel) once, and then pumped up from inclined shafts and vertical shafts which are used as access passageways and discharged to the outside the shaft. Inside the accelerator tunnel, not only experiment equipment and various devices, electronic equipment and precision devices which are sensitive to moisture are located but also many people such as researchers and engineers are entering and continue their works and maintenance. In order to avoid submergence accidents of these precision equipment and people entered into the shafts, installed drain facilities should be maintained to be operable at any time. And it is the important measure against power failures to install emergency electric power source for the drain facilities.

In addition to this, it is important to connect the gravity flow type drain tunnels to the accelerator tunnel if possible. The gravity flow type drain tunnel is the facility installed so that the mine water flows into the rivers on the ground naturally to the utmost, the joint part with the accelerator tunnel should be installed at higher location than the river to which the mine water is discharged. Therefore, it greatly depends on the geographical features of the site at where the ILC facilities are constructed and can be installed at limited locations. On the other hand, due to the limitation of the longitudinal slope of previously mentioned accelerator tunnel, to which location of accelerator tunnel can the drain tunnel be connected becomes the important key for the planning of effective drain system in the shaft. It is difficult to satisfy all conditions for geographical features at the site and drain function. However, to seek the possibility of installing gravity flow drain tunnel is very important since it can lead to the reduction of expenses for installing and operating the drain pump, expenses for the countermeasures against power failure such as emergency power source, and furthermore the improvement of safety of the accelerator tunnel.

Mine water in the central section which is laser straight is gathered at the central part where its attitude is low. On the other hand, it becomes stagnant water in the main linac tunnel at its both sides in case that the longitudinal slope is the geoids surface. In case that the longitudinal slope around 0.5% can be secured, mine water can be collected at various points along the tunnels. For the sections with no or small longitudinal slope which mine water does not flow naturally, generally drain pits equipped with axial flow pumps for pumping-up are located at the interval of around 500 m and mine water is introduced by connecting the pits with drainage which has enough longitudinal slope for gravity flow. However, it is desirable to adopt the drain type with less pumping-up for mine water. Therefore, mine water should be efficiently introduced and discharged to the outside the shaft in consideration with the difference of elevation for entire facilities including main linac tunnel, damping tunnel and experimentation hall etc. At this time, based on the volume of spring water in the shaft at the site, the following items should be considered.

(i) Longitudinal slope of drain facilities
(ii) Type of introduction for mine water (pumping type, gravity flow type etc.) and accumulation point
(iii) Structure type (culvert, open ditch) of drainage (waterway), structure dimensions (cross sectional shape, cross sectional area) and reinforcement method (operational water pressure, load from natural ground, earthquake resistance etc.)
(iv) Type of discharge to the outside the shaft (pump relay type, gravity flow type)
(v) Methods of replacement and maintenance of materials and equipment used such as pumps and piping
(vi) Volume of grit and silt and treatment method (in case drain separation cannot be done and muddy water is possible to be mixed)

These items should be carefully considered not only for normal and maintenance period, but also for the effects and countermeasures of stagnation, flooding, grit and silt which will occur when the pump and drainage stop due to the loss and stoppage of power source. In case that muddy water is possible to be mixed due to the power failure accidents, treatment of silt accumulated inside the drainage and drain pipe and the possibility of abrasion of pipeline by flowing silt should also be considered.

(2) Construction

a) General construction

Prior to the construction, the safe and economic construction plan should be formed in consideration with the construction scale, construction period, natural ground conditions, site conditions, surrounding environment etc. by investigating appropriate construction method, construction machineries, facilities etc.

It is important to form a construction plan not only for the main linac tunnel and damping ring tunnel but also for the entire project, and the construction plan should have good conformity with other underground structures (access tunnel, experimentation hall, etc.). During construction, attentions to changes in natural ground and surrounding environmental conditions, behavior of the natural ground should be considered, and necessary surveys and measurements should be implemented so that the appropriate construction can be carried out.

Especially, regarding granite distributed in the area where the ILC facilities is planed, the fresh part is hard and fine and is a stable hard rock, however it sometimes becomes decomposed granite by weathering and the influences may reach the deep part. And granite is the bedrock with developed cracks and sometimes it may have week layers caused by hydrothermal alteration and fault fractures. Furthermore, sudden and large quantity of spring water may occur through penetration of porphyrite, fault fracture zone, open cracks as the permeation channels. These in mind, the survey, measurements etc. should be implemented. In case the construction method is found to be inappropriate judging from the situation of the site, the prompt and feasible measures should be taken with the priority given to securing safety and alter the construction method without delay. And it is desirable to respond with the cooperation of each construction area by implementing information exchange between neighboring construction areas.

