Construction engineer should play more major roles in sustainability of urban environment

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ABSTRACT

The world trend in the recent decades is characterized by the profound development of science and technology that has drastically changed the civilization and people's life style. In this favorable atmosphere for many fields of science and technology, it appears that geotechnical engineering (GE) is not so highly recognized by the people as other disciplines. In response to this situation, this paper picks up three topics that may help improve it. The first one is ignorance of GE by people because all the GE products are underground and not visible. More efforts should be continued in this respect with emphasis on the remarkable contributions of GE to people's welfare. One of such contributions is the installation of water supply / sewage facilities that drastically reduced the risk of epidemics in modern mega cities. However, such efforts may not be sufficient. So, the second topic is promotion of ground investigation that helps reduce georisk. In conjunction with the Georisk Society, the author interpreted 143 case histories to demonstrate that more investigation efforts bring more profit in construction projects. Clients should be notified of this. The last topic is the importance of direct communication between GE and people. One of the favorable proposals for people is construction of underground water reservoir in arid and densely populated regions. Advantages and disadvantages of underground dam are described based on a case history.

Keywords: Image of geotechnical engineering, georisk management, underground dam

1 INTRODUCTION

The second half of the 20th Century and the first decades of the 21st century saw economic developments in many parts of the world where construction booming drastically changed the appearance of the region. Although those era may be called the happy era of the construction people, negative situations have been encountered at the same time and all the relevant lessons have not been learned. The negative situation are caused by ageing / decay / deterioration of materials, leading to strength loss, instability, abnormal deformation and reduced serviceability. In most cases, the community was not prepared for the incipient ageing problem and relevant reaction was not taken until the occurrence of final emergency. It seems that human nature does not want to pay attention to unfortunate future. However, many lessons have been learnt already and the future engineering community needs to take necessary provisional actions from now on.

The public status of geotechnical engineering (GE) and engineers has been of my major concern in the recent years because I have been and will be serving as the Chair of the Professional Image Committee (PIC) that is placed in the Board of the International Society for Soil Mechanics and Geotechnical Engineering. Despite many valuable and successful infrastructures and structural foundations that have been constructed by GE, the public do not pay much attention to those under the ground surface simply because they are not visible directly. Consequently, those who are working for geotechnical projects are not considered high-tech and sometimes called "dirty". The present paper refers to what the public is advised to do from the geotechnical viewpoint and what geotechnical engineers have to do.

2 CONSTRIBUTION OF GEOTECHNICAL ENGINEERING THAT DESERVE PEOPLE'S RESPECT

It is easy to pick up GE's significant contributions towards development of human civilization and welfare of people. Among them, the most traditional one was good foundations that support the weight of superstructures resting on soft subsoil. Pitiful is that foundation is not visible and people do not pay attention to it. Good performance of foundation is taken to be granted by people, clients and even building engineers for superstructures. It should be noted that there are cases in which foundation exhibits excessive subsidence after completion of the superstructures, which is induced often by insufficient information on soil conditions. Thus, successful foundation requires careful efforts of engineers and should not be taken for granted by people.

Transportation infrastructure is another important GE contribution. Roads, canals, bridge foundations, tunnels, subways, airports and many others are not possible without GE. Contribution of those transportation infrastructures are enormous in the convenience of life and development of global / regional economy. However, very few people relate those infrastructures to GE. In extreme cases, people misunderstand that they were designed and constructed by architects.

Supply of good water and treatment of sewage is a remarkable GE contribution as well. Until early 19th Century, many major cities in the world did not have such water facilities as supply of drinking water and treatment of waste water (Fig. 1). Hence, epidemics propagated among people very easily through water and many patients were killed by food poisoning and infectious diseases. This situation was drastically changed after installation of water infrastructures, and urban environment attracts many people nowadays.

