

## **SITE INVESTIGATION AND GEOTECHNICAL FAILURES**

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### **Abstract**

Site investigation is normally required and carried out prior to the commencement of design of a construction project. Due to lack of or inadequacy of guide/code requirement regarding the extent as well as quality of site investigation work, geotechnical failures often occurred. These failures sometime led to catastrophic disaster and imposed serious threat to public safety. This paper gives a brief review of the code requirements and current practice in several countries in the region, including Singapore, Malaysia, Hong Kong, Taiwan and China. Three case histories are presented to illustrate the problems of poor ground investigation, inadequate knowledge of site condition, and importance of geotechnical supervision.

**Keywords:** Site Investigation, Geotechnical Failure, Quality Control, Code.

### **Introduction**

For any construction project, a site investigation is normally carried out. Site investigation has been defined as investigation of the physical characteristics of the site and includes documentary studies, site surveys and ground investigation. The last item refers to the actual surface or subsurface investigation, including on site and laboratory tests. In broad sense, site investigation should also include study of the site history and environment, interpretation and analyses of all available data, and making recommendations on the favorable/unfavorable locations, economic and safe design, and prediction of potential risks. A proper site investigation work is carried out by the combined effort of geotechnical engineer and ground investigation contractor.

In any site investigation work, the questions which should be resolved in determining the investigation program are: (1) what type of investigation is needed, (2) why they are needed, (3) where the actual field work should be performed, and (4) how the work is to be done. Another question which one should always ask oneself is whether the investigation is sufficient or too much. From this program, the stages of investigation, the type of field work, the number and location of boreholes, type and number of sampling, type and number of testing, etc., are determined.

The ground investigation contractor is responsible for providing reliable factual data. The geotechnical consultant should be responsible for the planning & execution of the investigation program, interpretation and analyses of results, and making appropriate

design recommendations, to avoid over design as well as unsafe design. In order to ensure the quality and reliability of the investigation results, full time supervision on site by qualified geotechnical engineer is a must for any ground investigation work.

Proper expertise for geotechnical engineering solutions and recommendations should be referred to by engineers in other disciplines, and not rely on the opinions of the ground investigation contractors alone. The division between the investigation contractor and geotechnical consultant, in terms of professional judgment and responsibility must be clearly defined.

In the following sections of this paper, a brief review is made on the code/regulations and current practice of site investigation in several countries in the region, including Singapore, Malaysia, Hong Kong, Taiwan and China (PRC). Three case histories are presented to illustrate geotechnical failures attributable to poor ground investigation, inadequate knowledge of site condition, and lack of geotechnical supervision.

### **Codes and Regulations**

In this section, a brief review is made regarding codes and regulations on site investigation currently in practice in several countries in the region, including Malaysia, Singapore, Hong Kong, Taiwan and China (Peoples' Republic of China). A summary of the requirements is shown in Table 1.

Table 1. Summary on Code/Regulation Requirement for Site Investigation

Items \ Country	Singapore	Malaysia	Hong Kong	Taiwan	China
Site Investigation Code/Regulations	No	No	Yes	Yes	Yes
SI Contractor Special Registration	Yes	No	Yes	No	Yes
SI Contractor Personnel Requirement	No	No	Yes	No	Yes
Site Supervision by Geotechnical Consultant	No	No	Yes	No*	Yes
Professional Geotechnical Engineer	No	No	Yes	Yes	Yes
SI Report Endorsed by P.E.	Yes	Yes	Yes	Yes	Yes

\*Not required, but often practiced by major geotechnical consulting firms.