b) Environmental conservation

Constructors must try to observe the related laws and regulations, and suppress noise, vibration, low frequency air vibration, drought, ground surface subsidence, alteration of structures, discharge of dirty drain, traffic obstruction by transportation works outside the shaft etc.

and prevent contaminations by harmful minerals and conserve natural environment during construction. Especially, at the granite zone where the ILC facilities are planed, there may be a case that nature-derived heavy metals (fluorine, boron etc.) are included in rock wastes and spring water. For that case, attention shall be paid to the treatment of rock wastes and spring water (muddy water).

c) Survey

Attention should be paid to that the level accuracy required for floor surfaces is extremely strict due to the requirements from experiment facilities located in the ILC facilities. And in the accelerator tunnel, since the level management is different for the section along with geoids surface and the laser straight section, it should be carefully planed so that the required accuracies are secured. And in the ILC facilities, despite the long and large tunnel whose tunnel extension is more than 30 km, horizontal and inclined type access tunnels are attached to the accelerator tunnel and experimentation hall at the interval of around 5 km. Moreover, required accuracies to maintain the linearity of accelerator tunnels including the main linac tunnel are extremely high in comparison with the general structures. Therefore, to arrange the reference point at the outside the shaft and to clarify the reciprocal positional relationship become the first step to ensure the construction accuracy of the ILC facilities and the extremely important point.

d) Timbering

The cross sectional shape of main linac tunnel is flattened compared to general mountain tunnels, since the stability of crown part at the construction is poor, it is desirable that the necessity of fiber reinforced sprayed concrete and high strength sprayed concrete are considered for the purpose of increasing the toughness of sprayed concrete. Especially, repairs after the start of operation for the ILC facilities are extremely difficult and great hindrances will occur in operations if the displacement behavior, including roadbed subsidence occurred. Therefore, it is desirable to secure the sufficient stiffness of timbering at the construction.

Furthermore, since the accelerator tunnel is connected to the outside the shaft through access tunnels, the ventilation distance during the construction of the tunnels becomes longer and the ventilation and countermeasures for mine dusts in the shafts should be implemented elaborately. Especially, dusts generated from sprayed concrete must be suppressed and the use of dust suppressing agent and installation of large-scale dust collection facility should be considered.

(3) Other tunnels (Damping ring)

Since the section of damping ring tunnel widening cross section has the identical cross section with the main linac tunnel, the same construction method and construction management method as for the main linac tunnel are applied including center partition concrete etc.

Since the standard cross section of damping ring tunnel is smaller than the widening cross section that is first excavated, construction machineries and facilities adapted to small cross section should be adopted. Here, 2 types of methods are conceivable as discharging method of rock wastes and they are rail type and continuous belt conveyor type. In consideration with constraint conditions of the processes in entire project and competing conditions for the use of access tunnel, reasonable methods of discharging rock wastes and construction machineries and facilities appropriate for the method should be selected. And 4 faces at the maximum can be located in the section with the standard cross section of damping ring tunnel and the construction period can be shortened. However, number of faces should be selected in considering with constraint conditions of the processes in the entire project and cost performance of facilities.

(4) TBM

In case of excavating long and large tunnels, rapid construction by TBM (Tunnel Boring Machine) construction method has many advantages such as improvement of safety, slack reduction of natural ground, confirmation of geological features by TBM pilot tunnel, drainage, pre-reinforcement, ventilation effect etc., and is often considered as one of choices of mountain tunnel construction method. Therefore, methods of planning, survey, machinery specifications, timbering design, construction management etc. are mentioned in the materials at the end of the guidelines assuming that the TBM construction method with the diameter around 4-6 m is applied as the pilot tunnel for damping ring tunnel and main linac tunnel which the semi-cylindrical cross section is planed to be adopted. Still, TBM here means the all cross sectional tunneling machine corresponding to soft and hard rocks that assures propulsion counterforce by grippers and excavates while crushing bedrock by wedge actions of roller cutters, and is distinguished from the sealed machine that assures the counterforce only by liners and excavates while cutting natural ground by teeth cutters etc.

4.4 Special shafts

4.4.1 Special shafts in general

Special shafts in the ILC facilities connect ground facilities and main facilities underground and represent inclined and vertical shafts that become arteries from the construction time to the operation period. Summaries on design, construction, facility planning, surrounding environment countermeasures and maintenances are described in the followings subject to access tunnel, drain tunnel, ventilation and vertical shafts for survey and these cross point and connecting point.

4.4.2 Inclined shaft

(1) General

The access tunnel will be used as an approach to the main facilities underground such as the experimentation hall, main linac, damping ring etc.

In the current plan, access tunnels are planed as shown in Figure 24 and 25.

