Proposal of Japanese Geotechnical Society for More Reliable Installation of Prefabricated Piles

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ABSTRACT

The construction community in Japan has recently been jolted by tilting of one condominium building that is said to rest on insufficient length of prefabricated piles. Although the legal issue is unclear yet, the developer and the contractor decided to demolish the entire condominium complex, including four intact buildings, and reconstruct them on the companies' own expense. The governmental section in charge is calling on the importance of construction quality management. It is actually true that the extent of tilting is merely 2 to 3 cm over the building length of 56m but it stimulated the concern of the entire public. The Japanese Geotechnical Society established a special committee to shed light on the social aspect of this problem and has been discussing that the subsurface investigation needs to be conducted more elaborately in order to capture the non-uniform soil conditions. It deserves attention that the importance of geotechnical information is not understood by the society, resulting in many unnecessary troubles.

INTRODUCTION

This paper addresses an incident of a condominium building in Yokohama City, Japan, that was constructed in 2007, was of 10-12 stories and later subsided unexpectedly (Fig. 1). The differential subsidence was detected by residents in November, 2014. According to many public reports, differential settlement between two neighboring condominium buildings was about 2cm while the length of the affected building was 56 m. Thus, the gradient of tilting is 0.02m/56m = approximately 0.04 %. Although many discussion and documents have been published since then, no final conclusion has been reached yet. Hence, the present paper is of an intermediate nature and cannot provide sources of all information.

Figure 1. Subsided building in Yokohama

Situated upon very soft soil deposits along a river, the buildings were supported by prefabricated RC piles that were constructed by first drilling holes by augers down to the bearing layer (soft mud stone), embedding prefabricated piles and reinforcing soils around the pile tips by injection of cement slurry that is mixed with soil (Fig. 2). Note that the pile tip should be embedded in the bearing layer by 1 m or so. The depth of the bearing layer could be determined by monitoring electric current of the auger motor. It is suspected that some piles were not long enough to reach the bearing layer (8 out of 28 studied piles). The insufficient pile length requires additional piles to be designed, fabricated and connected to the lower pile, which takes additional days for pile completion. The problem was worsened when the urgent investigation detected that many construction records (electric current and flow amount of cement slurry) had been lost or replaced by irrelevant ones copied from other piles. Thus, the reliability of construction community was seriously affected. Although the final conclusion on the cause of settlement has not been drawn when this manuscript is written (November 2016), many discussion has been made on data abuse. The developer and contractors of the condominiums decided to reconstruct 5 buildings in the complex free of charge for the residents, although only one of them tilted.

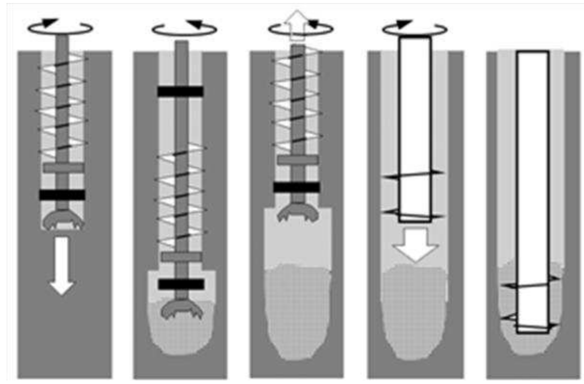

Figure 2. Construction sequence of prefabricated pile foundation (Drawn after JSCA)

In response to this problem, an intensive study was conducted by officials of the data recording practice and site engineers said that they had been copying data from other piles many times in the past due to inconvenient nature of the recording devices. The investigation, however, did not find any other building tilting in spite of construction by the same companies. The problem has been made more complicated by the multistoried structure of the project in which many companies are involved (Fig. 3). The real pile construction was conducted by two sub-companies while "Company A" did not play real role. Thus, apparently it is difficult to determine who is more responsible than others.

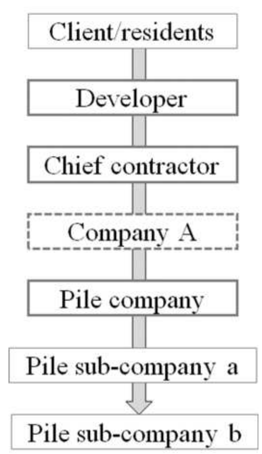

Figure 3. Multi-storied subcontract structure of project

The argument consists of two points which are 1) cause of tilting and 2) reasons why construction record are lost so often. So far, most arguments concerns 2) and many proposals have been made to solve this problem. However, the true cause of tilting has not been concluded yet.