### *Singapore*

There is no building codes or regulations regarding site investigations in Singapore. Clause 31 of Building Control Regulations says: "Where foundations or related earthworks are proposed on any premises, an investigation of the site shall be undertaken by the qualified person". This is in fact not followed by many PEs in the local practice as the works are usually handled by the drilling contractors. This clause is currently

being discussed between the Association of Consulting Engineers Singapore (ACES) and the Building and Construction Authority (BCA) as many PEs feel not comfortable for being held responsible for the accuracy/validity of the SI report prepared by others under this clause. Recently, Advisory Notes have been issued by the BCA to PEs as guidelines for SI works. Advisory Note 1/03 gives advices on SI work for building structure of 10-storey or more. They include: (i) the number of boreholes shall be the greater of one hole per 300 sq.m or one hole at 10 to 30 m c to c, and not less than 3 number in a site; (ii) the depth of borehole should be minimum of 5 m into N>100 layer or 3 D beyond the design founding level of piles.

In Singapore, geotechnical engineering is not a discipline for PE license. There is neither any special recognition of qualified geotechnical firm by the Professional Engineers' Board (PEB) or any other relevant government authorities. On the other hand, drilling contractors are required to register with the Construction Industry Development Board (CIDB), with little or no control on the professional level knowledge.

Current practice in selecting SI organization can be classified into Public Projects and Private Projects. For Public Projects, SI works are usually carried out by invitation or open tender. Only CIDB registered contractors are qualified for submission and award of contract is generally based on price. A number of "qualified" and experienced geotechnical consulting firms are unfortunately being excluded unless they are willing to be treated or considered as a "contractor". The practice of award purely based on low price is definitely a problem since this system would exclude quality work.

For Private Projects, selection of SI works firm depends very much on the understanding of problems of the Architect/Engineers. Generally, three types of SI invitations are in practice: (i) drilling contractors only, generally adopted by small Architects/Consulting Engineers, (ii) drilling contractors and geotechnical consultants, and (iii) geotechnical consultants only. Usually (iii) is preferred by large architects/consulting firms. When invitation is issued to both drilling contractors and geotechnical consultants, cost comparison becomes an improper factor because these two categories of SI firms are not on the same basis, just like comparing pharmacy with medical practitioner, or book keeping company with accounting/audit firm (CPA). In many cases, the owners' (or their representatives') influence to the selection is significant where architects/engineers' ability to convince the owner regarding quality work becomes important.

### *Malaysia*

There is no specific codes or regulations in Malaysia regarding SI requirements. Although many of the principles for carrying out proper SI works have been discussed in details but very few SI work really followed the recommendations (IEM, 1997). The current practice in Malaysia in selecting SI contractors depends a great deal on the consulting engineer (i.e. the architect/structural consultant). Reputable consulting engineer will normally select SI contractor on the basis of qualification, merits and reliability but cost often plays an important factor. Majority of the consultants, however, select SI contractor purely on the basis of cost. In addition, there is one practice in

Malaysia which is of great concern is that the architect/structural consultant would leave it to SI contractor to propose the SI program, leading to many occasions with insufficient information or even wrong information. In most of the cases, there is no supervision, or best by technicians, of the site work.

After the Highland Incident in Kuala Lumpur in 1993, the government initiated a second opinion or independent checking system on geotechnical reports submitted by consultants. However, there is no strict requirements or regulations on this, but left to the discretion of each local council. Some states, for example Penang, has an Ad Hoc Committee on Hill Land Development vested with authorities of approving the geotechnical study report and the second opinion report. Recently, second opinion report will also be required in some states on geotechnical study report for buildings with basement excavation.

### *Hong Kong*

Hong Kong is probably one of the few countries in the world who has extensive and detailed regulations and code requirements for the practice of geotechnical engineering including SI work. Hong Kong Building (Construction) Regulation (Hong Kong Government, 1990) specifies, "where foundations are proposed to be constructed, an investigation of the site shall be undertaken to establish, to the satisfaction of the Building Authority, the type and character of the ground on which the foundations are to be placed. Site investigation shall be carried out in such a manner and to such recognized standards as to provide adequate geotechnical and other relevant data for design and construction of building/foundation works".