(i) Access tunnel for the main linac and access hall: 8

(ii) Access tunnel for the experimentation hall: 1
(iv) Access tunnel for the damping ring: 1

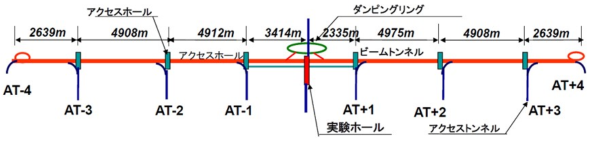


Figure 24 Position diagram of access tunnels (First plan)

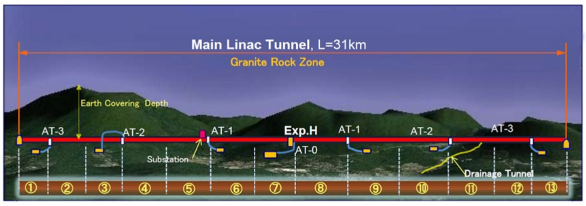


Figure 25 Image diagrams of access tunnels (First plan)

(2) Design

The yard which can secure the following site area is required at the entrance of each access tunnel. (Table 6).

Table 6 Main ground facilities at shaft entrance (First plan)

Item	No. of place	Site area
Shaft entrance for main linac tunnel	8	4,000 m^2
Shaft entrance for experimentation hall	1	20,000 m^2
Shaft entrance for damping ring tunnel	1	3,000 m^2
Central power receiving facilities	1	8,000 m^2

The horizontal alignment is desirable to be a strait line as much as possible, in case that there are curved lines, the linear shape should be determined in considering that whether the conveyance of materials and machineries at excavation and maximum experiment equipment in service can be done.

The longitudinal slope is limited by the method of transportation for rock wastes and the conveyance of experiment equipment in service. There are many examples that the slope for belt conveyor type is around 14°and the slope for tire type is 7° to 8° at the maximum for the transportation of rock wastes. The hill climbing ability of low floor trailers for conveyance (225 t × 2) is around 4°. The slope is only allowed up to 10◦for the cold box, liquid helium tank etc. of helium cryogenic system.

Cross sectional shapes of the tunnels are determined from the type of transportation for rock wastes and the maximum dimensions of conveyance machineries at excavation and the maximum dimensions of experiment equipment in service. In the current plan, the access tunnel for experimentation hall is width 11 m × height 11 m (Figure 9) and the access tunnel for main linac is width 8 m × height 7.5 m (Figure 14).

By the result of Seikan tunnel, 1 axis compressive strength etc. as the long term strength of sprayed concrete is not decreased even if it has passed for 37 years. Therefore, it can be determined that there is no problem to adopt sprayed concrete finish as the basic method for the lining of access tunnel.

(3) Construction

Since the construction of auccess tunnel is implemented at downhill slope, spring water will build up at faces during the excavation. It is desirable that geological features and underground water are confirmed by pilot boring, logging of hole drilling etc. and countermeasures for spring water such as drain method, still water infusion method etc. are implemented as necessary. And water dripping from sprayed surfaces is treated by water introduction measures (monodrain, gutters etc.).

(4) Facilities

Ground facilities include temporary storage facility for rock wastes, explosives related facility, storage site for materials and machineries, concrete production facility, electric power facility, various buildings etc. and especially reinforcement and new construction of electric power facility are required since the ILC facilities consume a lot of electric power. And emergency electric power sources should be prepared assuming power failures during construction. Among the supplemental facilities, drain facilities at the downhill slope become important. Generally, water is collected at pits and pumped up to the shaft entrances by pumps.

(5)Environment

In case that the construction in underground space has possibilities to have negative impact to surrounding environment, appropriate measures should be implemented. Influences to surroundings at construction include in general terms blast noise and vibration, noise and vibration of construction vehicles, traffic obstacles, water pollution by elution of heavy metals and construction drain, drought of river water and underground water and land subsidence by mine water, pollution of underground water and land uplift by chemical grouting, ground surface subsidence influences to the neighboring structures and by slack of the ground at excavation etc. And after the completion, the influences include drought of river water and wells by the outflow of underground water, ground surface subsidence and cave-in by slack of the natural ground and drawdown of underground water and water quality changes in surface water and underground water by chemical grouting.

(6) Operation and maintenance planning

Since the ILC facilities will be used for over a period of 30 years, it is desirable to implement initial inspections in details and create the database of geological features at construction and the situation of displacement in order to operate and implement maintenance effectively. For example, there is a method for initial inspection by measurement system of traveling vehicle, images and shapes of sprayed concrete surfaces can be recorded.

4.4.3 Drain tunnel

(1) General

The combined total length of the tunnel becomes 80km when it is used and it is assumed that the amount of mine spring water will increase. If it is estimated based on the results of railroad tunnels (Table 7), the estimated amount of spring water becomes around 50t/min (0.6t/min/km).