Figure 1 One of the earliest sewerage systems in Paris

3 MY THOUGHTS ON CURRENT SOCIETAL SITUATION OF GEOTECHNICAL AND CONSTRUCTION ENGINEERING

Quality and cost are two important aspects in purchasing ordinary goods. Infrastructure construction and management are not an exception. An essential difference between purchasing ordinary goods and infrastructures lies in the life time; not more than several years for the former while many decades for the latter. Those who purchase PC (personal computer) in a market desire to start using it immediately and will use it for a few years, after which they buy a newer one. In case the purchased PC is not satisfactory, it is possible to buy a better one immediately. It is not necessary to be substantially careful of the quality and the maintenance because PC can be easily replaced. The same holds true for most goods, possibly including expensive automobiles.

In contrast, infrastructures are subject to natural and environmental actions for decades and tend to deteriorate with time. It is seldom possible to demolish deteriorated structures before decades of life. Therefore, significant maintenance efforts and expenditures are needed for a long time. Such efforts and associating expenditures would be reduced most likely if the initial quality of the structure is better. It is often the case in reality that the initial quality is sacrificed in such a community where the construction budget is limited or the increasing population demands a profound amount of new infrastructures. Under such circumstances, maintenance budget is never sufficient. Consequently, the built infrastructures of low quality deteriorate within a short period and their serviceability decreases drastically. The fundamental problem is that many clients who are of strong business mind are not aware of the long life of infrastructures and overlook the importance of the initial quality as well as the continued maintenance.

IMPORTANCE OF SCHEDULED MAINTENANCE AND RENOVATION OF INFRASTRUCTURES

Repeated and scheduled maintenance is essential in many infrastructures and one of the typical examples can be found in river levees. Because levees are often situated on soft soil, the consolidation settlement and consequent deformation are not rare. Plants and animals affect the water-tightness of levees. Accordingly, thus deteriorated levees may not be able to protect the community from flooding. Noteworthy is that consolidation settlement starts in an early stage of the levee's life and this situation is different from that of ordinary goods that exhibit good performance when new. Unexperienced public sector that does not have a GT knowledge but is affected by economic background demand no-maintenance brand-new infrastructures at "as low as possible" cost. This may force engineers to sacrifice the quality and finally the community is damaged by unnecessary flooding. Being different from ordinary goods, infrastructures have to be taken care of continuously and even improved in quality by scheduled maintenance efforts. This idea is similar to what we do in bringing up children.

Figure 2 schematically illustrates the importance of scheduled maintenance for a longer service period and the sustained value of infrastructures. Due to the aforementioned deterioration with time, the value decreases with time. This trend can be changed upon maintenance after which the value is increased. It may be good to practice a fundamental renovation when the societal demands have totally changed and the original shape of the structure is out of date. Then, the value increases substantially. Consequently, the value can be maintained high for a long time. In other words, the Life Cycle Cost (Towhata et al., 2009) or Benefit is an important measure to evaluate the design and construction at the beginning of the life of an infrastructure. It is unfortunate in many countries that projects are given to the lowest (initial) construction cost.

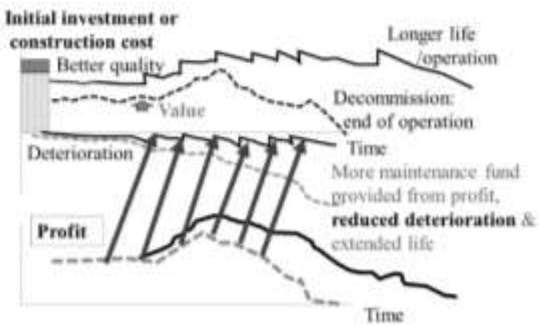

Figure 2 Value of infrastructures improved by scheduled and repeated maintenance

4 WHAT IS GEORISK?

Construction projects are disturbed by many factors among which one of the most substantial problems is called "georisk." Georisk is a problem caused by poor soil/rock conditions that were not anticipated/expected during the period of planning, design and even early stage of construction. During construction, georisk becomes reality and causes extra construction cost and elongated construction period. The problem lying behind georisk is that the subsurface condition is invisible and has to be assessed/judged on the basis of a limited number of ground investigation associated with judgment of experts. It is an unfortunate reality that some clients are not aware of georisk and fully trust the available investigation data. Even worse is that some clients insist of cost reduction and allocate less budget on ground investigation in the early stage of a project. Later, georisk occurs and the total expenditure increases profoundly beyond the reduced investigation cost. Geotechnical accident is an extreme example of georisk.