PNAP 132 (Hong Kong Government, 2000) further stipulates that "site investigation" is defined as "investigation of the physical characteristics of the site and includes documentary studies, site surveys and ground investigation". Ground investigation refers to the actual surface and subsurface investigation and are required to be carried out by registered specialist contractor under ground investigation field works category [RSC (GIFW)]. The RSC (GIFW) organization shall have the following personnel with academic qualifications and work experience specified (PNAP 244, Hong Kong Government, 2000):

- (i) Authorized Signatory to act for the contractor.
- (ii) Technical Director if the contractor is a corporation.
- (iii) Geologist or geotechnical engineer to carry out logging and preparation of borehole logs.
- (iv) Technical competent person to supervise on site the different stages of GIFW.
- (v) Geotechnical field technician to provide full time on-site supervision.

For private projects, selection of SI organization is usually based on cost only with little reference to company reputation. For government projects, technical qualification, capability, resources available and past performance are also taken into consideration in addition to cost. In Hong Kong, the ground investigation contractor usually only prepares factual report. Geotechnical consultants are generally engaged by Authorized Person

(Architect or Engineer) to provide adequate site supervision and to prepare geotechnical report. PNAP 132 has detailed regulations on the level of supervisions to be provided.

Geoguide 2 published by the Geotechnical Engineering Office (Hong Kong Government, 1987) present recommended standards of good practice for site investigation in Hong Kong. Site investigation carried out with the recommendations of Geoguide 2 is deemed to meet the minimum acceptable standards. The current ground investigation requirements/practice in Hong Kong are summarized in Table 2.

Table 2. Current GI Requirements/Practice in Hong Kong

Foundation Type	Borehole Spacing	Borehole Depth
Percussion Pile (a) H-Pile (b) Concrete Pile	15 m – 20 m 15 m – 20 m	In-situ weathered soil with $N \geq 200$ $N \geq 80$
Mini-Pile, H-Pile Socketting into Rock	10 m	At least 5 m below rock head of specified grade or designed length of the rock socket of the nearest pile, whichever is the deeper <sup>(a)</sup>
Bored Piles Founded on Rock	One borehole at each Pile location	At least 5 m below rock head of specified grade <sup>(b)</sup>

Notes:

- (a) For area underlain by marble, ground investigation is recommended to be carried out in stages. It must be adequate to ascertain whether marble with cavities exist beneath the site.
- (b) If marble is encountered, a minimum penetration of 20 m of the drillhole into sound marble rock is recommended. Where cavities are encountered in the hole being drilled or in adequate drillholes, increased penetration is necessary.

### *Taiwan*

In Taiwan, the Building Design Code (Ministry of Interior, 2001) revised in year 2001 has relatively simple requirements on the extent of ground investigation. The code says: “the ground investigation program should be planned in such away by considering the stages of construction plan, complexity of the site, type of building construction including it’s size and importance”. In principle, at least one borehole shall be drilled for every 600 sq. m of site area or every 300 sq. m of building area. For every site, the minimum number of boreholes should be two. For development on large sites, when the site area is large than 6,000 sq. m or building area in excess of 3,000 sq. m, the number of boreholes to be drilled may be adjusted according to geological condition of the site and the structural requirements of the building.

The guidelines are provided for depth of boreholes as summarized in Table 3.

Table 3. Current Requirements for Boring Depth for Building Construction in Taiwan

Foundation Type	Minimum Borehole Depth, m
Shallow Foundation	bearing layer or 4 times footing width below foundation level
Pile	bearing layer or 4 times pile diameter below pile tip
Caisson	bearing layer or 3 times caisson diameter or width below bottom of caisson
Floating Foundation	depth where the vertical load increase <10% effective vertical overburden
Deep Excavation	1.5 to 2.5 times depth of excavation or bearing stratum or impermeable layer

For highway bridge design, the code (Ministry of Transportation and Communications, 2001) specifies the minimum number of boreholes as well as depths for ground investigation as summarized in Table 4.