Table 7 Results of combined length of the tunnels and amount of and spring water

Name of the tunnel	**Track section**	**Combined length (m)**	**Time of penetration (Year/month)**	**Amount of spring water during construction(t/min)**	**Amount of spring water at completion (t/min)**	**Constant amount of spring water (t/min)**
Seikan tunnel	Tsugaru kaikyo line	53.850	1985.03	50.0	30.0	20.0
Hakkouda tunnel	Tohoku shinkansen (Between Hachinohe and Shinaomori)	26.455	2005.02	44.1	20.1	15.9
Iwate Ichinohe tunnel	Tohoku shinkansen (Between Morioka and Hachinohe)	25.808	2000.06	15.1	6.3	6.3
Iiyama tunnel	Hokuriku shinkansen (Between Nagano and Kanazawa)	22.251	2007.12	25.5	19.0	13.7

The drain plan will be drafted based on the estimated amount in planning stage and it is desirable to consider the possibility of adopting gravity flow drain tunnel which utilizes surrounding geographical features as much as possible.

(2) Design, construction and facilities

The location of drain tunnel is desirable to be the deepest part in the vicinity of experimentation hall where spring water naturally accumulates. And in case that the drain tunnel is installed in the main linac tunnel, the method that mine water is led by natural flow to the drainage with the longitudinal slope of around 0.5% underneath the bottom slab, pumped up with pumps at intervals of approximately 500 m and then forwarded can be considered. The effective cross section of drain should be determined in consideration with the amount, slope and length of drain.

Construction method and facilities confirm to "4.4.2 Inclined shaft".

4.4.4 Vertical shaft

(1) General

The use of the vertical shaft includes going-in and going-out from the shaft, conveyance of materials and machineries, ventilation, caring out of rock wastes at construction same as for inclined shafts. And in case of emergency in the main linac tunnel, the shaft takes on a role as the evacuation route. The features of vertical shaft are that the ground and underground can be accessible with the shortest distance. Compared to the inclined shaft, it often becomes advantageous in terms of construction period and economy with the depth of around 200 m as the border. As the domestic representative example, there are vertical shafts for ventilation of Enasan tunnel (621 m and 571 m), the second Hanna tunnel (481 m), Awa vertical shaft for ventilation (450 m) etc.

(2) Design

The cross section of vertical shaft is circular from the viewpoint of stability of cavity as far as there is no special requirement and the dimensions should be set in accordance with the applications at construction or in service.

For example, in the short step method which is the standard method for the super great depth vertical shaft, since it becomes possible to place the concrete within several tens of minutes after rock wastes were carried out and only the lining should have the enough timbering ability. Normally, in case of good bedrock, the thickness of around 40 cm for tunnel lining is often adopted. On the other hand, measures such as increased diameter of excavation and thickness of the lining and placing reinforced rods are taken in case that the natural ground is defective.

Great depth underground is stable against earthquakes, however, in case that the ground neighboring shaft entrance and ground surface are weak, the earthquake-proof quality of the vertical shaft should be carefully considered.

(3) Construction

Excavation methods of vertical shaft are classified as shown in Figure 26.

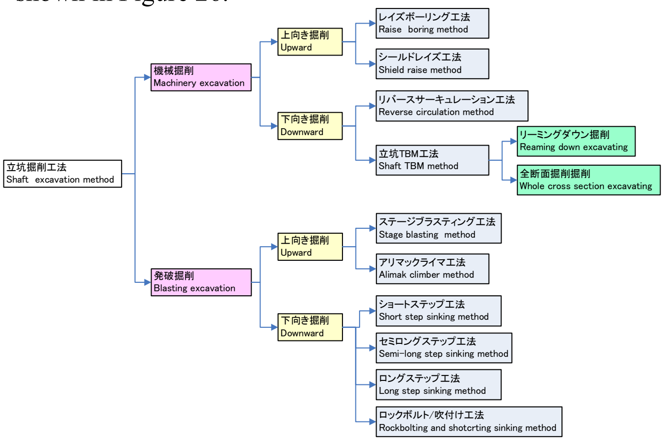


Figure 26 Major excavation methods of vertical shaft in Japan

Raise boring method which excavates upward and short step method which excavates downward are the mainstream in Japan.

(4) Environment

Conform to "4.4.2 Inclined shaft (5) environment".

(5) Operation and maintenance planning

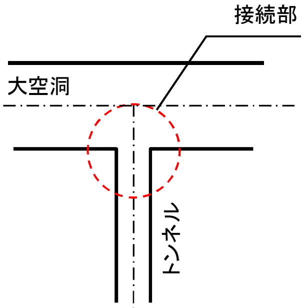
Conform to "4.4.2 Inclined shaft (6) Operation and maintenance planning".

