Geotechnical Engineering Accompanied by Risk

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Abstract. Geotechnical construction encounters many unexpected troubles and one of the important reasons for this is the lack of subsurface information and knowledge. This paper calls the troubles “georisk” and exhibits that more subsurface investigations have to be practiced in order to reduce this risk. Case history data was interpreted as a collaborative work with several institutions and it was demonstrated that the risk can be mitigated by allocating more budget to the investigation. Another source of risk is the lack of knowledge and one need to pay more attention to the history of troubles that were experienced during projects in the past.

Keywords: Georisk, Cost, Soil Investigation.

1 Introduction

The engineering industries in the second half of the 20th Century was characterized by mass production in which both amount and quality were maintained at high levels. This type of engineering achieved such a great success that people nowadays take the success as normal situation. However, we need to get recalled of the situation in the previous times when most daily goods were produced by hand in a small scale, in response to individual client’s order. Naturally, each client had different orders and the production changed from time to time. Having disappeared nowadays from most fields of engineering, this “make-to-order (MTO)” practice remains universally in construction projects. In the era of mass production, people and the social system are not accustomed to MTO and many conflicts/inconveniences are induced in construction.

Geotechnical engineering is fully accompanied by MTO obviously because of the following reasons;

- Soil and rock condition is never uniform in both horizontal and vertical directions. There is no couple of sites with exactly same subsurface conditions.
- Subsurface investigation relies on skill of individual technicians. Different results and interpretation may occur on very similar subsoil. Accordingly, the assessed bearing capacity, stability and deformation change and affect the design details as well as construction procedures.

This situation results in unexpectedly increased cost and longer construction period. This is particularly the case when unexpected subsoil condition is detected during design or construction. This is called “georisk” in this paper. People are not familiar with georisk. From the viewpoint of high-level mass production, they accuse geotechnical engineers of the consequence of georisk.

Georisk is not a new topic. MacDonald [1] stated that the overrun cost was 23% or more in over half of 58 highway projects and showed that more subsurface investigation efforts reduces the overrun more efficiently. It was also shown that only 1/4 of projects kept the overrun within 10%. By referring to this paper, Clayton [2] stated that detailed soil investigation is meaningful in some projects with good returns. It was also pointed out by him that there are other kind of projects in which existing information and expert opinion are essential.

Another difference between mass-production and civil/geotechnical engineering products is the longer life time of the latter. While cars and electric tools are used for several years only, the latter is used for decades or centuries in which the materials are subject to ageing or deterioration and the external actions may become more serious than expectation. People are not much informed of such negative-condition and would tend to feel unhappy against the construction sectors many years after the completion of their structures.

2 Example of Georisk

The most famous example of the consequence of non-uniform subsurface condition is shown in Fig. 1. Although this tower is making a marvelous contribution to the local tourism today, its leaning has been taken seriously by engineers over centuries [3]. Obviously, there was no soil mechanics and subsurface investigation technology when this tower was planned and constructed. Hence, nobody accused of the unexpected leaning of this tower. In contrast, there are more examples of leaning buildings today that have caused safety and financial conflicts between owners and project developers, designers and contractors. Whoever may be responsible for the problem, the unexpected leaning and subsidence are the consequence of insufficient information on subsurface soil/rock conditions. It may be said that more concern on underground uncertainty had been necessary.

The second example is taken from the falling of street surface into ongoing metro tunneling (Fukuoka City, Japan, 2016). This tunnel was constructed at shallow depth by using the New Austrian Tunneling Method. The official investigation committee concluded that this accident was caused by collapse of an impervious layer above the crown of the tunnel that was locally thin and could not sustain the ground water pressure above it [4]. Another point was addressed to the insufficient subsurface investigation that could not find the critically thin part of the impervious layer. Furthermore, this site had been known over decades before the accident for the varying thickness of the impervious layer and one of the engineers who used to work there called upon his successors of this risk. It seems, however, that this important information was not transferred after years.