Table 4. Ground Investigation Requirements for Highway Bridge in Taiwan

(A) Borehole numbers

	Minimum Number of Boreholes
Each bridge	2
Each structure element of substructure	1
Simple and uniform geological condition	2 (when width >30m) 1 every 100 m

(B) Borehole depths

Foundation type	Minimum Borehole Depth
Spread Foundation	$2 \times B$ when $L \leq 2B$ $4 \times B$ when $L > 5B$
Deep Foundation	Estimated bottom depth of foundation or 3m into rock

Geotechnical site investigations in Taiwan are usually carried out by geotechnical consultants. The executions of ground investigation are performed by ground

investigation contractors. Geotechnical reports are normally required to be endorsed by Registered Professional Geotechnical Engineer or Civil Engineer. For public infrastructure works, geotechnical investigation is often a part of the overall study or design. Selection of the consultants is normally made on the basis of two envelopes system, i.e. work proposal & qualifications in one envelope and cost proposal in a separate envelope. In majority of cases, selection is made on the basis of first envelope and price negotiation is made with the first ranked party. Recently, a number of public projects adopt the policy of pronouncing the price before the selection process.

For private projects of significant size, geotechnical consultants are often engaged by the Architect/Engineer. Cost element usually becomes the decisive factor.

#### *China (The Peoples' Republic of China)*

After eight years' intensive study, evaluation and discussion among geotechnical specialists, construction industries and government officers, the government of the PRC in March 1994 issued a very comprehensive Code for Investigation of Geotechnical Engineering as national standards (Ministry of Construction, 1994). The code contains 13 chapters and 17 appendices. It not only sets requirements for site investigation, but also gives specifications and procedures for analyses, calculations and verifications. In view of the vast geographic territory, complex geological conditions and variable nature of the construction projects which need site investigation, the code divides site investigation work into three levels on the basis of safety, site condition, and complexity of geotechnical condition. The extents of investigation required for each level are different.

The code also gives detailed requirements for site investigation in different types of soil/rock formations and for different categories of construction. Parts of the code were further revised in 2001. The codes in fact are so detail and rigid which leave little room for a geotechnical engineer to exercise his knowledge and judgment.

Up to the present, all the site investigation works are carried out by state-owned Survey and Investigation Design Institutes. There are three different levels of Institutes qualified on the basis of personnel qualifications, experience and facilities. Possibly due to the rigid code requirements, many site investigation reports, except for large infrastructure projects, only contain description of the ground investigation. Design recommendations are often made by just quoting the code without actual analyses.

Under the PRC's planning economy system, site investigation works normally were assigned to the investigation institute under standard fees (Ministry of Construction, 2002). With the promotion of market economy, the investigation and design institutes are encouraged to be commercialized and privatized. Competition by open tender based on price is gradually taking place. However, the standard fee structure is still in effect, and theoretically it should be enforced. During this transition period, the market is somewhat confusing and quality of work will undoubtedly be affected.

## Cases of Geotechnical Failure

### Case One

#### *The site*

On 18 August 1997, a major landslide occurred in the Lincoln Community during Typhoon Winnie where 28 lives were lost. The community was a relatively high density residential development on slopeland in Taipei Country. According to report prepared after the disaster (Chen et al, 1998), the topography of the site before the landslide has relatively steep slopes in the northwest and east part of the site at slope angle of about  $30^\circ$ . The southwest and southern parts of the site were at lower elevation. Maximum difference in elevation was about 75m. During the site inspection after the landslide, it was observed that the direction of the upper sliding surface was  $N73^\circ\sim 84^\circ E$  with dip angle of  $28^\circ\sim 29^\circ S$ . The direction of the lower sliding surface was  $N79^\circ\sim 81^\circ E$  with dip angle of  $29^\circ\sim 30^\circ S$ . The inclination of the slopes was about the same as the dip angle of the rock formation.

From the outcrops exposed after the landslide, the geological structure at the site is primarily composed of alternative stratum of sandstone and shale. The sandstone in the upper strata was weathered with well developed joints. The sliding surfaces were relatively smooth shale.

The sliding area was rectangular in shape, about 140m in the E-W direction and 50m in the S-N direction. Figure 1 shows the extent of the landslide, displacement and distribution of tension cracks.

