Paths to reduce failures caused by misinterpretation of ground conditions

H. Todo 1)

i) Consultant, Overseas Department, Kiso-Jiban Consultants Co., Ltd., 1-5-7, Kameido, Koto-ku, Tokyo 136-8577, Japan.

ABSTRACT

We often misinterpret ground conditions in various stages of a construction project, such as planning, investigations, design, and construction stages. The misinterpretation occurs because the ground conditions are usually uncertain to various degrees even after geotechnical site investigations. The paper first discusses the occurrence of the misinterpretation, which (1) largely depends on the volume of quality data and human skill, and (2) generally happens while making geological models, geotechnical models, and civil/structural designs. Secondly considered is the uncertainty of the ground conditions, the awareness of which varies depending on people who handle the geo-information. Thirdly, among many misinterpretations we make, only a few cases result in failures, because of some traditional safeguards. However, due to changing practices of geotechnical designs and construction contracting recently, the conventional safeguards are not as secure as before against the failures caused by the misinterpretation of the ground conditions. Lastly, discussed are possible ways to reduce misinterpretation. Keys could be awareness of the uncertainty of the ground conditions and improvement of communications throughout the construction projects by all stakeholders. Geotechnical societies are well suited to contribute to this area, and project owners and managers have great power to prevent failures cause by the misinterpretation of the ground conditions.

Keywords: site characterization, risk management, human error, geo-information, uncertainty

1 INTRODUCTION

We often make wrong interpretation of the ground conditions, which sometimes leads to failures. Two recent construction-related incidents in Japan remind us of the risks of the misinterpretation of the ground conditions. Illustrated below are the two cases:

(1) Yokohama case

In November 2012, residents in Yokohama, Japan found the settlements of about 20 mm at their 12-story, pile-supported residential block, which was completed in November 2007 (Yuri, 2016). The design of the pile foundation reportedly assumed a flat bearing layer overlain by a uniform thickness of soft clay, and the piling work followed the design, which dictated all the piles driven to a depth of 14m. The soil investigation performed thereafter revealed that the bearing layers were present as deep as 16m at some pile locations. Fig. 1 illustrates the image of the misinterpretation of the ground conditions in Yokohama case.

(2) Fukuoka Case

During 5:15 to 7:30 am on November 8, 2016, a sinkhole of 30m by 30m in plan and 15m in depth took place in front of Hakata Station in Fukuoka (Public Works Research Institute, 2017). Tunneling work was going on at this place for subway construction. The overburden at the crown was about 19m from the ground surface. The tunnel was driven through Tertiary sedimentary rocks, which underlie water bearing sand layers. The rock cover above the tunnel roof is a few meters thick, weathered sedimentary rock. The design reportedly assumed the weathered rock cover to be solid, impervious, and of uniform thickness, while the investigation after the accident found that the rock cover was highly weathered, variable in thicknesses, and fissured at some portions, as shown in Fig. 2.

Fig. 1 Image of misinterpretation of ground conditions for Yokohama case

(a) Pile design assumption (b) Possible conditions revealed after building settlements

Fig. 1 Image of misinterpretation of ground conditions for Yokohama case

2 ELEMENTS OF MISINTERPRETATION OF GROUND CONDITIONS

The misinterpretation occurs because the ground
conditions are usually uncertain to various degrees even after geotechnical site investigations. There may be three elements for the misinterpretation of the site geology, which leads to false geological modeling. They are data, human factor, and ground conditions. Where the geological conditions are simple and uniform, the mistakes may be rare even if the data are scarce and the person engaged in the geological interpretation is inexperienced. Where the geological conditions are complex, it is obvious from the comparison below that both the volume of the quality data and the proficiency of the person engaged in the geological interpretation are essential for making good interpretation (little misinterpretation) of the site geology.

Table 1 Comparison of combination of data volume and human skill for interpretation of complex ground conditions

<table>
<thead>
<tr>
<th>Data volume</th>
<th>Proficiency of person</th>
<th>Chance of mistakes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Small</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Large</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Large</td>
<td>High</td>
<td>Low</td>
</tr>
</tbody>
</table>

2.1 Data collection

The more data we have, the more accurate the interpretation of the ground conditions is. Then how much data is sufficient is a question we usually face especially when the budget for the investigation is tight. There is no direct answer to this question. However, a traditional recommendation is a step-by-step investigation, which is cost-effective and can gradually reduce the uncertainty of the ground conditions. The following procedures by applying the principle of the step-by-step investigation seem to be effective and logical to prevent failures caused by the misinterpretation of the ground conditions.