4.4.5 Crossing part and connecting part

(1) General

Approaches for the design and construction at the special locations where main linac tunnel, access tunnel, experimentation hall, access hall etc. are crossed and connected are presented. Here, these are defined as follows.

(i) Crossing part is the place where tunnel and tunnel cross with an angle (Figure 27).
(ii) Connecting part is the place where tunnel connects to large cavity (Figure 28)



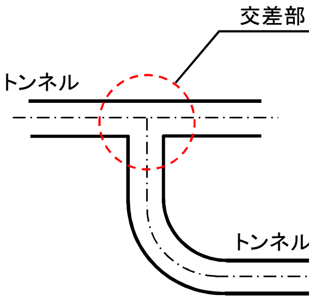


Figure 27 Example for crossing part Figure 28 Example of connecting part

(2) Design

Timbering materials, lining, and method of reinforcement should be considered for the crossing part and connecting part at the time of construction and usage so that the surrounding natural ground becomes always stable. Especially, installation sites, natural ground conditions and crossing angles are important and it is desirable to select the places with good natural ground and install them so that they cross at right angle.

The lining for crossing part and connecting part is the sprayed concrete finish as a basis. However, in case of the followings, it is desirable that the necessity of the lining reinforcement is considered and implemented properly.

(i) Extremely bad geological features were encountered
(ii) Earthquake-proofness is required
(iii) Cross section is large and semi-circular and the large bending moment is generated locally
(iv) Displacement behavior after excavation is not settled yet
(v) Large changes in conditions occurred during excavation
(vi) Large amount of spring water was found

It is desirable that the range to be reinforced is determined by the past examples (Figure 29) and the results of numerical analysis. And the reinforcement will be implemented with lock bolts, steel timbering method, sprayed concrete etc. and supplemental methods such as forwarding method, mirror reinforcement etc. will be also adopted.

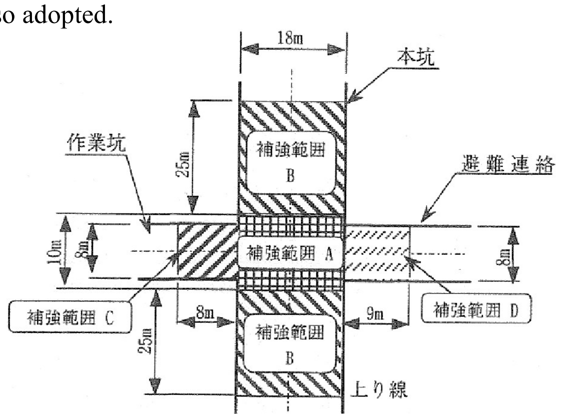


Figure 29 Example of determining range of reinforcement

(3) Construction

The construction methods for crossing part and connecting part include the case that the following tunnel is connected after completing the lining of the preceding tunnel and the following tunnel is connected to the preceding tunnel whose lining is not constructed yet. The former is the strong structure that the timbering materials and lining of the preceding tunnel are integrated and bears the load of natural ground. On the other hand, the latter is the relatively flexible structure and bears the load of natural ground.

Points to be considered for crossing part and connection part at the time of construction are the following items.

(i) Effective and economical construction procedures
(ii) Natural ground conditions
(iii) Measurement management
(iv) Method of excavation etc.

Yatsukazeyama tunnel, Toyohama tunnel, Kanetsu tunnel and Shinnihonzaka tunnel are described in the text as the past construction examples of crossing part and connecting part.

4.5 Disaster prevention

Assuming the following phenomenon, disaster prevention should be planned.

(i) Fire...Outbreak of fire is assumed by leakage of electricity, spark, contact failure, and motor coil dust. Combustion of cable, condenser and trans oil are thought to be as the flammable.
(ii) Flood...Permeation of rainwater and underground water and water leakage from piping are conceivable.
(iii) Power failure...Power failure of commercial power source became less frequent in Japan, the emergency power source to be ensured even when the power failure occurred should be considered in order to furthermore enhance safety.
(iv) Helium leakage...Leakage of liquid helium for cooling cryogenic module is conceivable.
(v) Earthquake...When earthquake occurs, security of facilities and equipment and safety against discontinuation of lifeline must be ensured.

(1) Fire

As well as existing ground facilities, for the purpose of preventing human casualties, safety measures should be established not only for facilities and equipment but also their management and operation. Especially, many of big damages in underground facilities in the past were caused by fire, countermeasures against fire are important field in considering the guarantee of safety.