The author has been studying georisk and its management in collaboration with the Georisk Society (http://www.georisk.jp/?page_id=13). According to this society, there are three types of georisk management which is an attempt to reduce the negative effects caused by unexpected poor ground condition. The first type is a successful management (type A) in which a problem is expected before initiation of construction (in the planning and design stage), additional ground investigation is conducted, based on the result the design and construction process are modified, and the project is completed successfully. This successful georisk management of this type often reduce the total construction cost and, sometimes, shorten the period as well.

The georisk management of type B is an unsuccessful case in which the detection of georisk is too late and cost/time deficits are substantial. It is herein possible to compare the total cost/time against those of the imaginary case in which georisk management would have been started well in advance so that the importance of better georisk management may be evaluated.

The georisk management of type C is an intermediate case in which georisk is anticipated during the early stage of construction, necessary management is conducted and a catastrophic consequence is avoided. The necessary management includes additional ground investigation and change of design. In fortunate cases, the additional ground investigation reveals that the risk is unlikely to occur. The value of georisk management is evaluated by comparing the total cost and time caused by the worst scenario and the real ones.

The Georisk Society has organized annual symposia on georisk since 2010 and the content of the following chapter is based on the information published in the symposia.

5 IMPORATANE OF GEORISK MANAGEMENT

The Georisk Society has organized annual symposia on case histories of both successful and failed risk management and provided detailed information quantitatively. While the Society has summarized the details of cost and construction period, the author re-interpreted all the cases and presents his view in this chapter.

One successful georisk management is found in the foundation design of a bridge that connects an offshore Kitakyushu Airport Island and the mainland of Japan (Watanabe, 2008). Being 2100 m in length of the offshore part, the original design proposed end-bearing piles that reached deep stiff layer (Fig. 2). This design was based on conventional SPT data. Because the pile length was typically as long as 50-70 m, an alternative design of shorter friction piles was proposed. Hence, the second kind to design was made on frictional piles based on SPT data. Furthermore, by running additional ground investigation, the length of friction piles was made shorter; even shorter than the design length based on SPT. The additional investigation cost was US 2 Million $ and the construction cost saving was 100 Million $ (Fig. 3). Thus, the cost-benefit ratio is 100/2 = 50. This case is classified into "type A".

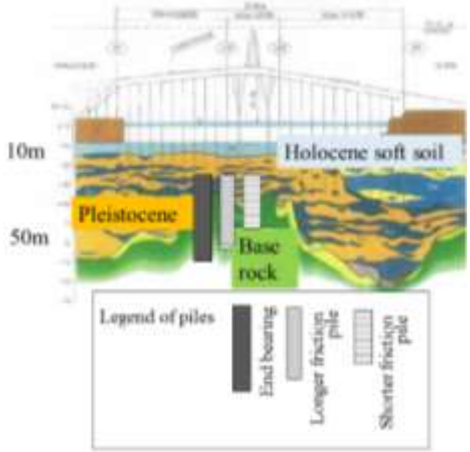

Figure 2 Conceptual sketch of the airport connecting bridge (after Watanabe, 2008)