REACTION OF GOVERNEMNT AND RELATED INSTITUTIONS

Although the chief issue in the problem is the unsatisfactory behavior (insufficient length?) of piles, no definite conclusion has been obtained to date or has not been open to the public. Most reactions so far published discuss the engineering ethics and reliable recording of construction procedure.

Ministry of Land, Infrastructure and Transport

This Ministry set up a special committee to investigate the problem and propose measures to improve the situation and its intermediate report was published in December 2015. According to this report, the developer reported to the committee that 28 piles were checked to find that possibly 6 of them did not reach the bearing layer and 2 were not sufficiently embedded in the bearing layer. There were 6 bore hole data obtained during the construction of a factory that existed in the same site in the past. The chief contractor conducted 10 bore hole investigations for design and additional 10 because of the non-uniform soil conditions. The committee states that, out of 810 piles, data abuse was found for auger drilling for 38 piles and 45 injection of cement slurry. Note that many of the abuse was caused by the inconvenient type of recording device. Importantly, a site engineer told the committee that he believed that piles reached the bearing layer according to his experience (although he did not touch upon the required embedment of piles in the bearing layer: remark by the first author).

The committee proposed measures to avoid repetition of the same problem in future. First, it was pointed out that the multi-storeyed structure of construction industry (Fig. 3) makes unclear the responsibility. The chief contractor should take the due responsibility of the entire construction procedure, including foundation. However, it was stressed that safety of buildings and abuse of data should be separately discussed. No final conclusion was reached on the situation of piles under the condominium building.

Japan Federation of Construction Contractors

A guide line for construction of prefabricated concrete piles was published in March, 2016. It puts emphasis on the responsibility of experts and site engineers in maintaining the good quality of pile foundations. It states that the depth of bearing layer has to be precisely captured in case that the depth is variable from place to place. It also states procedures that have to be taken when an installed pile does not reach a bearing layer at an expected depth. Also, it is stressed that construction procedure, such as energy for drilling and injection of cement slurry, has to be recorded in such a way that records may not be damaged by weather and also no human mistake may be possible. Thus, efforts were made to improve the construction procedure. Noteworthy is that the wrong practice in recording the construction procedure may not necessarily cause tilting of the building if piles are constructed in a reasonable way.

ON POSSIBLE CAUSES OF TILTING OF A BUILDING

This chapter addresses possible causes that have been discussed so far. It should be noted that no final conclusion has been drawn yet.

Insufficient pile length

The site is situated in a shallow valley near a hilly terrain (Fig. 4). The valley is filled with very soft alluvial soil that was deposited by a river (Fig. 5). Because of the ancient erosion procedure, the bearing layer, which continues to the nearby hill slope, is not horizontal. Its depth varies from place to place by the order of meters (Fig. 6). The data in this figure was obtained from a public data base but no bore hole data within the condominium site is released to the public.

Figure 4. View of the condominium site from nearby hill (tilted building shown by an arrow)

Figure 5. River whose soft sediments deposited in and filled the local valley

In principle, the depth of piles had to be determined by carrying out subsoil investigation. However, the pile company was asked by the chief contractor to prepare prefabricated piles of 14 meters in length (according to the pile company's own remark). It is argued nowadays that some piles were too short to reach the bearing layer and that the pile engineer could have noticed this problem to take necessary reactions. On the other hand, there had been a big electric factory prior to the construction of the condominium buildings and it is argued that the chief contractor had known upon demolition of the factory that the length of the end–bearing piles was 18 meters, which was 4 meters longer than the new piles. This may imply that 14 meters was an underestimation. If the previous bore hole data had been released to the public, the present pile company could have known more clearly the problematic nature of the subsoil. To see the argument on 14 m or 18 m, the first author feels that the depth of the bearing layer and the required length of piles (including necessary embedment in the bearing layer) may be confused.

