A case study of the geological risk management using suitable investigation in mountain tunneling

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***ABSTRACT*:** In mountain tunneling, it is important to avoid or reduce the geological risks such as a weakness of the bedrock and a large volume of ground water beyond assumption from a safety and economic efficiency point of view.

The author has experienced a mountain tunneling project in which uncommon geological risk management was conducted. The objectives of this study are, thus, to introduce this risk management, discuss its benefits, and describe future issues in geological risk management.

In this project, a research was conducted on the risk management technique for occurrence prevention of the above-mentioned latent geological risks on a mountain tunnel in Japan. It was presumed that a ground had many geotechnical problems based on results of restricted investigation in a prior stage.

In order to cope with the geological risks and to advance construction more smoothly, the tripartite council which consisted of owner, constructor and geological consultant were established before construction, and various technical advices were given on the construction and auxiliary method.

Since geotechnical information was always shared in the tripartite council, quick investigation was conducted by the geological consultant when collapse of the crown and water inflow occurred in tunnel.

The geological consultant played important role about the revaluation for unexcavated section and the proposal of a suitable construction method from geotechnical viewpoint. The geological risk management was continued until end of the construction using detailed geomorphic analysis and observational construction control system in addition to various kinds of investigations.

Eventually, designed case was compared with actual case adopting modification index (i).

A geotechnical base line of ground classification was drawn up on the basis of the information acquired by this construction and it is applied also in other tunnel. Moreover, the degree of the geological uncertainty in a ground at the planning phase will become more clear by application of this geotechnical base line. That serves as an important factor to examine the construction method, cost and planning of construction.

The geological risk management research of ground evaluation utilizing this experience is continued in other mountain tunnel with the same kind of geological features.

It is an important future subject to quantify the geological risks as the degree of deviation and extent from assumed geological condition, and to reflect them in the design and construction.

KEYWORDS: Geological risk managements, mountain tunneling, suitable investigation

INTRODUCTION

Investigation of the prior stage of mountain tunnel with long length and high oberburdun was conducted for the purpose of clarifying each following item.

・The overall geological structure, distribution of geological features and characteristics of the tunnel section

・Ground classification with synthetic technical consideration based on the results of investigation

・Topography and geology of portal locations, basic data for a problem and its measure design, and

・Basic data for evaluation of face stability, design of support, selection of auxiliary method, selection of excavation method and tunnel driving method

Especially in a tunnel design stage, geographical and geological data of high accuracy are required.

However, it is difficult to do the highly precise geological survey which covers all the extension of the tunnel as the linear structural object before excavation given the present technical level, and investigation period and current requirement of economic efficiency for geological survey.

Moreover, the Japanese Islands belong to the mobile belt through the geological age, and have very complicated geological structure and distribution of geological features. For this reason, recognition of the uncertainty about the geological phenomenon in tunnel construction and the correspondence to them have been an important subject. In tunnel construction, how it grasps in a prior stage has linked to the subject resulting from the latent geological risk by the heterogeneity of the ground, and the uncertainty of geological information with cost and construction period directly.

The geological risk in tunnel construction expresses degree and grade of a size of the uncertainty which "the phenomenon which is not desirable" generates for construction and control of maintenance.

This paper describes an example which reduced deviation of ground evaluation in the prior stage and construction stage in the mountain tunnel built on the steep mountains area, and the future view from the viewpoint of geological risk management.

2. GEOMORPHOLOGICAL FEATURE AND GEOLOGY OF RESEARCHED TUNNEL

This tunnel is planned by steep mountain area with 1200-1400m altitude, and some mountain streams which have channel in the direction of northeast-southwest cross tunnel alignment (Figure 2.1).

The direction of these mountain streams is partly in agreement also with the lineament by an aerial photograph interpretation. Moreover, it is analyzed as low-velocity zone by seismic refraction method, and is geomorphological weak zone.