The third example comes from Urayasu City, Japan, where, after the 2011 Tohoku earthquake of Mw=9.0, ground improvement was carried out as mitigation of future liquefaction disaster. During the preliminary stage of jet mixing, unexpected plastic drains (Fig. 2) were encountered and the in-situ mixing of cement and soil was prevented. Those drains had been installed during the land construction in shallow water in order to accelerate the consolidation settlement. The existence of those drains had been forgotten afterwards and caused a serious problem in 2017. Although the procedure was improved to overcome this problem, the cost and the construction period increased substantially. The national government decided to provide additional fund to cover the cost increase. However, the elongated construction period was not accepted by the local community and the size of the project was significantly reduced [5].

These examples indicate the problem of underground uncertainty that have caused and is causing many problems in the construction practice.

Fig. 1. Leaning of tower induced by different soil conditions under the foundation

Fig. 2. Detected plastic drain that affected procedure of jet mixing.

3 Example Problems Caused by Age

It is widely believed that soil has eternal life as a construction material and this belief has been supported by experience. However, it must be recalled that some kind of rocks and rock-forming minerals are subject to weathering by which mechanical strength of materials decays with time. Asada [6] collected SPT-N values from residential embankments of different ages and exhibited that the range of SPT-N value decreased with increasing age (Fig. 3). This finding suggests ageing of soil in the embankment. It seems that the same problem occurs in natural slopes and affects the stability of slopes as well as anchors and rock bolts.

Moreover, deterioration of aged infrastructure is often encountered. Fig. 4 illustrates one of the examples in which an aged sewage pipe had been broken as shown here, ground water had flowed into this broken pipe, the backfill soil had been eroded by this water flow, a big cavity had developed and finally the sidewalk surface fell down suddenly into the cavity. What is significant in these examples is that one cannot find the ongoing underground problem until the ultimate failure happens.

Deterioration of (geotechnical) structure is induced by the customer's lack of knowledge of nature. At an anonymous place, a small valley was filled with soil. At this moment, the client did not have a clear idea about the future use of this site. Because valley is a place where stream water flows and also ground water comes in from mountains, the ground water level in the fill gradually rose. Before the water level became very high, the client decided to use the fill for a factory. The construction project was given to another contractor who was not informed of the history of fill construction. During this phase, the water level reached the critical level and the embankment deformed substantially. The contractor had to install stabilization measures with its own expense, while the client refused to pay, saying that completion of the project was the responsibility of the contractor.

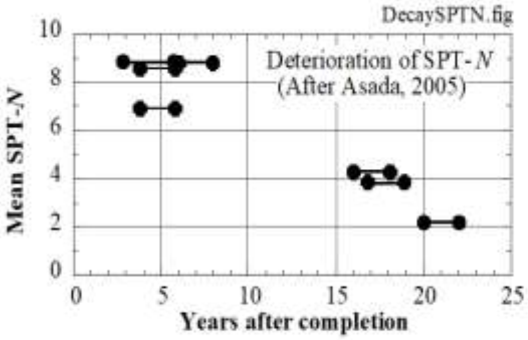	
Fig. 3. Decreasing of SPT-N value in residential embankment.	**Fig. 4.** Collapse of sidewalk induced by deteriorated sewage pipe.

4 Need For More Detailed Geotechnical Investigation

The preceding two chapters indicated that many troubles, which are called georisk herein, have been induced by insufficient subsurface information. Different from manufacturing in modern industries in which materials are subject to quality check, the ground condition is never uniform and has never the quality examined. Moreover, the material cannot be checked by eye inspection due to invisibility of the underground space. In this respect, the number of subsurface investigations is as important as the quality/ accuracy of individual investigation.

The Georisk Society in Japan has been organizing annual conferences since 2010, focusing on the importance of subsurface investigation in reducing georisk in a variety of construction projects. Respecting this effort, the author has been collaborating with this society and re-interpreted the case history data. This chapter addresses the findings from this activity.

First, the Georisk Society introduced a successful project of bridge construction (Fig. 5) in which the bridge pier design was improved by detailed subsurface investigation [7]. The bridge connected the Kita-Kyushu Airport Island with the main Kyushu Island of Japan, having 2.1 km in length with 28 piers underneath. Because the local geological condition was not uniform, the traditional pier design proposed different and substantial depth of end-bearing piles. The traditional design was based on SPT-N value. To reduce the cost, it was attempted to design friction piles with shorter length that were designed either by SPT-N again or additional detailed investigation. Finally, the data from detailed investigation enabled the shortest pile length and the construction cost was drastically reduced. According to the above-mentioned report, the investigation cost increased from the original US 1 million $ to 3 million $, while the construction cost was reduced by 100 million $. The cost-benefit ratio of 100/(3-1)=50 was very good.