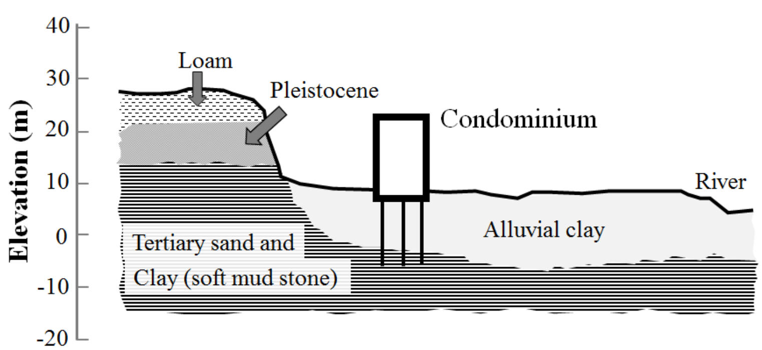

Figure 6. Conceptual sketch of the North-South cross section of the site

Choice of employed prefabricated pile

There is an argument that the selected type of prefabricated pile (Fig. 3) has been authorized only to sandy or gravelly bearing layers and not to soft mud stone which is the present case. However, the chief contractor carried out a pile loading test in the field to confirm the bearing capacity. Although the test result is not available to the public, the present paper trust this test and does not touch upon this issue.

ACTIVITY OF JAPANESE GEOTECHNICAL SOCIETY

The problem concerns not only the insufficient length and bearing capacity of pile foundations but also the serious practice of abusing of construction records. Because those records were intended to verify the good practice of pile construction, the construction community feared that its public fame might be seriously damaged. Several emergency actions were described in the former chapter. It appeared, however, that there were more problems to be solved. Therefore, as the President of the Japanese Geotechnical Society (JGS), the first author decided to take necessary actions.

At the beginning of the activity, it was agreed that the societal work would not hunt criminals. Also, detailed procedure of pile construction is not a matter of the society because the government (MLIT) and JFCC had commenced needed activities. Moreover, lawyers had been investigating this issue from their professional viewpoints. In this regards, JGS decided to pay its attention to the public background that could have led to the problem. The output from the activity is summarized in what follows.

Consideration on non-uniformity of subsoil condition

The depth of the bearing layer is an essential information for successful installation of prefabricated piles because, different from driven piles, it is difficult to directly confirm the existence of firm layer during pile construction (Fig. 2). Moreover, if the bearing layer is found deeper than the estimation during pile installation, additional pile has to be manufactured and connected to existing piles, which creates additional time and cost. Hence, care must be taken in advance of the depth of the bearing layer which may be different from pile to pile. This is particularly so near the hill slope where the soil profile is highly variable. In spite of these situations, the present practice does not pay sufficient attention to the importance of soil profile information. Efforts are needed to improve this unsatisfactory situation.

Need for more soil exploration technology

Ideally, soil condition should be explored at all sites of prefabricated pile locations. However, the Standard Penetration Test procedure, which is widely used and preferred in practice, requires time and cost. Hence, it is difficult to recommend to run it for all piles. Therefore, simplified and less time-consuming technology has to be introduced into practice so that soil profile can be interpolated between available SPT sites. The first author believes that this simplified technology does not have to be so advanced as to provide all the information for pile design because its aim is nothing more than interpolation. Interpolation, if conducted during the design stage, can demonstrate the variation of the depth of bearing layer in details. Even during construction, it helps urgent action be planned if installed pile is found too short.

Importance of open-access subsoil data base

There are open-access databases of existing bore holes. However, most of the data are from governmental infrastructure construction such as road and bridge, thus, the location of bore holes are limited along roads. This point will be shown later in Fig. 7. Although many more bore hole investigations have been conducted for design of pile foundation of private buildings, those data are scarcely included in the data base. If private bore hole data had been included, the present pile contractor could have studied it and understood that the "14 m" specification was nothing more than an idea and conducted more realistic pile design. JGS has been long insisting on the necessity of such an open-access bore hole data base, saying that the geo-space is a common property of the public and that its nature should be shared by the public as well. This point has not been understood generally. It is also a problem that existing open-access bore hole databases are not consistent with one another, using different data formats even including non-digital pdf format.

Need for involvement of good geotechnical experts

Buildings with very good design may fail if subsoil condition is bad. It is significantly important to capture the subsoil conditions precisely prior to design and it is particularly so when the local geology suggests non-uniformity. In this regard, good geotechnical experts should be involved in the design stage so that they can propose the needed amount and quality of soil investigations and interpret the obtained data. Those experts should be also involved in decision making during construction because unexpected soil condition may be encountered. Such a goal is not yet reached in the present practice.