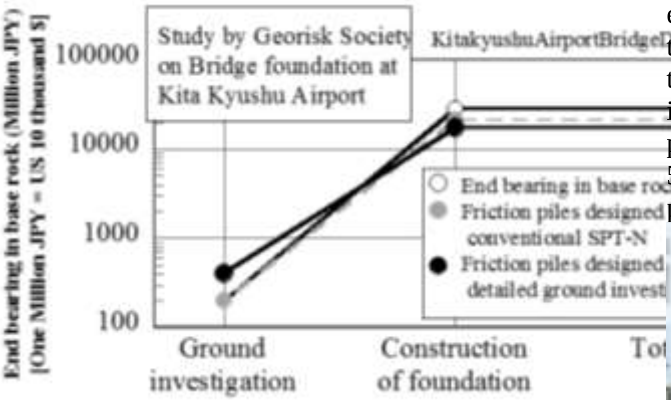

Figure 3 Cost reduction by reasonable ground investigation for foundation of bridge connecting Kita Kyushu Airport with main land (Watanabe, 2008)

Since 2013, the author has been a chief advisor of ground improvement project in Urayasu City where significant seismic liquefaction affected residential areas and mitigation (underground slurry grid walls; Towhata, 2019) was intended to be installed under existing houses. Considering the fragile structure of houses, the grid-type underground wall was designed so that cyclic shear deformation during earthquakes might be reduced. For this purpose, small jet grouting machine was developed so that ground improvement might be possible in a narrow space between houses (Fig. 4). With ample financial supports from public sectors, the construction cost per house was US 50,000 $ in which 1/3 was charged to individual residents. The remaining cost was provided by national and local governments on the condition that unanimous agreement on the project should be made in districts with, e.g., 50-200 families. Despite the high cost, about 500 families were officially accepted to the project and ground improvement started by using jet grouting machines. Thereafter, an unexpected trouble stopped it in early 2017 when preliminary construction was going on.

The problem was that many plastic drains had been installed in clayey parts of the area when the island was constructed on 40-meter-thick soft clay deposits in 1960s. To promote the consolidation settlement, plastic drains had been installed at an interval of approximately 1.5 – 2 meters. Those drains were caught by jet grouting machines and hindered the flow of grout (Figs. 5 and 6). Because underground walls had to be constructed in the clayey part for the overall stability of the grid wall, the number of grouting was increased to twice or even three times in clayey parts (Towhata, 2019). Accordingly, the cost and construction period increased drastically. The cost per family increased to US 300,000 $ that includes that for improving the public space (ground under streets) as well, and public sectors decided to shoulder all the increased cost, without increasing the personal payment. However, most people did not accept the elongated construction period of 5 years and declined the project. Consequently, only 40 families accepted the project and underground grid wall was completed in early 2019. Although many dynamic cone penetration tests were run at a typical interval of 50-100 m for this project, they could not detect the plastic drains.

Figure 4 Ground improvement by jet grouting in a narrow space

Figure 5 Jet grouting machine whose operation was stopped by plastic drains

Figure 6 Plastic drain that disturbed jet grouting

One more negative example occurred in Fukuoka City, Japan, in 2016 when ongoing subway construction at shallow depth caused caving of the surface (https://www.youtube.com/watch?v=1KYTXQXe5Ls). An official investigation (Investigation Committee and PWRI, 2016) concluded that an impervious layer above the tunnel depth was supposed to bear the ground water pressure near the surface, that its thickness was not uniform, and that the thinnest part failed when tunnel excavation came below it (Fig. 7). Thus, more detailed ground investigation could have detected the weakest point and helped avoid the disaster. Another issue is that one of the past projects at the same place had recognized the variation of the impervious layer and that a senior engineer left a caution to future projects. This lesson had not been transferred to the next generations.