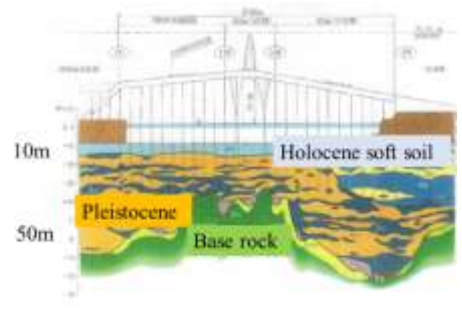

Fig. 5. Kitakyushu Airport Bridge constructed on complicated subsurface condition [7]

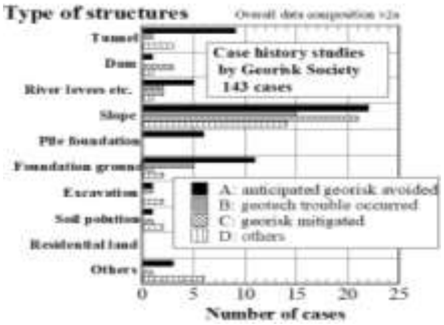

Fig. 6. Composition of Georisk Society's case history study

Second, the composition of the 143 case-history data in the Georisk Society's study (2010-2018) is shown in Fig. 6 where the studied types of construction consist of tunnels, dams, levees, excavation, pollution etc. while the majority consists of slope instability and foundations. The author found during his comprehensive review that a good number of georisk occurred in cut slopes in which the geological structure (stratum) was normal to the slope surface (opposite dip). Possibly, instability was not cared in such a stratum before cutting but the material deterioration due to water percolation was found later. It is one of the points to show that geometric investigation was not enough and that subsurface investigation on mechanical properties was needed.

The Georisk Society classified the studied cases into 4 groups that are namely

- Group A: Original design was over-conservative and additional ground investigation helped reduce the cost (59 cases),
- Group B: Risk (trouble) occurred during project and countermeasures increased the total cost (24 cases),
- Group C: Risk was anticipated during early stage of project and mitigation helped avoid the catastrophe (29 cases), and
- Group D: Detail is not clear (31 cases).

The following discussion addresses Groups A-C with more detailed information.

4.1 Group A With Successful Risk Management

This group addresses the successful cases in which the possible georisk was anticipated or measures to remove unnecessary conservatism was found. Hence, more detailed investigation was carried out with additional budget and the risk was avoided or total construction cost was reduced. It is noteworthy that, although cost was reduced, the construction period was scarcely shortened probably because contractors and clients wanted to keep things going as scheduled. Fig. 7 compares costs when georisk was (○) or was not (●) avoided by relevant (additional) subsurface investigation, which is otherwise called georisk management. The costs are plotted against the original construction budget that was planned before finding the risk. Evidently, the cost was reduced. Then, the ratio of profit by management is defined by

Profit ratio = [(Total cost without additional investigation, including damage by georisk) – (Total cost after relevant management)] / (Costs for additional subsurface investigation, changing design etc.) (1)

This ratio is plotted against the original construction budget in Fig. 8. There is no clear correlation between the ratio and the budget (size of project). Noteworthy is that the profit ratio may reach 2.0 or more but that the ratio < 1 still contributes to the project.