Fire will pass through the stages of outbreak and spread and then develop to serious disaster. Because of this, outbreak of fire and damages from fire should be suppressed as much as possible by fireproofing facilities and reduction of flammable at first. And it is important to implement appropriate measures in the initial stage of fire. And, countermeasures for suppressing outbreak of fire such as fireproofing the linear facilities like accelerator tunnel and reduction of flammable etc. are required by referring to the ways of thinking of safety countermeasures for similar facilities such as long and large tunnels and multistory building. For the point facility like experimentation hall, countermeasures such as adaptation of fire protection and smoke protection section with high security, proper implementation of communication to the persons inside the shaft and the persons outside the shaft, appropriate arrangement of the approach pass for fire-fighting, installation of sensors to confirm the situation and communication facilities for emergency etc. should be taken.

For the point facility in the ILC facilities, countermeasures different from a multistory building should be considered while referring to the ways of thinking for the safety measures of multiple story building.

(i) The longer evacuation time by evacuating toward the direction of ground against the gravity

(ii) Evacuation toward the same direction with the smoke

(iii) Direction that fire-fighting team enters is opposite to the direction that the smoke flows

(iv) Difficulty of gathering information from the outside of facilities

In all cases, at the time of fire outbreak, early detection of fire, suppression of fire smoke, safety evacuation of persons inside the shaft, elimination of hindrances to fire fighting and rescue activities, ordinary maintenance and operation of disaster prevention facilities and equipment should be implemented as the countermeasures are taken in the existing similar facilities. Furthermore, it should be prevented from the other facilities being influenced by the fire that occurred.

a) Suppression of fire outbreak

Countermeasures to suppress fire outbreak should be taken for the facilities that become underground space as much as possible by reducing the use and carrying in of flammable as much as possible, and countermeasures for suppressing fire for gas facilities that the use of fire cannot be avoided should be implemented as much as possible. For this purpose, the following items should be implemented.

(i) Non flammable measures

(ii) Suppression of carrying in of flammable

(iii) Elimination of causes of fire outbreak

(iv) Countermeasures to leakage, fire, and explosion of gas facilities

b) Detection and communication of fire

In order to prevent fire that occurred from spreading and make the safe evacuation of persons inside the shaft possible, the following system for detecting and communicating fire should be established.

(i) Detection system for early detection of fire outbreak

(ii) Information gathering and communication system required for decision making regarding the intensity of fire at the time of outbreak, suppression and expansion prevention of spread of fire and fire smoke.

(iii) System for gathering and providing information required for evacuation guidance of persons inside the shaft at the time of fire outbreak etc.

c) Evacuation

Countermeasures should be taken so that persons inside the shaft can evacuate to the safe place without accidents at the time of a fire. At this time, equipment and system for communicating information and evacuation guidance should be established in order to secure safety of persons inside the shaft so that necessary information can be surely communicated and evacuation guidance can be implemented promptly and smoothly. Especially, in considering features of facilities with long and large underground space at great depth, it is desirable to put new thoughts by properly arranging fire prevention and smoke prevention sections so that persons inside the shafts can smoothly evacuate to these sections by horizontal movement as much as possible when the fire occurred.

d) Fire fighting activity

Countermeasures should be taken promptly to control fire smoke and suppress the spread as much as possible at the time of fire outbreak. For this purpose, safety countermeasures to equipments, facilities, management, and operation should be taken so that fire fighting activities can be implemented smoothly. And, countermeasures such as proper arrangement of access route for firefighting with the countermeasure for fire prevention and smoke prevention, installation of various sensors and emergency communication equipment etc. should be taken depending on the features of facilities.

e) Ordinary inspections of disaster prevention equipment and periodical disaster prevention training

Ordinary inspections should be implemented so that early detection of fire, early suppression of fire and suppression of the spread can be implemented and facilities and equipment for securing safety of persons inside the shaft can be surely operated at the time of fire. Furthermore, a system that enables smooth information exchange and cooperation between persons in charge by conducting periodical disaster prevention training should be established.

f) Prevention of influence to surrounding facilities

Countermeasures for preventing fire spread and collapse of structures should be taken so that local residents and surrounding facilities will not be damaged when the fire occurred. Countermeasures should be taken for gas facilities so that fire, explosion, poisoning etc. will not occur by the leakage. Furthermore, countermeasures should be taken to prevent local residents near the facilities from being influenced by burns, poisoning etc.