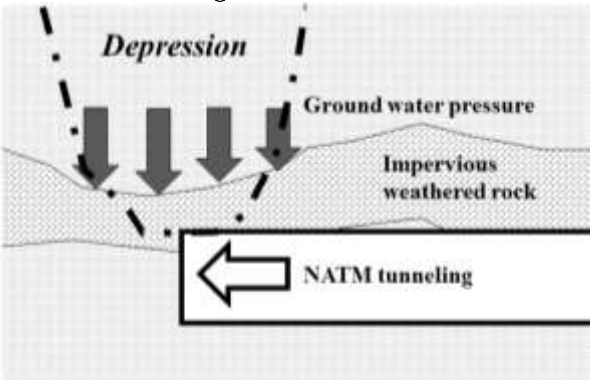

Figure 7 Schematic illustration of mechanism of tunnel collapse

6 CASE HISTORY STUDIES ON GEORISK MANAGEMENT

Based on many experiences as described above, it is reasonable to state that more detailed ground investigation can reduce the onset of georisk. To make this point more evident, the author has collaborated with the Georisk Society that has been collecting many case history records that are classified into the abovementioned three types; A, B and C, depending on the extent of success of georisk management. The author studied those records collected from 2010 to 2018 and re-interpreted all of them. Fig. 8 illustrates the distribution of 143 studied cases; kinds of construction projects and their types. Most cases of tunnel construction belong to the “successful georisk management” of type a probably because experienced site engineers anticipated problematic geology and set up relevant measures well in advance. In contrast, many projects on slopes are classified into types B and C.

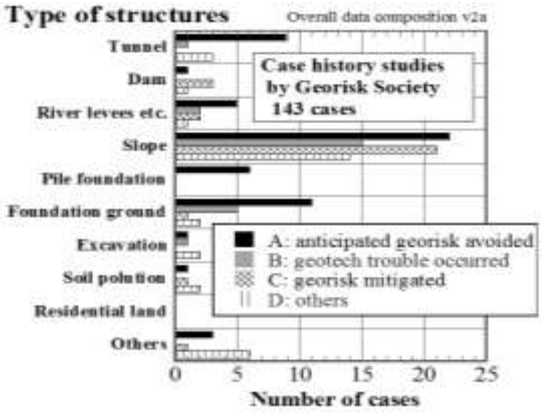

Figure 8 Summary of studied cases

(a) Successful georisk management (Type A)

This section addresses those cases in which georisk was anticipated well in advance and necessary measures were taken. Those measures consist of additional ground investigation and, if necessary, change of design. Hence, the real total cost was less than the imaginary cost that would have been needed when risk management had not been taken. Fig.9 compares these costs. In some cases, the supposed risk was ruled out by detailed investigation, no further georisk management was taken, and, accordingly, two costs become very similar to each other. Then, the remaining majority of cases demonstrates successful cost reduction by georisk management.

Figure 10 illustrates the profit (the-worst-scenario cost without risk management – real cost) achieved by the successful georisk management over the original cost. The ratio > 1 means that the possible georisk was huge but was avoided by appropriate management. In this figure, there is no consistent correlation, which means that good profit ratio is possible irrespective of the size of the project.

Figure 11 indicates the kinds of ground investigation technologies that were employed in successful georisk management. It deserves attention that additional drilling of bore holes and laboratory soil tests on undisturbed specimens were important therein. This suggests that more detailed studies on both non-uniform ground conditions and stress-strain-strength properties of problematic geomaterials were important.

Figure 12 exhibits the correlation between the additional ground investigation and the obtained profit. While all types of risk management (A, B and C) are plotted, it is evident that the greater budget (effort) for ground investigation increases the profit. Noteworthy is that the obtained profit in most cases is not only positive but also greater than the expenditure on ground investigation. The meaning of profit for types B and C will be explained in later sections.