The first step is to assume site geological conditions by interpreting available information at the planning stage of the investigation. The second step is to plan the site investigation based on the assumed ground conditions and the third step is to test the assumed ground conditions by main investigations. If the main investigations prove the assumptions inadequate, the ground conditions should be re-interpreted and additional investigations be carried out. For the planning of the site investigations, it is, of course, necessary to consider layout/alignment of proposed structures, magnitude and distribution of loading, construction methods and procedures, and allowance or limitation of deformation.

The important point here is to apply this principle from the planning stage of the site investigation, rather than first performing the main investigations by blindly following codes that specify how much and how deep boreholes to be sunk. Unfortunately the importance of the planning stage seems unrecognized generally, and is forgotten or ignored perhaps because the work in the planning stage is unpaid or underpaid by clients compared to such efforts involved as described below.

The suggested procedure requires obtaining information on the surrounding ground conditions at the planning stage of the investigation. The following information may be useful:

- Past geotechnical investigation results such as borehole data, sounding data, soil/rock test results, water quality tests, groundwater levels
- Past geophysical investigation results such as PS loggings, seismic survey results, echo sounding results, electrical resistivity results
- Published surface information such as topographic maps, geological maps, land-use maps, vegetation maps, air-photos, satellite photos
- Papers and books on neighboring geomorphology and Quaternary geology
- Construction reports and
- Newspaper articles on construction accidents nearby

Such information may be available from geo-information databases, local libraries, universities, geotechnical consultant offices, and government offices. Site visits by experts can also bring in valuable information on the site ground conditions by inspecting outcrops, drainage conditions, vegetations, and defects of surrounding structures.

2.2 Qualification of person

Certain qualification is necessary for the person to interpret the site geological conditions. Mistakes will be less when more than one person do the job. In this regard, a team consisting of the following qualifications may effectively reduce the chance of making mistakes.

- A person who received formal training or education in geology
- A person who is knowledgeable about local topography, geology, and geological history
- A person who is knowledgeable about local history of reclamations, earth filling, slope cutting, excavation, and river improvement works
- A person who practices making geological models and is good at expressing uncertainties in drawings
3 AREAS WHERE MISINTERPRETATION OCCURS

Fig. 3 shows a general flow of geo-information in construction projects. While a project progresses from subsurface investigation to design to construction, the geo-information takes forms of subsurface investigation reports, geological interpretative reports, geotechnical interpretative reports, geotechnical design reports, civil/structural design reports, and construction details prepared by construction people.

In the above flow of the geo-information in construction projects, the misinterpretation of the ground conditions generally happens at three occasions: (1) when making geological models, (2) when making geotechnical models, and (3) when making civil/structural designs.

The first pitfall lies at the stage of the geological interpretation and geological modeling based on the subsurface investigation results. As discussed above, the quality of the geological interpretation and geological modeling depends on the data and human skill. The misinterpretation may occur if the data is not enough, or the persons who interpret the site geological conditions are not qualified, or both.

The second pitfall is present at the stage of the geotechnical modeling in Fig. 3. Potential mistakes happen if a geotechnical engineer assigned makes the geotechnical models directly from the data by omitting the geological interpretation. Even if he/she is good at interpreting geological uncertainties, he/she may be preoccupied with possible construction methods, a budget, and a construction period, and tends to ignore unconsciously or consciously possible geological uncertainties, thereby making wrong models, which would cause troubles in later stages.

The third pitfall exists in the civil/structural design stage. Similar to the geotechnical engineers’ mistakes by making the geotechnical models directly from the data by skipping the geological interpretation, a civil/structural engineer assigned also makes potential mistakes, if he/she directly takes some information from the raw data without geologists’ and geotechnical engineers’ interpretation of the site geological/geotechnical conditions.

4 AWARENESS OF UNCERTAINTY OF GROUND CONDITIONS IN CONSTRUCTION PROJECTS

The uncertainty of the ground conditions is a major cause of the misinterpretation. If all of us are aware of and alerted to the uncertainty of the ground conditions in general, someone could point out the misinterpretation if made. However, the awareness of the uncertainty varies depending on the people who handle geo-information.

In the flow of the geo-information in Fig. 3, the geological interpretative report is the first step to deal with the uncertainty. The report usually includes geological models such as geological cross sections or soil cross sections, and they inherently contain uncertainties about distribution of strata. The degrees of uncertainty about layer boundaries in the geological models are often expressed by different thicknesses of solid, dotted, and dashed lines together with question marks. So, those geologists who make the geological models seem to be well aware of the uncertainty contained in the geological models. However, in the author’s observation, the geological interpretative reports rarely describe the uncertainty of the geological models in detail by words. Thus, the clear information or messages regarding the uncertainty of the geological models hardly reach to the geotechnical engineers, civil/structural engineers, and construction people. Nevertheless, the models would be treated or considered as true representation of the ground conditions at later stages of the construction project.