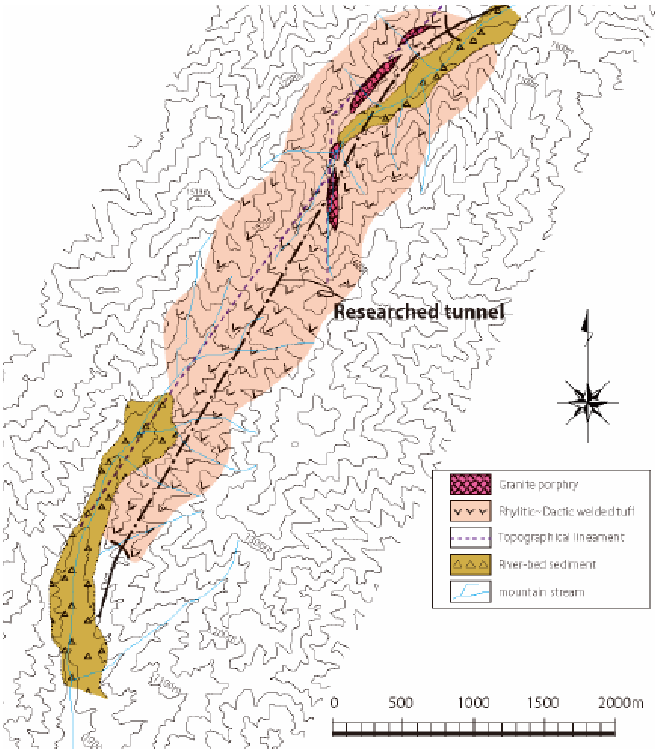


Figure 2.1 Locality map of researched tunnel

Ground consists of the Nohi Rhyolites (rhyolitic～dacitic welded tuff) formed at the Cretaceous age and granite porphyry which intrude them. These welded tuffs have received weathering and hydrothermal alteration, and lithofacies also changes intricately.

3. GEOTECHNICAL PROBLEMS

It became clear that the following geotechnical problems were held from the geological investigation carried out in the prior stage in this tunnel ;

・Geological outcrops was deficient in land surface as a whole, and it was difficult to grasp in detail about the geological structure of ground in the prior stage .

・It was presumed that welded tuffs were distributed over 96.6% of tunnel length, and granite porphyry was distributed to the remaining 3.4% in the tunnel formation level. However, the former has the development of fracture frequency and the extent of alteration in various forms, estimated accuracy for deep bedrock conditions is considerably low.

・It is considered that geological boundary between welded tuffs and granite porphyry is a alteration zone with many clayey thin layers, and possibility of being the bed rock which deteriorated is high in the depths also. Therefore, large increase of earth pressure caused by tunnel excavation or sudden water inflow occurs when clayey layer is an impermeable wall at section where overburden exceeds 300m. In such a case, it has a significant impact on excavating.

The ground classification was performed in consideration of the ground conditions on this tunnel based on the tunnel standard for road tunnel-structures (Japan Road Association; 1989).

The ground condition of the depths depend on the elastic wave velocity value acquired mainly by seismic refraction method. However, since the depth of not less than about 200m is a limit of exploration, the reliability of the acquired elastic wave velocity value is considerably low. Therefore, accuracy of the position of low velocity zone and boundary on the class of ground is also low in the tunnel formation level of these large depth sections. The low velocity zone is considered to be above-mentioned alteration zone or shear zone on the ground.

In the design phase, the FEM analysis was conducted in large overburden part. As a result, support pattern corresponding to the ground classification was ranked higher about the section where oberburdun exceeds 300m.

As a result of predicting the amount of water inflow using hydrogeological conditions and hydraulic formula, it is considered that the amount of steady inflow in this tunnel is about 0.7 m^3/min/km. The amount of concentrated water inflow at stage of construction is presumed to be those about several times. The generating position of concentrated water inflow can consider at the periphery of low velocity zone and directly under a mountain stream in the tunnel formation level.

4. GEOLOGICAL RISK MANAGEMENT

This tunnel is crossing some mountain streams with the right angle or the high angle. An intersection part is in agreement with the position of a low-velocity zone in many cases. In those parts, although the oberburden is large, face falling and generating of large volume of water inflow are assumed with construction.

In respect of safety of construction, such frequency and quantity pose a problem as a geological risk. The geological risk management about the countermeasure of emergency time or predicting of the geological risks are very important.

The example which was able to be reflected in construction is reported using the geological risk management technique.

In order to cope with the geological risks and to advance construction more smoothly, the tripartite council which consisted of owner, constructor and geological consultant were established before construction. Since geotechnical information was always shared in the tripartite council, quick investigation was conducted by the geological consultant when collapse of the face and water inflow occurred in tunnel.

The geological engineer played important role about the revaluation for unexcavated section and the proposal of a suitable construction method from geotechnical viewpoint. The role of geological engineer was concretely written together to Figure 4.5.

4.1 Case example 1(northern section)

After excavation was started, construction was advanced using TSP and non-core boring as prediction system for geological conditions ahead of the tunnel face in the northern section.

The face collapsed by STA.217+18.7 (A point) shown in Figure 4.1, and the outflow of soil was generated about 200 m^3 to the inside of a tunnel and the water inflow of a maximum of 0.85 m^3/min. The overburden of A point(STA.217+18.7) is 65m and is located in the end of the mountain stream