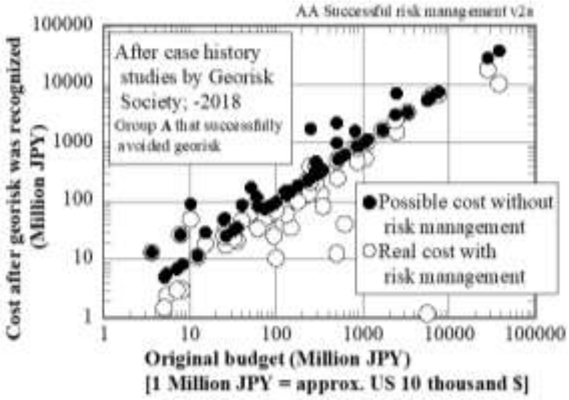

Fig. 7. Comparison of cost with and without successful risk management (Group A)

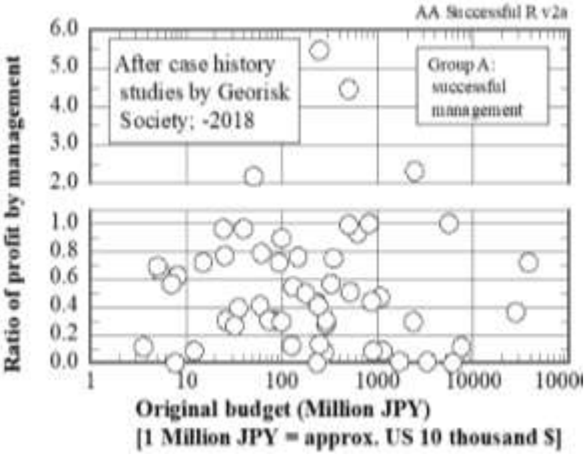

Fig. 8. Profit ratio versus original construction budget (Group A)

Fig. 9 plots the profit divided by the original cost against the worst-scenario cost that would have been increased if georisk had not been managed. The size of the worst disaster does not have a correlation with the plotted ratio. The ratio = 1 means that the entire project was canceled to avoid the risk. While some projects reveal smaller values of the ratio, it is very possible to attain the ratio > 0.5. Finally, Fig. 10 demonstrates the types of additional subsurface investigation after finding the possibility of georisk. The majority is borehole drilling and standard penetration tests partly because of the tradition of the engineering community (SPT is the must in practice) but also because the number of boreholes is considered important in heterogeneous subsoil. Note also that laboratory soil testing is important because, if conducted on samples of good quality, the soil properties can be more directly determined than assessing by means of sounding data (SPT-N etc.).

Fig. 9. Ratio of profit and original project budget plotted against total cost after possible risk manifestation (Group A)

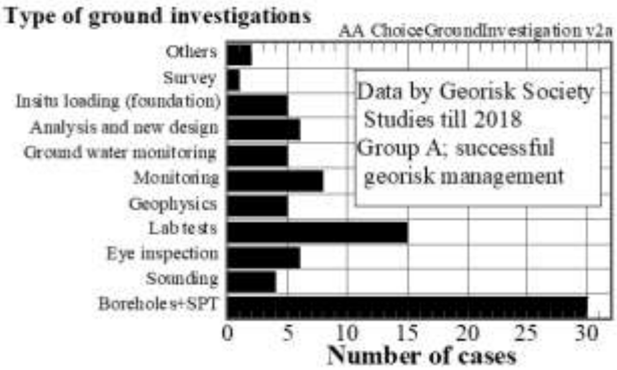

Fig. 10. Types of investigation employed for georisk management (Group A)

4.2 Group B in Which Georisk was not Avoided and Cost Increased

This group stands for the failure of georisk management. The risk occurred during the construction and the needed response resulted in increased cost or elongated construction period or both. In this group, it was attempted to assess the hypothetically reduced cost if georisk management had been performed. Fig. 11 compares the real cost increased by georisk and the hypothetically reduced cost. Certainly, the former is greater than the latter. The relative difference (ratio) between these costs decreases as the size of the project (original budget) increases possibly because the influence of one georisk becomes smaller in bigger projects. The difference between these two costs is defined as the (possible) profit obtained from georisk management, although it did not happen in reality. Fig. 12 indicates that the profit / original budget may take the maximum at the intermediate size of the project and decrease afterwards. This again implies that the influence of single georisk is not very large. Fig. 13 examines the relative extent of the missed profit either over the total cost increase (real cost – original budget) or the possibly reduced cost if georisk had been reasonably managed. There is no clear trend in this diagram but there is always a possibility to achieve the high ratio of 0.5 or greater.