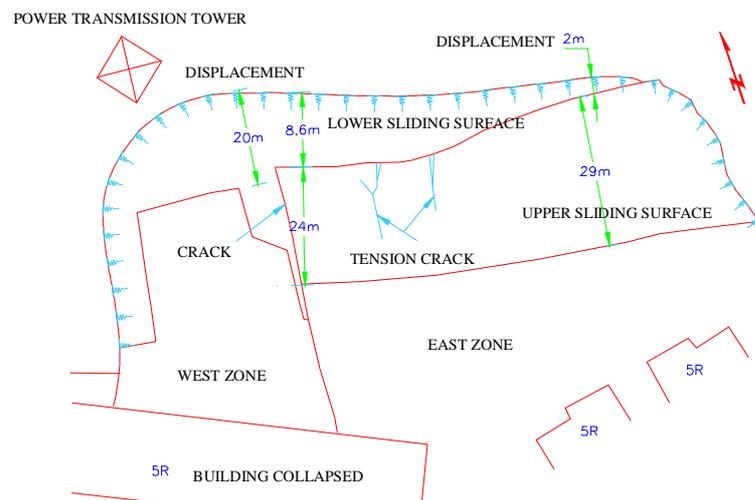


Fig.1 Extent of Landslide and Displacement, Case One

### The cause

Extensive investigation and evaluation were carried out after the incident, including testing of concrete cores taken from the R.C. retaining wall, additional soil boring and testing, review of the design and construction records. The conclusions included:

- (1) Inaccurate site investigation report – The site investigation report did not indicate the presence of shale.
- (2) Improper selection of geotechnical design parameters – The design did not give due considerations of effect of groundwater.
- (3) Poor construction quality – Construction of the retaining structure was not properly supervised by qualified person for quality as well as quantity control.

### Case Two

#### The site

The case is the construction of one of the underground stations of the Taipei Mass Rapid Transit Systems. Excessive settlements and tilting of adjacent structures occurred during construction of the guide trench of the diaphragm wall for one of the station exit. As shown in Figs. 2&3, there are two 3-storey building, i.e. SR-096 and SR-097, located immediately adjacent to the station Exit B. These two buildings were founded on R.C. spread footings. In view of the fragile nature of the structure and foundation, micropiles were installed to reinforce the building support and pressure grouting were made on both sides of the guide trench to a depth of about G.L.-12m prior to the excavation work.

The site area of the station is 3,750 sq.m. A total of 7 boreholes were drilled at the site during the design stage according to the Code for Building Foundations, i.e. one borehole for every 600 sq.m. Additional boreholes were also drilled during construction. In both cases, the data were quite consistent, the subsoil consists primarily of sandy soil with some gravel from ground surface to a depth of about 2.5m and followed by clay (CL) layer. Nothing unusual was revealed by the boring data.