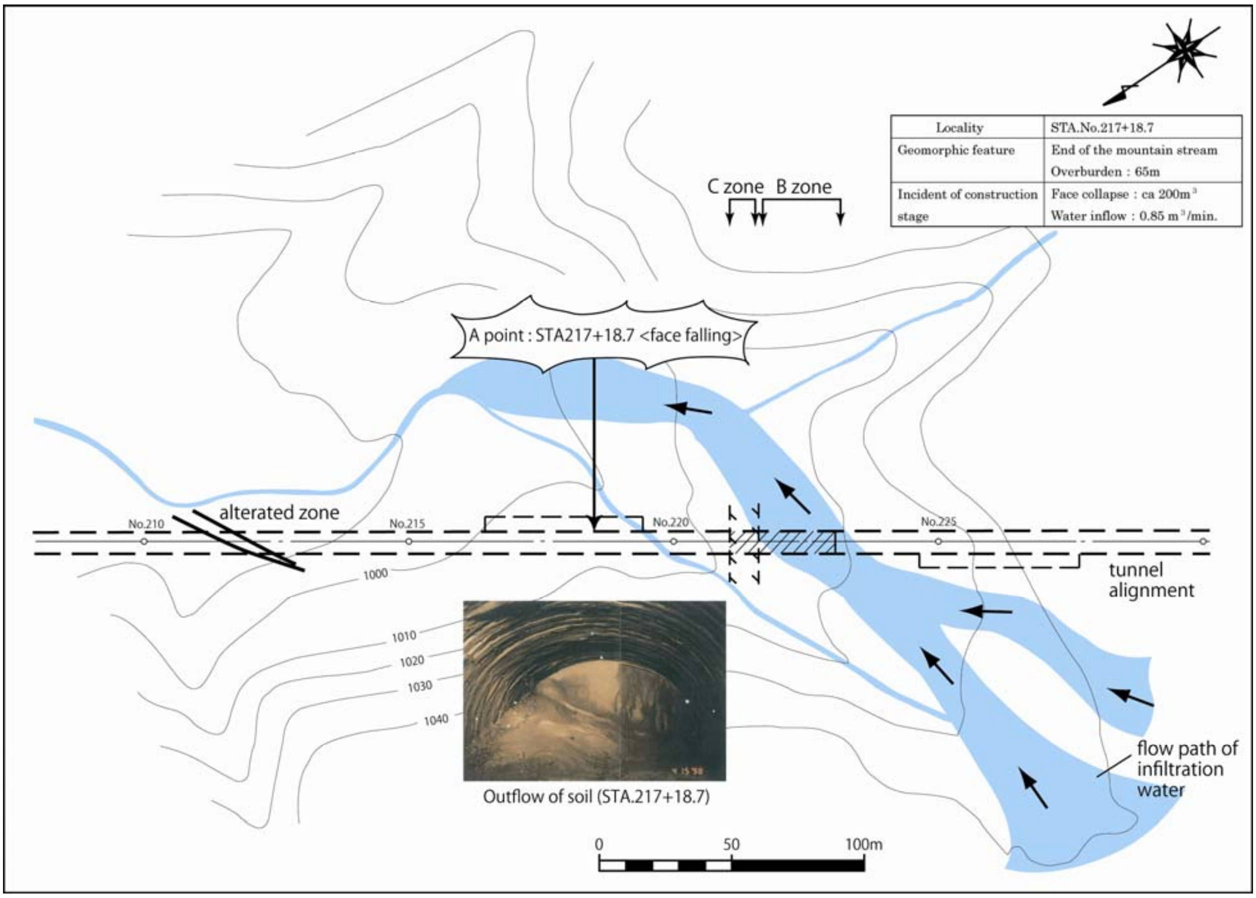


Figure 4.1 Location of the face collapse point

path which flows northeastward.

Moreover, near B zone, since a tunnel passes directly under the main flow path with infiltration water. And mountain stream water may flow in inside a tunnel.

Then, the geological risk management in this stage was considered as follows from the viewpoint of safety tunnel construction.

It is important to grasp the relationship between tunnel water inflow and mountain stream water. When mountain stream water turned into water inflow directly and flowed in inside a tunnel, it was expected that it will be succeeding occurred by large amount of water, and is obliged to construction interruption. In that case, the investigation of large-scale water sealing method is needed.

In order to solve this problem, the water quality analysis for tunnel water inflow and mountain stream water was proposed and carried out.

C zone detected as a low-velocity zone is observed ahead of collapsed face at STA.217+18.7 This zone is located near the directly under part of the main mountain stream.

It is necessary to acquire the detailed information about those bed rock conditions for investigation of a suitable support pattern. For this reason, exploration boring for checking the range of a cavernous part, drainage boring and core boring for check of geological condition for unexcavated part were carried out in a tunnel. Furthermore, high-density electrical prospecting was performed in ground surface (Figure 4.2; Ikuma et al., 2001).