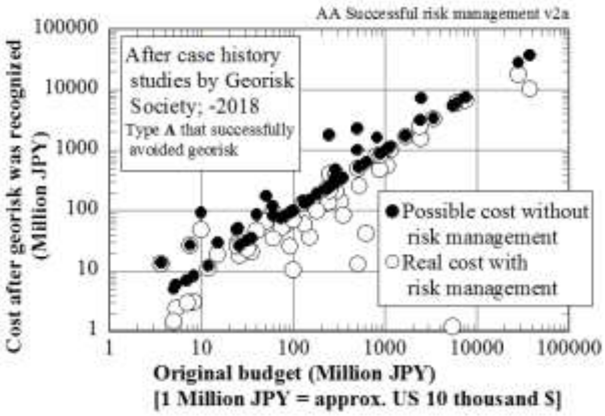

Figure 9 Comparison of original budget and expenditures after recognition of georisk (Type A; successful georisk management)

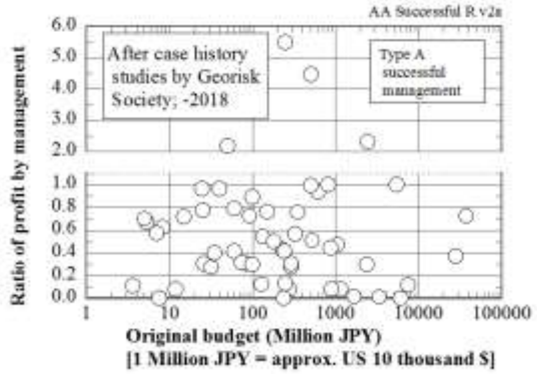

Figure 10 Ratio of profit by successful georisk management (Type A) over the original budget

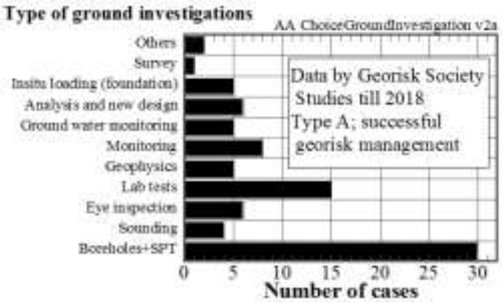

Figure 11 Kinds of ground investigation that contributed successful georisk management (Type A)

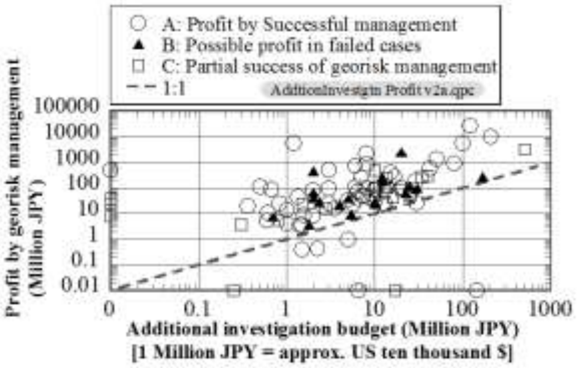

Figure 12 Correlation between budget for additional ground investigation for georisk mitigation and the obtained profit (all types of A, B and C)

(b) Failed georisk management (Type B)

This section address the cases in which unexpected georisk affected the project and the total cost increased beyond the original budget. Figure 13 compares thus increased cost and the possible reduced cost if risk management had been reasonably performed. Then, the possible profit of georisk management was calculated by subtracting the "reduced" cost from the increased cost. Fig. 14 plots the ratio of this profit over the original budget. It is seen herein that there is no clear trend but that a significant ratio of profit would have been possible if reasonable georisk management had been taken in early stage. Fig. 12 illustrated that greater profit would have been possible if more efforts had been made on additional ground investigation.

Figure 13 Comparison of original budget and expenditures after recognition of georisk (Type B; failed management of georisk)

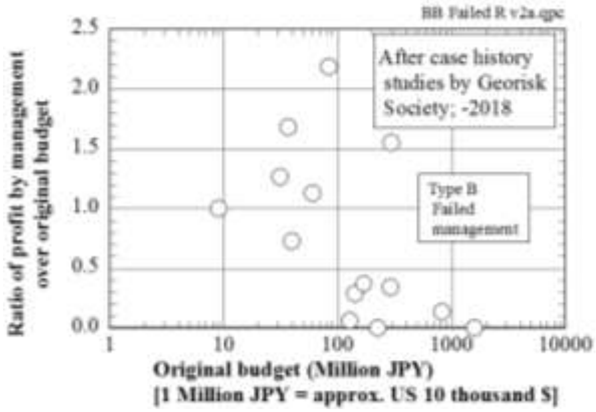

Figure 14 Ratio of profit by successful georisk management (Type B) over the original budget