(2) Flood

Water permeated in the facilities will gather at the lowest place. The permeated water in the great depth underground space where the natural flow drain cannot be done should be continuously pumped up to the shaft entrance which is located at the highest point and drained to the outside of shaft over the years. In the great depth underground space, in case that the drain system stopped and larger amount of water than drain capacity permeated, it easily results in the expansion of flooded space and flood damage. If the flood occurs, not only it impairs the safety of persons inside the shaft but also the operation of facilities becomes difficult. Furthermore, experiment equipment installed in the facilities are submerged in water and become impossible to use afterwards. Therefore, by considering the features of ILC facilities and local environments, elaborate and sufficient countermeasures to spring water, flood, and drain should be implemented. Especially, rainwater and surface water should be prevented from permeating to the inside of underground space. And, if the worst comes to the worst, in case that the sudden flood disaster is predictable by rainwater etc. flowing from the ground at the time of local downpour and flood, communicating the information and evacuation guidance to persons inside the shaft should be promptly and properly implemented.

a) Countermeasures to spring water, flood and drain

Permeating water in the ILC facilities that becomes a great depth underground space is assumed as the flowing.

(i) Surface water such as rainwater etc. flowing from the shaft entrance and the vicinity of it at the time of flood and local downpour

(ii) Underground water accumulated in or flowing through the water permeating layer near the ground surface

(iii) Underground water accumulated in the surrounding natural grounds of the cavity

(iv) Gestation water in fault crushing zone and hydrothermal alteration zone

(v) Underground water flowing along with open cracks

(vi) Cooling water leaked from piping

Among these, from (ii) to (v) are roughly classified as spring water of natural ground and it was assumed that the amount of water will be around 50t/min (0.6t/min/km) for entire facilities at the time of planning. If we try to stop these spring water by lining concrete, the water pressure will become higher and thick tunnel lining and a large amount of steel rod reinforcement will be required. Therefore, spring water is normally drained to the outside the shaft by the drain system consists of water introduction channels located at the backside of the lining, central drainage in the tunnel and drain pumps in access tunnels and hall without flowing into the inner space of the facilities. At this time, lining concrete is treated so that the water pressure will not apply to it.

Since the spring water at the backside of the lining that flew into the tunnel will normally be radioactivated during experiments, it will have to be treated as the controlled water. Therefore, the spillage into the tunnel should be prevented by properly locating waterproof sheets, water sealing plates etc. And in case that the drain system fell into malfunction and a large amount of mine water that is more than drainage capacity was occurred, since the experiment space will be submerged in water, safety for persons inside the shaft will not be secured and the experiment facilities will become impossible to operate. For this purpose, the drain system that has margins should be established including not only for maintenance but also for alternative equipment in case for power failures and malfunctions, and alternative power source etc. On the other hand, drain pumps installed in access tunnels and hall will be continuously pumping up mine water located inside of the main linac tunnel up to the entrance of access tunnel and cannot be stopped until the facilities is closed even at the time of power failure. For this purpose, the inflow of water to the inside of underground space should be minimized as little as possible since it may lead to the reduction of expenses for the operation and maintenance of the drain facilities. For example, since researchers, engineers and experiment equipment inside the shaft will be greatly affected, sufficient countermeasure for inflow prevention should be taken for "(i) Rainwater flowing from the shaft entrance and the vicinity of it". And, in case that the locations of spring water are limited as the above mentioned (iii) – (v), it is desirable that the possibility of reduction measures for spring water such as grout injection during the excavation of the tunnel is considered if possible.

b) Evacuation

In the ILC facilities, in case that the flood occurred, persons inside have to evacuate for long distance against the direction of water flow because of the features of great depth underground. Therefore, difficulties may occur when persons inside the shaft are evacuating, and proper communication of information and evacuation guidance should be implemented in considering the local situation. And in case that the possibility of flood is high, the early warning should be given to the changes of surrounding water level. And, in case that the flood occurred, countermeasures such as the installation of emergency facilities should be taken so that the information can be promptly communicated and the evacuation guidance can be given to persons inside the shaft safely. The safe system for evacuation and rescue activities at the time of flood should be established in reference to the examples of damages in underground space and researches.

(3) Power failure

The experiment facility underground is the space which can be functioned when the electricity to the means of transportation, lighting, space equipment etc. is supplied, the power failure may cause not only the stoppage of various facilities but also serious situation that leads to dangers to persons inside the shaft including a panic etc. Therefore, the worst comes to the worst, the system that enables to function the lighting, ventilation etc. continuously even in case that power failure in the ordinary power receiving system occurred. Furthermore, the receiving and distribution system for electricity with multiple lines should be adopted in order to enhance the stability and reliability of energy supply. And, in preparation for the accidents of supply side of electricity, countermeasures should be taken so that serious impairments do not occur to the system functions by installing the emergency electric power equipment with sufficient capacity and operating time. We constantly have to strive to improve the reliability of the system by implementing countermeasures such as earthquake-proof and fire-proof to receiving and distribution system of electricity and emergency power source especially for disasters like earthquake, fire, flood etc.