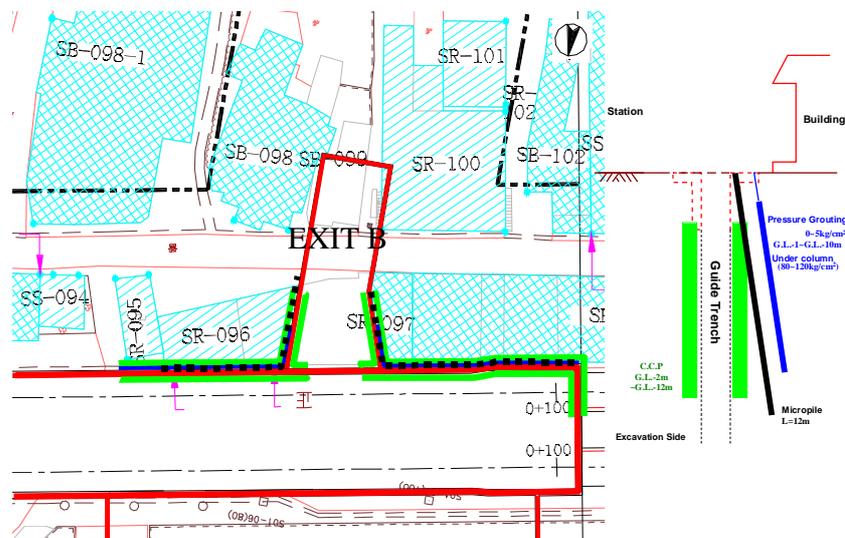


Fig. 2 Location Plan of Fu-Ta Station, Case Two

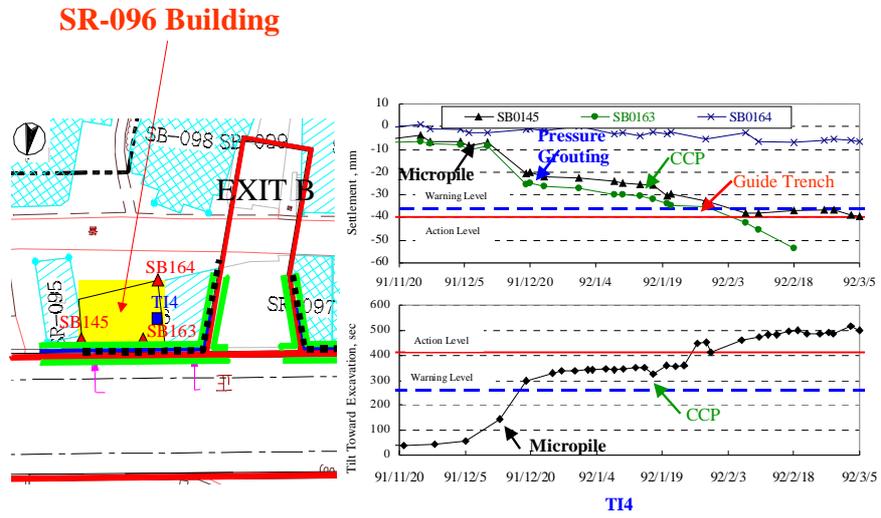


Fig. 3 Instrumentation data for Building SR-096, Case Two

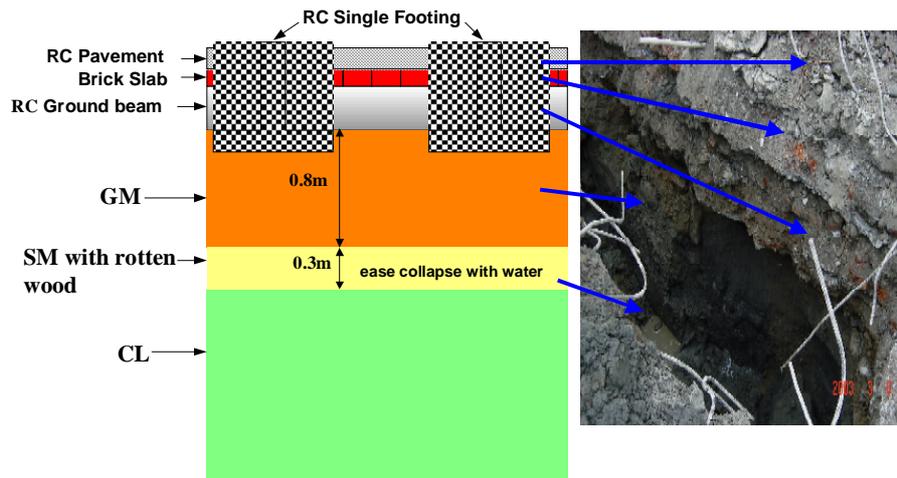


Fig. 4 Subsurface Condition Below Building SR-097, Case Two

### *The cause*

During test excavation of the area after demolishing of the tilted buildings, it was found that there was a thin layer (about 30cm) of sandy soil containing decayed woods within the upper sandy soil stratum as shown in Fig. 4. This compressible soil was not discovered during the site investigation even if the number of boreholes drilled was in accordance to the code requirement. However, if information were gathered from neighboring occupants during the SI work, continuous sampling of the upper subsoil payer would certainly reveal the existence of such unfavorable subsoil condition.