(c) Georisk management in an intermediate stage (Type C)

In this section, those cases in which georisk was found in the early stage of projects and relevant management was carried out by running additional ground investigation. Accordingly, the total construction cost became greater than the original budget but a catastrophic consequence was avoided. Fig. 15 shows that the increased real cost was lower than the cost of the worst scenario in which georisk management is not made. Then, the possible profit of georisk management was calculated by subtracting the real cost from the worst cost. The ratio of this profit over the original budget is indicated in Fig. 16. See in this figure that there is no clear trend again but that a significant ratio of profit is made possible by appropriate risk management.

Throughout the types of A, B and C, Fig. 12 demonstrates that the greater effort towards georisk management (ground investigation) helps increase the profit. Another issue is that the author noted many occurrences of georisk in cut slopes where joints are normal to the cut surface (Fig. 17). Because the orientation of joints prevents slide movement, engineers tend to feel safe and do not pay much attention to the slope instability. In fact, weathering and deterioration of rock are promoted by infiltration of water that comes in through joints, and slope instability is induced (Fig. 17).

Figure 15 Comparison of original budget and expenditures after recognition of georisk (Type C; georisk management in an intermediate stage)

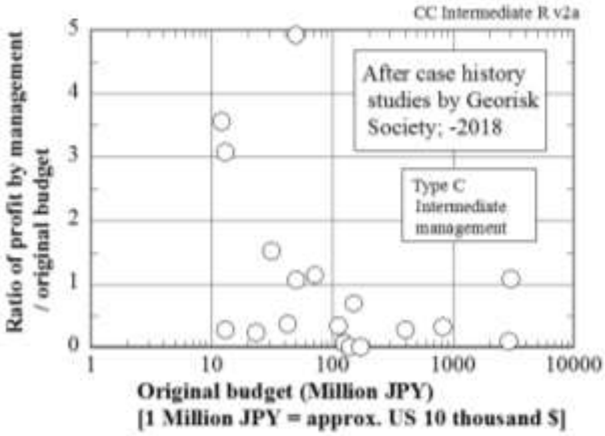

Figure 16 Ratio of profit by intermediate georisk management (Type C) over the original budget

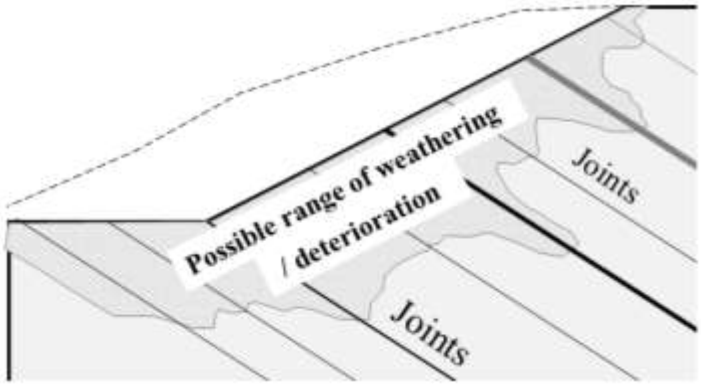

Fig. 17 Schematic diagram of instability in a cut slope

7 ON ENGINEERING PROPOSAL FOR BETTER FUTURE OF HUMAN

GE has made a huge amount of efforts for its successful practice, aiming at satisfaction of clients. As stated before, people do not recognize GE yet because they are not the target of the efforts. It is certainly important in this regard for GE to demonstrate directly to people its significance and contribution as illustrated in Fig. 1. The question is whether or not such efforts are good enough.