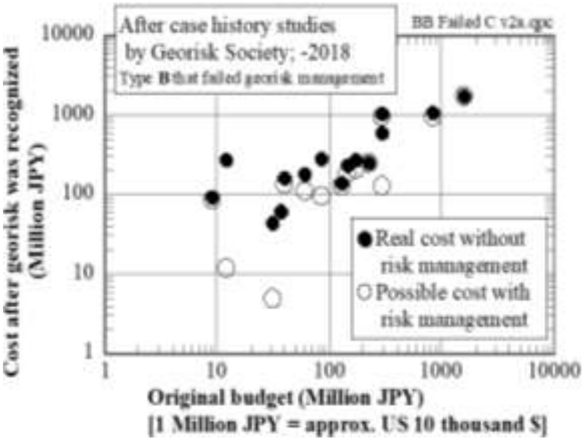

Fig. 11. Comparison of real cost increased by georisk and possible cost reduced hypothetically by missed risk management (Group B)

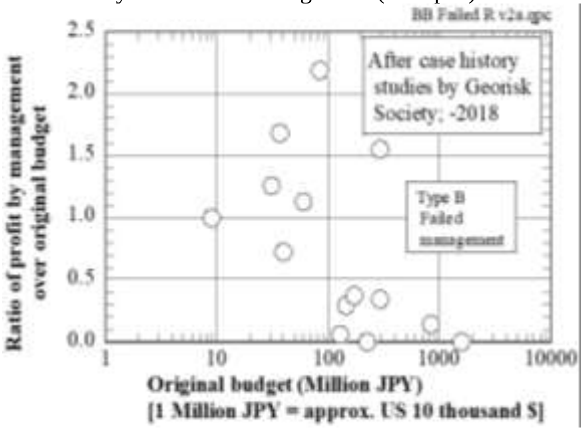

Fig. 12. Relative profit and size of project (Group B)

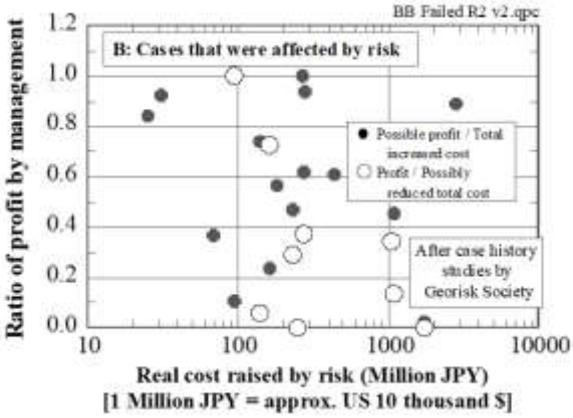

Fig. 13. Ratio of profit over two types of costs versus real cost increased by georisk (Group B)

4.3 Group C in which Georisk was found in the Intermediate Stage of Construction and was Partially Avoided

Group C is composed of the projects in which georisk was detected after the construction has started. In other words, risk was not fully mitigated but appropriate management by additional subsurface investigation and changed design reduced the total expenditure to some extent. Thus, Group C is called partial success.

Figure 14 compares two types of cost; the hypothetical cost without risk mitigation and the actual cost that was achieved by mitigation. In three cases, the actual cost was made successful by risk management, although the success remained partial. In the three best cases, the reduced cost was less than the original budget. Fig. 15 indicates the ratio of the profit (difference between the worst-scenario cost without management – real cost) over the original budget. It is possible thus to achieve a very good ratio of profit. Fig. 16 illustrates that the profit ratio over the hypothetical worst-scenario budget (without management) is not much related with the real cost after georisk management. It is implied that significant cost saving is possible even if georisk is detected during ongoing project.

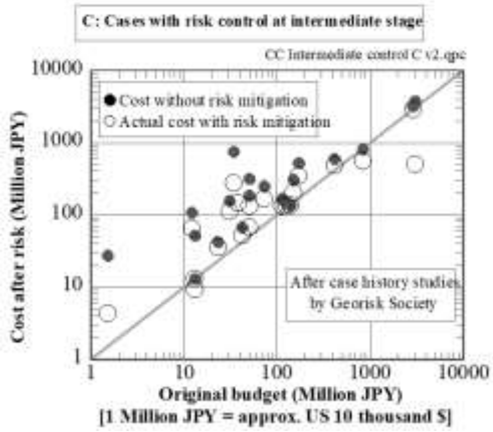

Fig. 14. Relationship between costs with and without georisk management and the original construction budget (Group C)