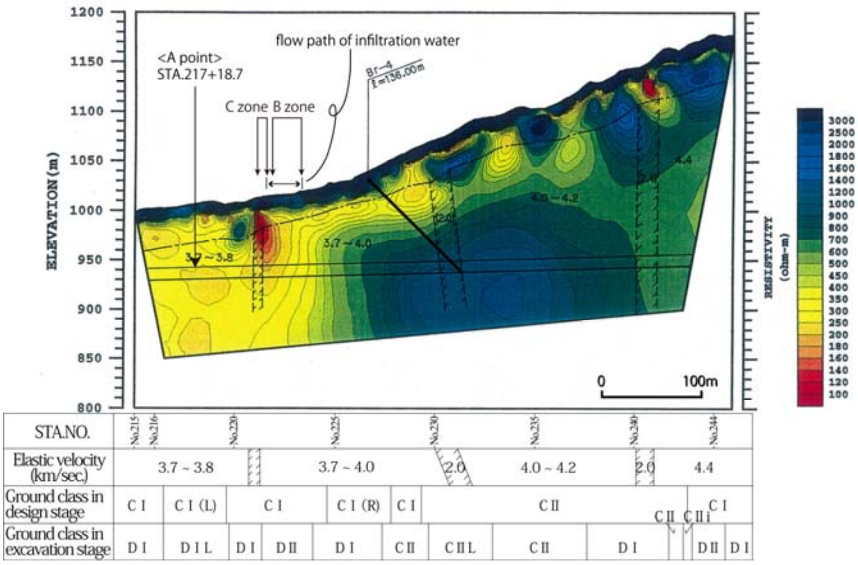
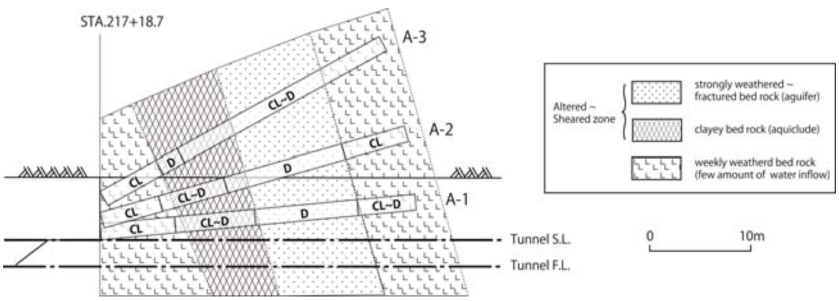


Figure 4.2 Tunnel cross section based on high-density electric prospecting (STA.215～244)



CL, CL～D, D: Rock mass class

Figure 4.3 Geology and bed rock condition of the ahead of face

From the investigation of the hexa-diagram based on a water quality analysis result, water inflow is the shallow groundwater which a part of underground water mixed, and it became clear that mountain stream water was not flowing in tunnel directly.

The geology and bed rock condition of ahead of face are shown in Figure 4.3. The aquifer was accepted behind the bed rock which presents clayey ～sandy deteriorated rock, and it is pointed out that there is a danger of being generated by the sudden water inflow at the time of excavation. The low specific resistance part below 200(Ωm) existed in the section of STA 221～223, and it became clear that it was also mostly in agreement with the above-mentioned low-velocity zone and the direction of a main flow path of a mountain stream. The possibility of developing water inflow and collapse of face are very high in these sections again.

According to these investigation results, the springwater which flowed into the tunnel is not artesian condition. Therefore, it is not based on water sealing method, but drainage by two or more drainage boring is more effective.

The most important subjects on the tunnel construction in a main stream path crossing part (B zone) were the change in the volume of water inflow and change of water quality.

Simple measurement was performed at construction site and these subjects were considered (refer to Figure 4.5). Drainage boring took effect and the amount of water inflow decreased gradually. The ground situation of this section was well adjusted with the resistivity value.

About the deterioration section of the bed rock, the suitable auxiliary method was able to be used in consideration of economic efficiency and constructability together, and excavation was able to be continued.

4.2 Case example 2(southern section)

In southern section, after excavation was started, construction was favorably continued by performing TSP and horizontal core boring as investigation of ahead of the tunnel face. However, from the vicinity of STA338, the deteriorated bed rock came to appear frequently, and the squeezing from a tunnel sidewall also became remarkable.

When excavation work advanced to STA.333, the convergence was increased. A maximum of 500mm displacements by squeezed are found at the lateral side of tunnel at the point of STA.331+15, and excavation was stopped. The cave of about 3m ×4m size was checked in the upper part of this face. The amount of springwater from a cave was 1.3m^3/min.

When an alteration zone appears in tunnel formation level with deep overburden, face falling, expansion of loosen zone accompanying excavation and the increase in lateral pressure are given. Moreover, it became clear that the confined aquifer existed in ahead of the face from result of horizontal core boring.

The support pattern accompanied by the high rigid auxiliary method is needed in continuation of excavation judging from these situations. Then, the steel pipe fore-piling as the prevention for face falling, increase of rock bolt as lateral pressure preventive measures and drainage borings as measure against water inflow were proposed, respectively. Although displacement headed for convergence, water inflow was not decreased. Pressure of water inflow also had 1.7Mpa.

The geological condition in a tunnel was examined synthetically, and an excavation of drainage drift was proposed as a prevention which breaks through the confined aquifer with irregular distribution from a viewpoint of construction and economical efficiency. As shown in Figure 4.4, a drainage drift was excavated.

In the point of No.331+16, it encountered the expected artesian aquifer by excavating the drainage drift. At that time, the face fell suddenly, the clayey～sandy deteriorated bed rock of 80m^3 collapsed, and the water inflow of 2.5 m^3/min was occurred.

The drainage drift was blockaded by this collapse. However, the generated water inflow advect from the main tunnel to the drainage drift, and the water level and the volume of water inflow have been decreased. The total volumet of water inflow of tunnel was ca.7500 m^3 /day.