The author is suspicious about this point. It should be recalled that other fields of science and technology have been doing the same public demonstration more successfully. Accordingly, the importance of Information Technology, Robots, Bio-technology and many others are well recognized by the people. The fundamental difference between those successful fields and GE is that their activities can directly affect/improve people's life style and even the human civilization, while GE cannot; only clients are satisfied ant people do not know GE.

In the business perspective, satisfaction of clients is important. It is certainly good enough for successful business. The point is whether or not GE wants to improve its image among people. If the answer is YES, GE needs to do something more. GE needs to provide a future scope of people's life style and human civilization.

The author is thinking of development of new water resources in arid and populated countries. Water shortage is becoming more serious in arid countries and regions where population is increasing quickly. The existing water resources are under strict control and it is very difficult to change the rights of stake holders. In this regard, it deserves attention that a huge amount of ground water is flowing from the coast out into the sea and that there is no owner/right of this water because it becomes salty water. Hence, collection of this water resources before it becomes salty is an interesting topic. Fig. 18 illustrates the concept of an underground dam that is constructed in a pervious layer near the coast.

The technology of an underground dam is not new.

Nilsson (1988) summarized the situation of many small underground dams in Africa and India. In more recent times, bigger dams have been constructed in Miyako-Jima Island in Japan where available water resources was only 10% of the annual precipitation of 2200 mm. The problem is that most surface water infiltrates into the pervious limestone layer and does not stay at the surface. The infiltrated water directly flows into the sea. To stop this flow, several dams have been constructed. Fig. 19 shows one of the facilities.

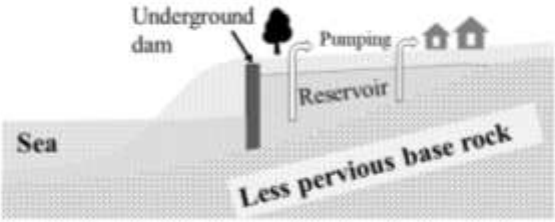

Figure 18 Schematic illustration of underground reservoir in coastal area

Figure 19 Facility for monitoring ground water level in underground reservoir (Minafuku, Miyako-Jima Island, Japan)

Figure 20 Ground surface without appearance of underground dam (upon the crest of Sunagawa or Uruka underground dam in Miyako-Jima Island, Japan)

The advantages and disadvantages of underground dam are as what follows (monthly magazine of Japanese Geotechnical Society, 1982).

Advantages:

- Sandwiched by ground on both upstream and downstream sides, underground dam does not need high mechanical strength. Big underground dams have been constructed by sheet pile walls or cement mixing of soil.
- It does not affect land use at the surface; no dam is visible at the surface in Fig. 20. No community is submerged in reservoir.
- Quality and temperature of dam water are held constant.

Disadvantages:

- Detailed subsurface investigation is needed to capture the local geology and geohydrology. This is actually an opportunity for GE to show its ability.
- Salty water may remain in the reservoir of underground dam along coast.
- Careful environmental assessment is necessary.
- Community has to make efforts to avoid ground water contamination by reducing fertilizer in agriculture and waste water discharge from families: need for collaboration of community. The community in Miyako-Jima Island has been successful in this respect.
- Energy is spent on pumping ground water.

Moreover, Taiwan has enjoyed water supply from an underground dam since 1920s as well (Ting and Wang, 2008).

8 CONCLUSION

This paper addresses the worldwide improvement of the professional image of geotechnical engineering (GE). The major conclusion drawn from recent discussion and studies are summarized in the followings.

1. GE has made significant contributions to the welfare and happiness of human communities. The problem is that people are not aware of them.
2. Georisk management is a good way to appeal the value of GE to clients.
3. Appeal to clients is not sufficient to improve the image. It is important to directly propose to people the future of life style and human civilization that can be made possible by GE.
4. One of the proposals in this direction may be construction of large underground dams in arid and densely populated regions in the world.

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