Importance of geotechnical professional education

The recent development of science and technology has produced many "specialists" who have deep knowledge and experience in their fields of profession but are not familiar very much with other fields. This is not a good situation in a construction project which is an integration of different disciplines. In this respect the geotechnical education community should make efforts to produce experts of a wide scope. It is feared that design procedure will rely more on specified geotechnical design formulae and that engineers do not have to care their back grounds.

FIRST AUTHOR'S ADDITIONAL DISCUSSION

This chapter describes the first author's opinions on the problem and is not related with the JGS activity although relevant consistency is aimed.

Non-uniformity of subsoil condition

Figure 7 was drawn to show the locations of open-access bore hole data around the condominium site. All of them are located along roads, as mentioned before, and many of them (shown by ○) are limited within the surface soft soil only. Thus, less number of data help assess the depth of the bottom of soft soil (●) or the depth of the bearing layer (soft mud stone in general) (●).

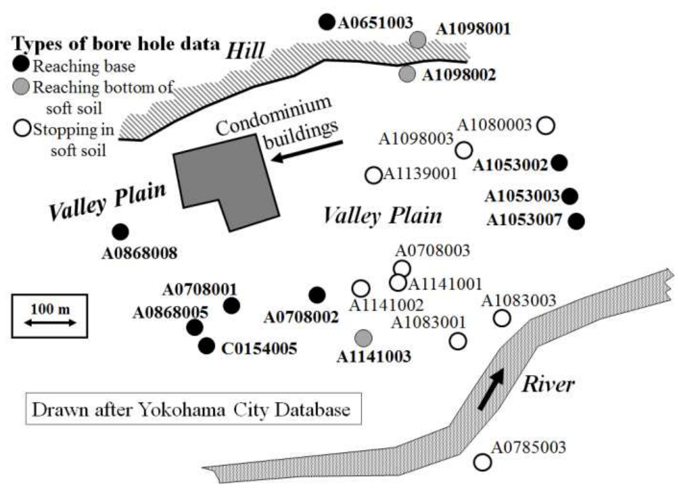

Figure 7. Location of subsoil data around the condominium obtained from a site of Yokohama City Government (http://www.asyura2.com/15/hasan104/msg/435.html)

According to Fig. 7 there is no open-access bore hole data, reaching the bearing layer, in and around the condominium site. This is a pity because there is a big shopping mall immediately to the east of the site and many bore hole investigations had been carried out for its pile foundations. Because of their private nature, their data are not open to the public. Hence, Fig. 8 plots the data at sites of ● symbol to the south and west of the condominium site in spite of the distance of hundreds of meters. Over a substantial depth, SPT- *N* was zero because of very soft clayey and organic soils. *N* value exceeding 50 is the idea of a bearing layer. Bore hole A1141003 (△) did not reach *N* = 50, and stopped at *N*=3 at the depth of 10 m. This figure implies that the data is classified into two groups shown by open symbols of □ and ○ at which the bearing layer was encountered at the elevation of -3 m and solid symbols (■, ▲ and ●) for which the bearing layer starts at -7 m. By comparing this data with Fig. 7, it is found that the bearing layer becomes lower towards the river. Moreover, Fig. 9 illustrates SPT-*N* profile reaching the bearing layer at three sites to the east of the condominium site. The elevation of the bearing layer is rather uniform here at -7 to -8 m but deeper than at sites in Fig. 8. This increased depth may be due to their more downstream locations.

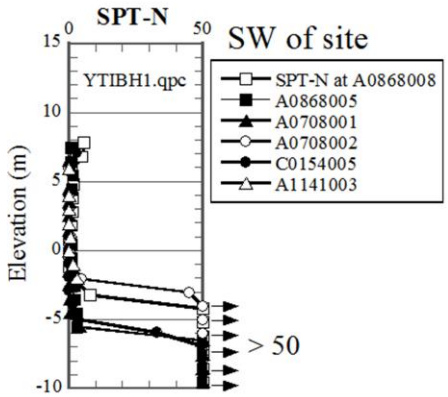

Figure 8. SPT-*N* profiles in soft soil area near the condominium site (SPT-*N* starts from 1 meter below the ground surface)