Since it was still generated by large volume of water inflow from the face of this tunnel and the steel pipe fore-piling also after that, five more drainage boring were executed with STA.331+5.9.

As a result, the volime of water inflow from the face also decreased and continuation of excavation was attained.

However, since the deep overburden section will continue and occurring of sudden water inflow is also predicted, management of water inflow processing is needed.

For this reason, drainage capability was reexamined and proliferation of the facilities for drainage in always and an emergency was proposed.

From these two examples, the technique of the geological risk management to construction in the section where deterioration of the bedrock and generating of a large volume of water inflow are summarized in Figure 4.5.

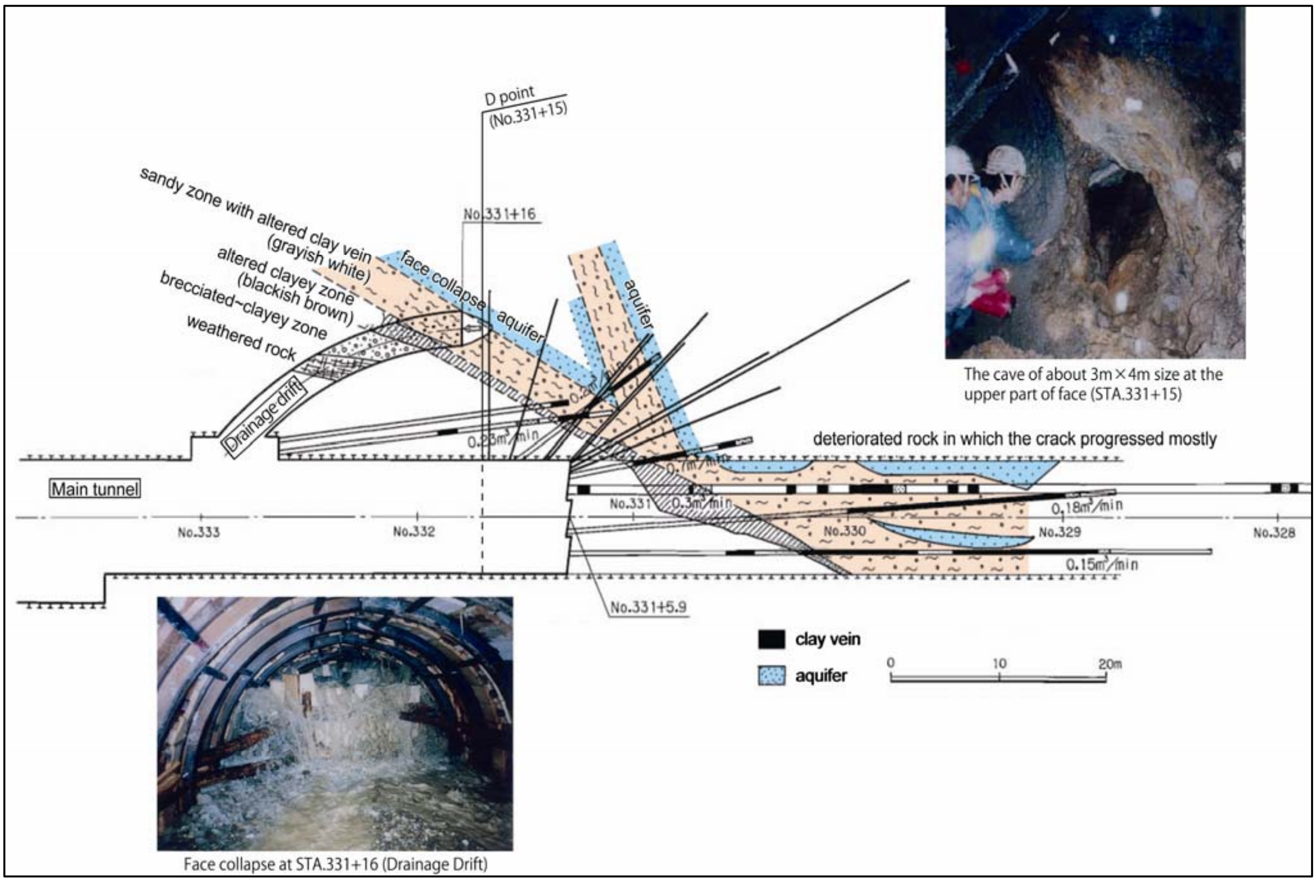


Figure 4.4　Base rock and water inflow situation around STA.331

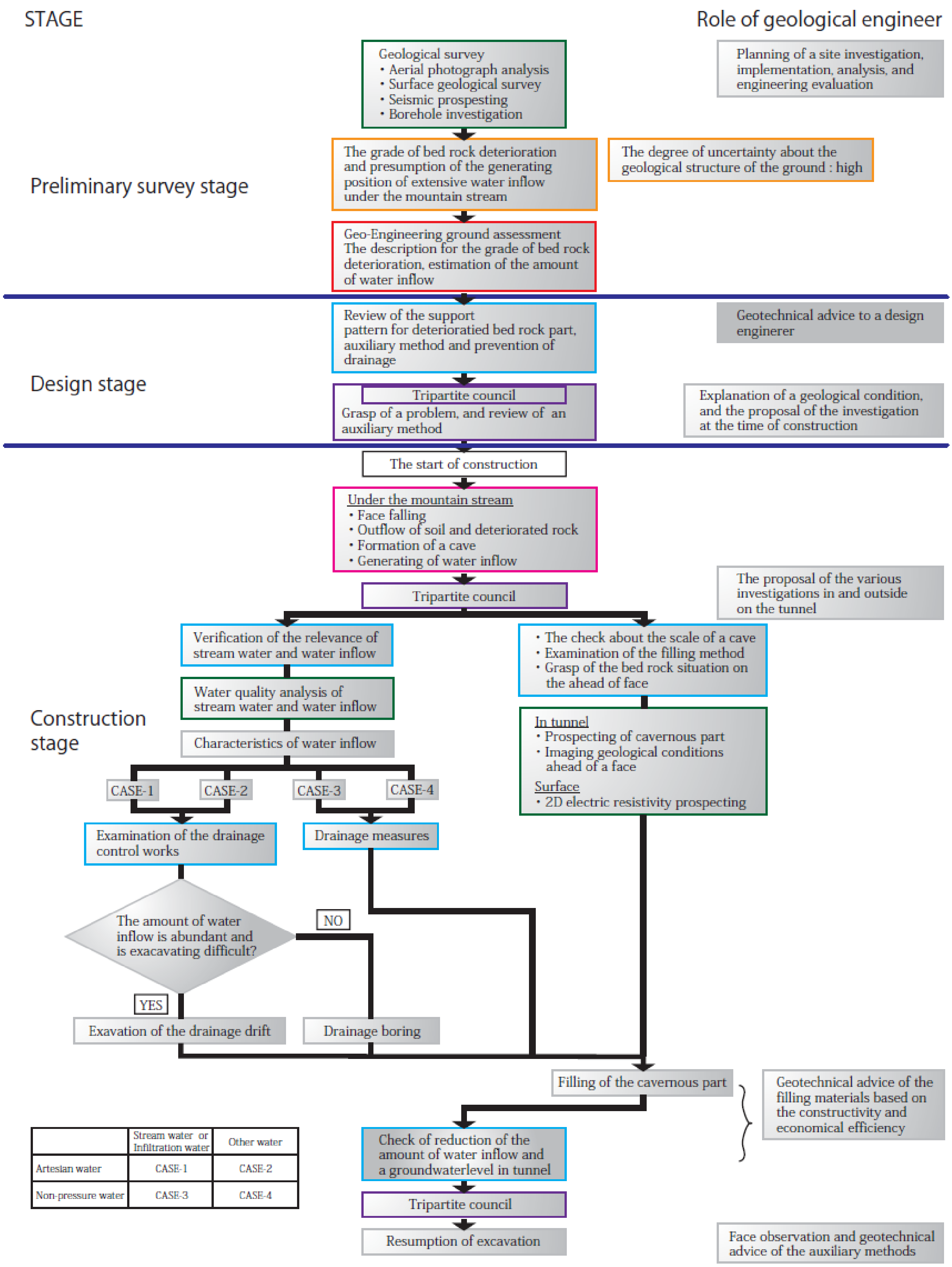


Figure 4.5 Construction flow chart about the face falling section and role of the geological engineer

4.3 Orientation of geological risk

Although generating frequency was low about the sudden water inflow under tunnel construction, it was predicted that a large volume of water inflow was expected at occurred time.

The mountain stream which flows through near a portal part is a clear stream, and mountain trout inhabits. Moreover, in the downstream region of southern section, there is a source of tap water using the infiltration water of the river, and it is used as drinking water. It is necessary to care about enough the measure against drainage of the water by which it is generated from the inside of a tunnel also from a viewpoint of social environment.

The amount of convergence displacement measured by real construction is settled in the range presumed in the preliminary survey stage. The crack situation of the shotcrete surface was also observed carefully, and lining concrete was placed after checking displacement convergence.

Those positioning is shown in Figure 4.6 about the amount of sudden water inflow and convergence among the geological risks in each stage of tunnel construction.

In the maintenance stage, these geological risks are monitor by visual observation and periodical measurement.

4.4 Quantitative evaluation of ground by modification index

Next, the comparison between initial design phase and actual results after excavation stage of the ground classification in the above-mentioned each section is done by using the modification index (i).

The modification index (Inoma：1984) was used to analyze comparison between initial design stage and actual results after excavation stage of the ground classification in the above-mentioned each section quantitatively. Modification index (i) is defined by the following formula.