The geological models are then handed over to the geotechnical engineers for making the geotechnical models. The geotechnical engineers use the geological models as the basis for the geometry of the geotechnical models. If a geotechnical engineer who makes the
geotechnical models fails to understand rightly the uncertainties inherently involved in the geological models, such geotechnical models may result in construction troubles at later stages. In this situation, the geological models are incorrectly translated into the geotechnical models. However, the geotechnical models so established would be treated or considered as right models of the ground conditions at later stages of the construction project. In addition to the geological uncertainties, the geotechnical models include uncertainty in soil parameters, and errors derived from over-simplification of the geological models, which are beyond the scope of this paper.

The geotechnical engineers’ awareness of the uncertainty of the geological and geotechnical models may depend on their positions or responsibility in a construction project. Those who are involved in decision-making process or risk management are perhaps more concerned with the uncertainty than those who are not, and are likely to propose additional investigations or several alternative geotechnical designs for possible scenarios of ground conditions to evaluate the effects of the uncertainty of the ground conditions.

The geotechnical models are next handed over to civil/structural designers for their design work. Where contracts separate the geotechnical works and the civil/structural designs, communication between those parties is generally poor or none. Where the civil/structural designers have to rely solely on the geotechnical reports prepared by someone else under a separate contract, they have to translate geotechnical language to their language on their own. Without close communication between the geotechnical engineers and the civil/structural engineers, crucial messages of the uncertainties contained in the geotechnical reports can easily be lost during the translation, or certain messages are wrongly translated.

The civil/structural design is further handed over to construction teams. Similar to the above, when the construction works are contractually separated from the design work, there will be little communication between the designers and the construction people. When the site conditions are different from the design drawings, the construction teams have to take care of the situation. Perhaps they can solve the problems on-site without referring to the designers. The solution may be rational construction-wise, but may not be so design-wise, if the construction teams are ignorant of designer’s intent in the design with respect to the ground conditions.

5 TOLERANCE OF MISINTERPRETATION

Although we often make mistakes in interpreting the ground conditions, such misinterpretation rarely results in physical or financial catastrophes. The following factors could alleviate the effects of the mistakes.

- factor of safety
- designers’ tendency to play safe
- structures’ ability to accommodate certain amount of deformation
- application of observational methods
- fixing during construction work
- contractual arrangement to accept contractor’s claims for adverse physical conditions

However, the above safety net may not be taken for granted in future. More accurate interpretation and modeling of the ground will be called for in view of recent trend of geotechnical design and construction contracting.

For example, our predecessors have derived the factors of safety based on accumulated experiences for generations in order to be applicable in general situations. Extra safety is thus buried in the factors of safety. However, rigorous assessment of the factors of safety in recent cost competitive projects cuts out a part of the extra safety. Even if the conventionally recommended factors of safety are used in the design, recent geotechnical designs require consideration of displacements/deformations of ground/structures. Now, many projects demand more strict control of settlement/deformation of the ground/structures as serviceability criteria, especially for excavations and tunneling in urban areas.

As to a little overdesign for designers’ insurance, similar to the above discussion of the factors of safety, the designers are under increasing cost-cutting pressures. They may have to trim extra safety.

While the observational method is traditionally effective method to deal with uncertainty involved in the ground conditions, recent tendency to shorten construction period may not allow the application of the method. As construction period is cut short, the monitoring instruments are merely for confirmation of design assumptions, rather than used to try, observe, and change methods if adverse situation occurs.

When the different ground conditions than the designed are revealed during the construction stage, the contractor could manage to handle such conditions. However, he may not be able to claim extra cost and time extension, if his contract follows FIDIC Silver Book (1999, 2017) for Condition of Contract for EPC/Turn Key Projects, in which the contractor bears such risks of adverse physical conditions.

6 POSSIBLE WAYS TO REDUCE MISINTERPRETATION

Whereas the misinterpretation of the ground conditions is probably unavoidable, we have to make efforts to reduce the catastrophic results caused by that. Keys could be awareness of the uncertainty of the ground conditions and improvement of communications throughout the construction projects.
6.1 Contribution by geotechnical societies

Geotechnical societies can contribute to raising the awareness levels about the uncertainty of the ground conditions and improvement of communications by:

1. Developing a guide for making geological interpretative reports for geotechnical engineering use. The guide may advise to include, in the geological interpretative reports, the description of the uncertainty of the geological models by words, as well as the descriptions of local topography, site geological setting, geological history, depositional environment, and local history of relocations, excavations, and civil works. In addition, the guide may suggest including alternative geological models based on pessimistic scenarios in addition to likely geological models. This is to help raise the awareness levels of geotechnical and civil/structural engineers about uncertainty of the ground conditions.