### Case Three

#### *The site*

Described below is a case history in which the replacement of a faulty piezometer without supervision by qualified geotechnical engineer led to ingress of water at the bottom of a deep excavation.

The excavation of interest was for construction of an underground station of the Taipei Rapid Transit Systems. It is located in central Taipei City. The subsoil distribution is typical of that in the Taipei Basin (Moh and Ou, 1979), with a thick layer of young sediments i.e. the so-called Sungshan Formation from the ground surface to a depth of about 48. The Sungshan Formation comprises 6 alternative layers of silty sands (SM/ML) and silty clays (CL/ML). Underneath the Sungshan Formation is a highly permeable gravel layer, i.e. the so-called Chingmei Gravels. This gravel layer was in artesian condition decades ago and the piezometric level in this layer had dropped to as low as RL 60m as result of excessive pumping before the 70's. The clayey sublayers in the Sungshan Formation are relatively impermeable and separate the entire subsurface soil stratum into three aquifers with different piezometric levels. The piezometric levels in the Sungshan Formation responded to the lowering and rising of the pressure heads in the Chingmei Gravels, there obviously are flows across neighboring aquifers. A typical subsoil profile is shown in Fig. 5.

#### *The events*

As shown in Figs. 5 and 6, the excavation was 23m in width and was carried out to a depth of 24.5m by using the bottom-up method. The pit was retained by diaphragm walls, 1.2m in thickness and 44m in length, and braced by 8 levels of temporary struts. The diaphragm walls toed in Sublayer II to provide a seepage cutoff. Sublayer II, which is an impervious layer consisting mainly of silty clay, essentially served as a seal at the bottom of soil plug which was enclosed by diaphragm walls on its four sides. With a length of soil plug of 20.5m, a factor of safety of 1.3 was obtained against blow-in for a piezometric head of 29.5m at the bottom of the plug. At the time when the incident occurred, the bottom of excavation had been reached and, except at the southern end where the incident occurred, base slab had already been cast.