(4) Helium leakage

a) Countermeasures to helium leakage

Large amount of helium that has not been used in existing facilities will be used in the ILC facilities. Therefore, elaborate countermeasures should be taken to secure the safety of persons inside the shaft by implementing surveys on characteristics of liquid helium, specified locations where helium leakage may occur, examples of accidents etc. at the design stage.

b) Evacuation

When a helium leakage occurs, countermeasures should be taken to let persons inside the shaft evacuate safely to the outside the shaft.

(5) Earthquake

It is regarded that underground is less influenced by earthquake vibration than ground surface, the evacuation route from the inner space to the outside is limited to access tunnels. Therefore, elaborate countermeasures should be implemented such as reinforcement of facilities and equipment inside the shaft, prevention of the function decline of supply lines for air, water and energy as the safety measures to earthquake.

(6) First aid and rescue activities

Most of the ILC facilities are underground space and not only entrances and exits are limited and but also moving distance in the vertical direction becomes longer. In consideration of these characteristics, the following countermeasures should be taken so that the first aid and rescue activities can be promptly implemented.

(i) To secure the safe route for entry and exit in order to smoothly implement the rescue activities by fire fighters and conveyance of injured persons and communicate the information

(ii) Installation of various sensors for the confirmation of disaster situation

(iii) Provision of the information such as the display of location for First aid center and contact method

(iv) Establishment of cooperation system among the facility management and persons in charge of first aid and rescue.

5. Conclusion

The subcommittee has compiled the conceivable countermeasures at present as the guidelines for tasks and problems related to the civil engineering work of the ILC facilities in Japan. The underground research facilities that we have not experienced until now are planned in the ILC plan. However, on the other hand, we have been continuing the construction of number of large-scale underground cavities such as tunnels, underground electric power plants, stockpiling bases on bedrock for oil and liquefied gases for the purpose of national roads, highways, subways, bullet trains, and water and sewer services. In considering of these backgrounds, the Japan Society of Civil Engineering decided to compile the guidelines by integrating expertise and knowledge for constructing underground spaces cultivated through past construction experiences for the purpose of making the economical and high quality construction of underground spaces for the ILC facilities in Japan possible. Especially, this is the first trial work to integrate construction technologies of underground space that have been constructed for various purposes such as roads, railroads, energy bases etc. into one. And, it is also the first trial to apply each technology to underground structures with different construction purposes. Finally, even in the case that similar underground cavities are to be constructed, we will encounter many differences and tasks such as the concept for design and construction, differences in terms and definitions etc. Therefore, for example, classification of bedrock that becomes the base of the tunnel design and evaluation of natural ground had to be left at the writing of existing materials side by side and just comparisons. However, in spite of the short period of time for 3 years, we think that it was compiled even in the depth of work contents for many items by the efforts of attending committee members including Chief and Secretaries. We believe that the guidelines will be effectively used for the works in planning of ILC in the future and furthermore discussions will be made to further enhance the technologies based on the guidelines. And, we sincerely hope that the guidelines will contribute to enhance the quality and safety and furthermore to ensure economy in construction of the ILC facilities.

On the other hand, it will be pleasure beyond expectation for all the committees if the guidelines will also be utilized for the construction of large-scale underground inside and outside the country in the future, furthermore, and contents can be improved through construction in the future. And it is regarded as the big result that existing technologies furthermore spiral up by becoming superior technologies and expertise which were found here and there thus far one.

Finally, the committee has selected the theme of realizing the ILC plan and implemented needs driven committee activities to respond to the social needs. We sincerely hope this experimental activity of committee will be applied to the other themes of the Japan Society of Civil Engineering in the future and new synergy will be created and as the result activities of the society will be vitalized.

Acknowledgement

The guidelines were decided to be compiled in accordance with the technical documents (TDR) which was compiled by the International design group (GDE) established by the future accelerator committee (ICFA) of the International Union for Pure and Applied Physics (IUPAP). In spite of the short period of working time for 3 years, we were able to complete uneventfully as planned. It is the gift of hard works done by attending committee members including Chief and Secretaries and furthermore big cooperation from the Japan Society of Civil Engineering Committee on Rock Mechanics and Tunnel Engineering. And attending committee members are the experts of underground cavity construction and seriously made considerations based on the technologies and expertise cultivated for long time and compiled the guidelines. And we think that the integration of standards and specifications of related institutions and organizations that were accumulated through the construction experiences such as national roads, highways, bullet trains, underground electric power plants, bedrock stockpiling base for energy etc. made the guidelines substantial and led to smooth work. In addition to this, in research forums and panel discussions held twice a year, opinion exchange and adjustments between section meetings that had worked individually were implemented and furthermore there were great opportunities to hear wide opinions from the persons concerned with accelerator civil engineering who were not directly participated in the compiling work and members of the Japan Society of Civil Engineering. And important information and precious suggestions were given to us from many people who cannot be listed here. We want to express sincere appreciation to advice and instructions from many people.