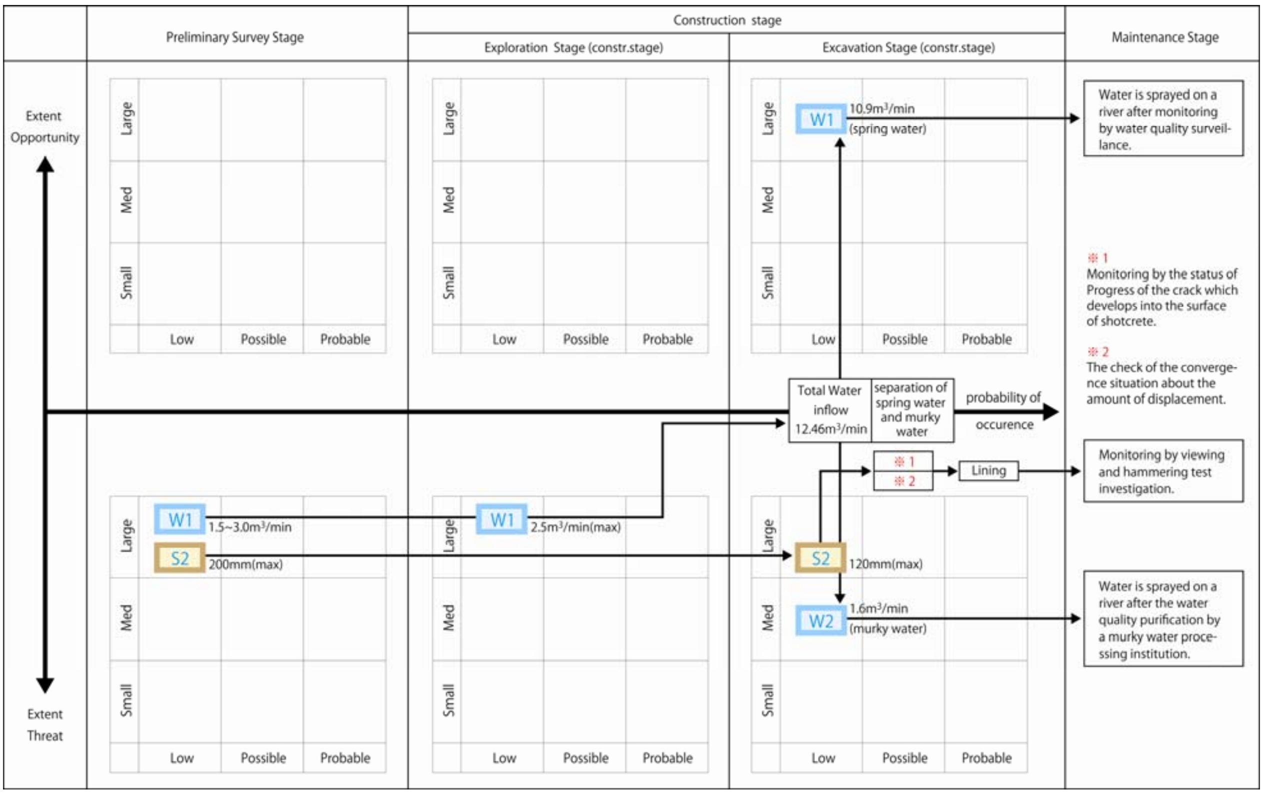


Figure 4.6 Orientation map of the geological risks

$$i = \sqrt{\frac{\sum (n R^2)}{\sum n}}$$

Where,

R : Difference of class numbers with corresponding rock mass between each designed and actual case

n : Ratio against the total length with each R.

The result of comparing the ground classification at initial design stage, ahead of the face investigation stage, and actual results after excavation stage is shown in Figure 4.7 and Figure 4.8 in each section.

If the modification index is calculated from the ground classification in the ahead of face investigation stage and excavation stage, it becomes 0.59 and 0.80, respectively. With the general technical level, it is considered i≦1.1 as a standard, and the quite effective face design was completed by the ahead of face investigation .

4. FUTURE VIEW

In the ground where geological and rock mass condition change intricately in tunnel extension and transverse direction like this tunnel, the difference of ground classification between initial design stage and construction stage is remarkable in many cases. About the unexcavated section which poses a problem especially in a construction stage, the ahead of face investigation result by two or more techniques is considered synthetically, and grasp of the three-dimensional ground condition of the tunnel extension is needed. However, an applicable exploration method is different according to overburden, geologic structure, and the rockmass condition of the ground. Therefore, the geological management which judges the more effective exploration method appropriately about quality grasp of the unexcavated part of a tunnel is important.