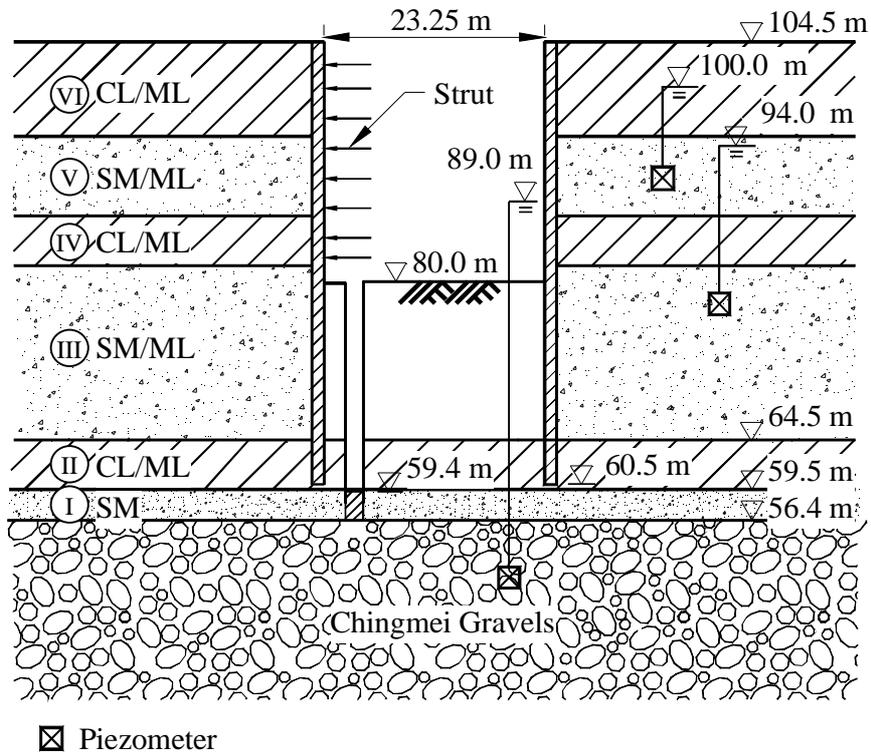


Fig. 5 Soil profile and configuration of excavation

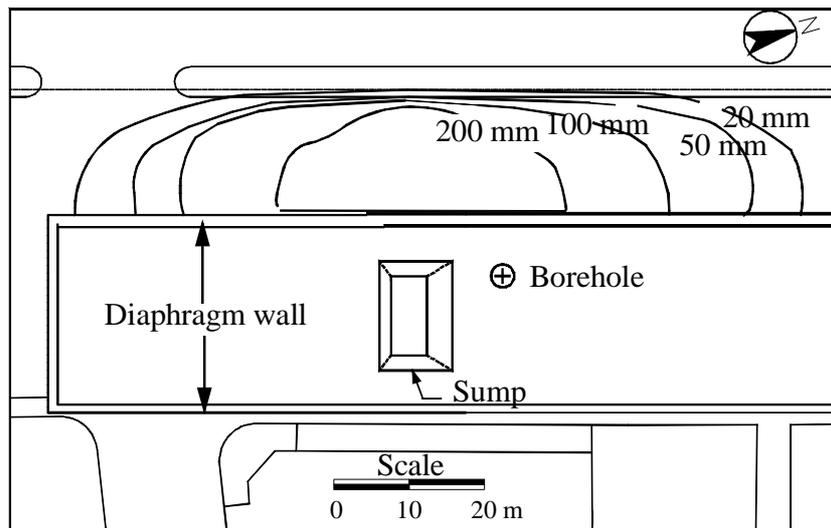


Fig. 6 Borehole, sump and settlement contour

The excavation was well instrumented with settlement markers, inclinometers, load cells, etc. Because blow-in was one of the major concerns, the piezometric levels in the Sungshan Formation and the Chingmei Gravels were closely monitored. One of the piezometers became faulty and the contractor attempted to replace it by a new one. At that time, the excavation at the southern end had already been completed and the bottom of excavation was protected by a layer of plain concrete. Drilling was carried out from the bottom of excavation at the location shown in Fig. 2. As drilling reached RL 59.4m, refer to Fig. 1, water started to overflow from the borehole.

Although various means have been tried, including extension of drilling casing, placing of sand bags on top of the borehole, grouting etc., the flow soon became uncontrollable and the pit had to be flooded to prevent the situation from deteriorating. As much as 70,000 tons of water was recharged to balance the hydrostatic pressure from the groundwater. It took 6 months to mend the damaged clay blanket under the bottom of excavation before the pit was drained and the works resumed. A total of about 3,000 cu m of LW (Labile Wasserglas) grout consisting of cement, sodium silicate and water and about 2,400 cu m of cement-bentonite grout was injected into the ground to fill up cavities made by the seepage flow. Figure 6 shows the settlement contour of the surrounding area. Effect of the incident extended to a distance more than 60m from the location of the borehole. Maximum ground settlement exceeded 250mm.

### **Conclusions**

1. The code requirements for site investigation, if any, usually stipulate the minimum amount of site work required.
2. Site investigation is a specialized operation, requires specialized organizations and specialized personnel.
3. Site investigation is the combined product from ground investigation contractor and geotechnical consultant. The contractor is responsible for obtaining reliable data. The geotechnical consultant is responsible for planning and execution of the site investigation work, interpretation and analyses of data, recommendations of design and assumed professional responsibility.
4. The extent and cost of site investigation should be such that the risk is at an established acceptable level to the designer and also comply to the accepted code of practice.
5. The practice of recommending lowest tender as the main criteria for site investigation should not be preferred but be discouraged. Selection should be made on the basis of the geotechnical consultant's competency and investigation contractor's ability to provide reliable factual data.

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