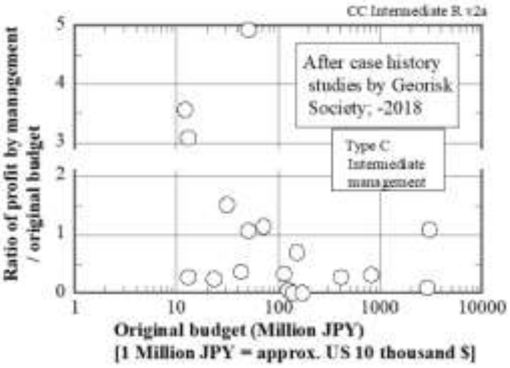

Fig. 15. Ratio of profit in Group C changing with the original budget

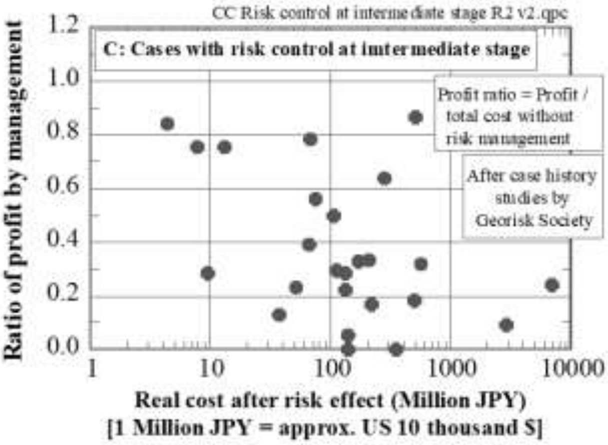

Fig. 16. Ratio management profit over total cost without management

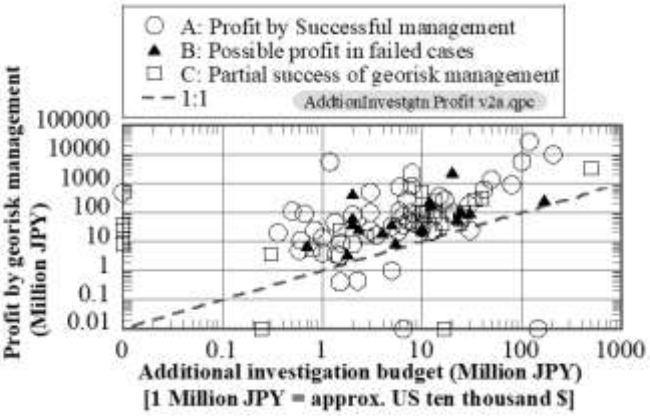

Fig. 17. Overall summary on profit of georisk management changing with cost for additional subsurface investigation (Groups A-C)

5 Complicated system of Nature

This chapter makes a brief remark on georisk of insufficient knowledge on nature. Because the size of construction projects increases in the recent times, their impact in nature becomes significant as well. Accordingly, there is a risk that unprecedent catastrophe may occur. Most probably, this risk in future is related with environmental issue.

Melting of glacier is one of the possibilities. Note that the disaster of Mattmark Dam in 1965 was caused by glacier melting [8]; Fig. 18. In 1960s, melting of glacier was not recognized as risk. Similarly, there may be a future risk about which we are not serious yet.

Fig. 18. Site of fallen glacier at Mattmark Dam site (this photograph taken in summer, 2010)

6 Conclusion

This paper addresses problems that are encountered in geotechnical engineering projects. At this moment, the most common problem is the one caused by insufficient information about subsurface conditions. By referring to case history studies, the importance of more detailed subsurface investigation was proposed. Moreover, the lack of knowledge on past projects and nature may cause further unprecedent problems. In this respect, optimism should be refrained from.

7 Acknowledgement

The present study on georisk management was carried out as a collaboration among the Japanese Geotechnical Society, the Georisk Society and the Japan Geotechnical Consultants Association. The case history data was collected by the long-term efforts of the Georisk Society. The author expresses his deepest appreciation to these institutes as well as Prof. T. Watanabe who is the President of the Georisk Society.

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