In evaluation about deterioration part of the ground which consists of the Nohi Rhylolitic rocks

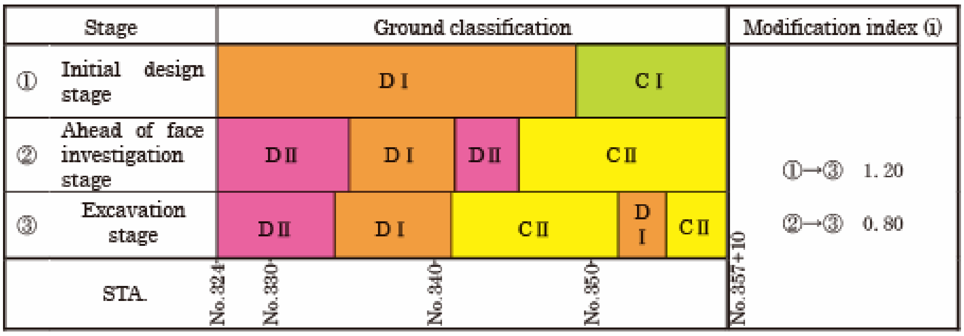


Figure 4.7 Contrast ground classification initial design stage and excavation stage (northern section)

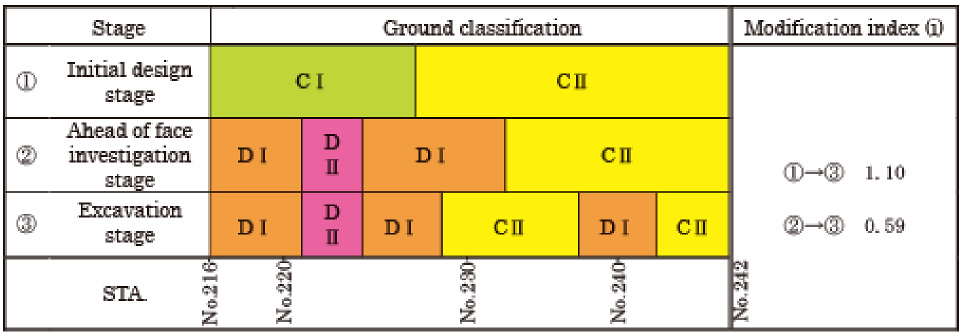


Figure 4.8 Contrast ground classification initial design stage and excavation stage (southern section)

like this tunnel, examination of the resistivity value was effective.

A ground classification in the design phase and excavation stage of this tunnel is shown in Table 5.1.

In the excavation stage, it became clear that granite porphyry had several times as many spread compared with a preliminary investigation stage.

Petrographically, the extensional shape of granite porphyry is stock, and widening toward deep.

Table 5.1 Ground classification of researched tunnel

Initial design stage		Excavation stage			
Class of ground	Elastic wave velocity(km/s)	Class of ground	Resistivity (Ωm)	Convergence (mm)	Geological condition of the face during excavation
C I C II	3.7~4.4	C I	≧1000	≦10	A crack surface is fresh and rock mass condition is good as a whole. Stand-up of face is good.
		C II	1000～500	10～40	Alterated clay adheres to a crack surface. The small rock masses may fall down along a crack surface. Steel support is needed.
D I	2.5~2.6	D I	500～200	10～50	A crack progresses notably and a soft rock condition is shown. The shape of a rock fragment ～grit are presented partly, and small collapse of face arises.
D II	2.5≧	D II	200≧	20～60 (max.130)	The rock masses show grit～clayey shape, and stand-up of face is bad. Disruption of rock masses ～ grit is remarkable.

However, the geological problem about the structure of granite porphyry remained during excavation, and the variation of ground evaluation was caused. Geological outcrop distribution of granite porphyry was fragmentary and details of those distribution and geological structure were uncertain in the preliminary investigation stage.

The depth distribution shape of granite porphyry remained as a residual risk until the excavation stage.

Moreover, the ground classification scheme in the planning stage of A and B tunnel which consists of same geological kind around this tunnel is shown in Figure 5.1. These two tunnels are under excavation now.

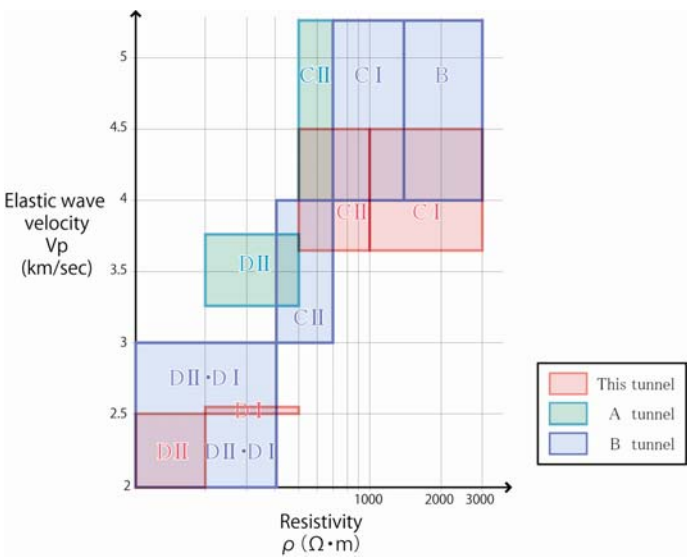


Figure 5.1 Ground classification of the planned tunnel with the same kind of geological features

By repeating observation of these tunnel face conditions and comparison of each ground condition, the more practical standard of ground will be built from now on.

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