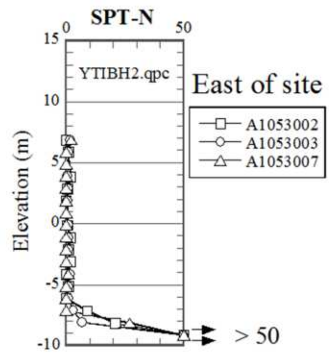

Figure 9. SPT-*N* profiles in soft soil area to the east of the condominium site (SPT- *N* starts from 1 meter below the ground surface)

Table 1 Depth of bearing layer (SPT-*N*>50) around the condominium site

Sites	Depth (m)
A0868008	13
A0868005	15
A0708001	14
A0708002	12
C0154005	15
A1053002	*17*
A1053003	*17*
A1053007	*17*

Table 1 compares the depth of first (shallowest) SPT-*N* greater than 50 at those sites. Herein depth means the distance from the local ground surface. It may be seen that the depth is variable to the west or south of the condominium site (first 5 sites) (12-15 m). If this extent of variation is the case at the condominium site as well, a constant length of pile is not a reasonable idea. Ignorance or insufficient attention to local soil conditions leads to a serious problem during construction and after completion.

Social pressure on geotechnical engineers

There are many uncertainties underground because we cannot directly see the subsoil. Even if many bore holes are drilled and other soil investigations (CPT etc.) are conducted, still there is a possibility to encounter unexpected soil conditions such as debris of former foundation, gravelly thin layer, locally deep bearing layer etc. As a consequence, auger drilling may be delayed or additional pile has to be manufactured. These situations result in delay of construction procedure and finally may affect the completion of the superstructure. Such a delay is blamed by the clients who is at the top of Fig. 3 and penalty may be claimed. Note that a delay is a significant problem to the clients because they have sold the present living places and need to move in to a new condominium on time; otherwise they have to arrange another tentative place to live with additional cost. To avoid such a situation, geotechnical engineers undergo significant pressure and stress. It seems that the construction of foundation should have reasonable flexibility in the work period as a provision for uncertainty. Such a delay is certainly reduced if more bore hole data is available through an open-access database.

On total demolition of buildings

As mentioned above, the detected differential settlement was 2 cm out of the building length of 56 m (0.04 %). According to the conventional liability rule, this range of tilting is not a legal fault of the contractor or even not detected by human sense. In the present case, however, the 2-cm differential subsidence was clearly visible at a joint of two buildings and the construction companies have been accused. It has been decided therefore that all five condominium buildings are demolished and rebuilt by the companies' own expense. There seems to be two points of discussion therein.

Significance of 0.04 % tilting

Because the differential settlement was probably (not yet concluded) caused by some deficit in pile foundation, residents were scared by the possible risk during future strong earthquake. This fear is understandable. Therefore, seismic resistance of the building was reconsidered and judged to be safe. Although details of this reconsideration are unknown to outsiders, the minor tilting suggests that there is no problem. It is desired that public sectors investigate many other buildings to show whether or not the 0.04 % tilting is exceptional.

Demolition of 5 buildings

It is very important nowadays to maintain the good fame of companies and industries among people. In this regard, the decision to demolish and rebuild the tilted building on the companies' own expense is not a bad idea. However, it is questionable to demolish and rebuild other 4 intact buildings. Now one building is going to be rebuilt by the companies because of 0.04 % tilting. If the same thing happens in other building projects in future, the present case may be used as a good reason to claim rebuilding. The first author is afraid that this very strict 0.04 % criterion will make the construction business very risky.

CONCLUSION

In response to a recent incidence of a condominium building, the Japanese Geotechnical Society established a special committee in order to publish a proposal from a society's viewpoint. The committee stated that the following 5 points deserve public attention which are

1. consideration on non-uniformity of subsoil condition,
2. need for more soil exploration technology,
3. importance of open-access subsoil data base,
4. need for involvement of good geotechnical experts and
5. importance of geotechnical professional education.

Moreover, the first author compared several bore hole data around the site and showed the possible range of variation in the depth of a pile bearing layer. He also pointed out that the significance of 0.04 % tilting should be discussed because this extent of tilting is very small.

ACKNOWLEDGMENT

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