2. Developing common languages for the expression of the uncertainty of the ground conditions, as well as training and education of such languages. Japan chapter of the AsRTC10 (Asian Regional Technical Committee No. 10 for Geo-informatics; International Society for Soil Mechanics and Geotechnical Engineering) is making an effort to develop such common wordings for the expression of the uncertainty of the ground conditions in the geological models. Such common wordings are beneficial for the improvement of communication among geologists, geotechnical engineers, and civil/structural designers, and help them understand and accept the fact that the geological models doubtless contain the uncertainty of the ground conditions.

3. Accumulating and analyzing case records of the misinterpretation and providing continuing education.

6.2 Role of project owners and project managers

All stakeholders need to raise their awareness to reduce the misinterpretation including geologists, geotechnical engineers, civil/structural designers, project managers, construction engineers, and supervisors, and project owners. The awareness by the project managers and the owners who are concerned with the successful completion of the projects is relevant because they have power to authorize spending money for ground investigations. Besides, the project managers and owners are in a good position to impose procurers for reducing the misinterpretations of the ground conditions on all engineering specialists and professionals participating in the projects. Those measures are:

1. Requesting the geotechnical consultants for their projects to propose plans for reducing uncertainty and misinterpretation of the ground conditions, especially plans for data collections and personnel assignment for geological interpretation.

2. Specifying that the geological interpretative report has to describe the uncertainty of the ground condition, and has to include the geological models interpreted based on likely and pessimistic scenarios.

3. Distributing such geological interpretative reports to all the stakeholders. This will perhaps remind them of the potential geotechnical risks.

4. Establishing project-specific feedback systems for geo-information as shown in Fig. 4. Whenever anyone of the geologists or the geotechnical engineers or the civil/structural designers has obtained new information on the ground conditions during design stages of the projects, it is essential, for reducing the mistakes, to
reevaluate the geological setting of the entire site by sending such information back to the geologists who made the original geological models. The geotechnical engineers and the civil/structural designers can then examine the geotechnical models and civil/structural designs using newly uncovered ground conditions and revise them if necessary. Similarly, the ground conditions revealed during the construction stage may be fed back to the geologists, geotechnical engineers, and civil/structural engineers. These feedback processes could prevent catastrophic results, even if the misinterpretation initially occurred. Only the project managers’ and owners’ strong will to reduce failures caused by the misinterpretation of the ground conditions can make the feedback system to function because such feedback of the geo-information will not happen automatically.

7 CONCLUSIONS

(1) We often misinterpret the ground conditions during the design and construction stages of civil engineering and building projects. The misinterpretation occurs because the ground conditions are usually uncertain to various degrees even after geotechnical site investigations.

(2) Good or poor interpretation of the ground conditions depends on data, human skill, and ground conditions.

(3) To minimize uncertainty of the ground conditions with minimum costs, recommended procedure is a step-by-step investigation with the cyclic process of (a) interpreting ground conditions, (b) investigating the ground, and (c) reinterpreting ground conditions.

(4) In the process of the construction projects, the misinterpretation generally occurs at geological modeling, geotechnical modeling, and civil/structural design, by those who are not well qualified to interpret geological and geotechnical conditions.

(5) If all of us are aware of and alerted to the uncertainty of the ground conditions in general, someone could point out the misinterpretation if made. However, the awareness of the uncertainty varies depending on the people who handle geo-information.

(6) To reduce the catastrophic results caused by the misinterpretation of the ground conditions, keys could be awareness of the uncertainty of the ground conditions and improvement of communications throughout the construction projects by all stakeholders. The following approaches may be worth consideration

- Contribution by geotechnical societies
  - Developing a guide for making geological interpretative reports for geotechnical engineering use.
  - Developing common languages for the expression of the uncertainty of the ground conditions, as well as training and education of such languages.
  - Accumulating and analyzing case records of the misinterpretation and providing continuing education

- Role of project owners and project managers
  - The awareness of the uncertainty by the project managers and the owners is relevant because they have power to authorize spending money for ground investigations. Besides, the project managers and owners are in a good position to impose the following procurers for reducing the misinterpretations of the ground conditions on all engineering specialists and professionals participating in the projects.
  - Requesting the geotechnical consultants for their projects to propose plans for reducing uncertainty and misinterpretation of the ground conditions especially plans for data collections and personnel assignment for geological interpretation.
  - Specifying that the geological interpretative report has to describe the uncertainty of the ground condition, and has to include the geological models interpreted based on likely and pessimistic scenarios.
  - Distributing such geological interpretative reports to all the stakeholders in order to remind them of the potential geotechnical risks
  - Establishing project-specific feedback systems for geo-information as shown in Fig. 4. Only the project managers’ and owners’ strong will to reduce failures caused by the misinterpretation of the ground conditions can make the feedback system to function.

REFERENCES


2) Yuri A., (2016): There are those who are more vicious than Asahi-Kasei, Bungeishunju, 2016(1), 158-167 (written in Japanese)