FIELD MONITORING OF SUBSIDENCE EFFECTS IN AIT CAMPUS, BANGKOK, THAILAND

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Abstract

Field monitoring and in-situ tests were carried out to evaluate the amount of subsidence and subsidence effects in the Asian Institute of Technology (AIT) campus. Precision surface levelling were done twice on marking points permanently attached to the structures, surface settlement plates, bench marks, and pavements to observe the absolute subsidence. Inclinometers were installed to observe the horizontal ground movements. The existing compression indicators were monitored to observe the deep and shallow layer compression. In-situ tests consisted of Field Vane Shear tests and Pressuremeter tests were done to find out the field soil properties in the soft clay layer down to 10 m depth. The results show that in three months period, the average settlement of the ground surface is 2.00 cm while the maximum settlement of the building walls range from 2.5 cm to 3.94 cm. The layer compression indicator showed that most of the compression occurred in the upper 10 m layer. The in-situ test results revealed the presence of a thick weaker layer of complicated soft clay layer of higher compressibility in the subsoil below the Central AIT Campus and NZ Housing Area where most of the damage due to subsidence occur.

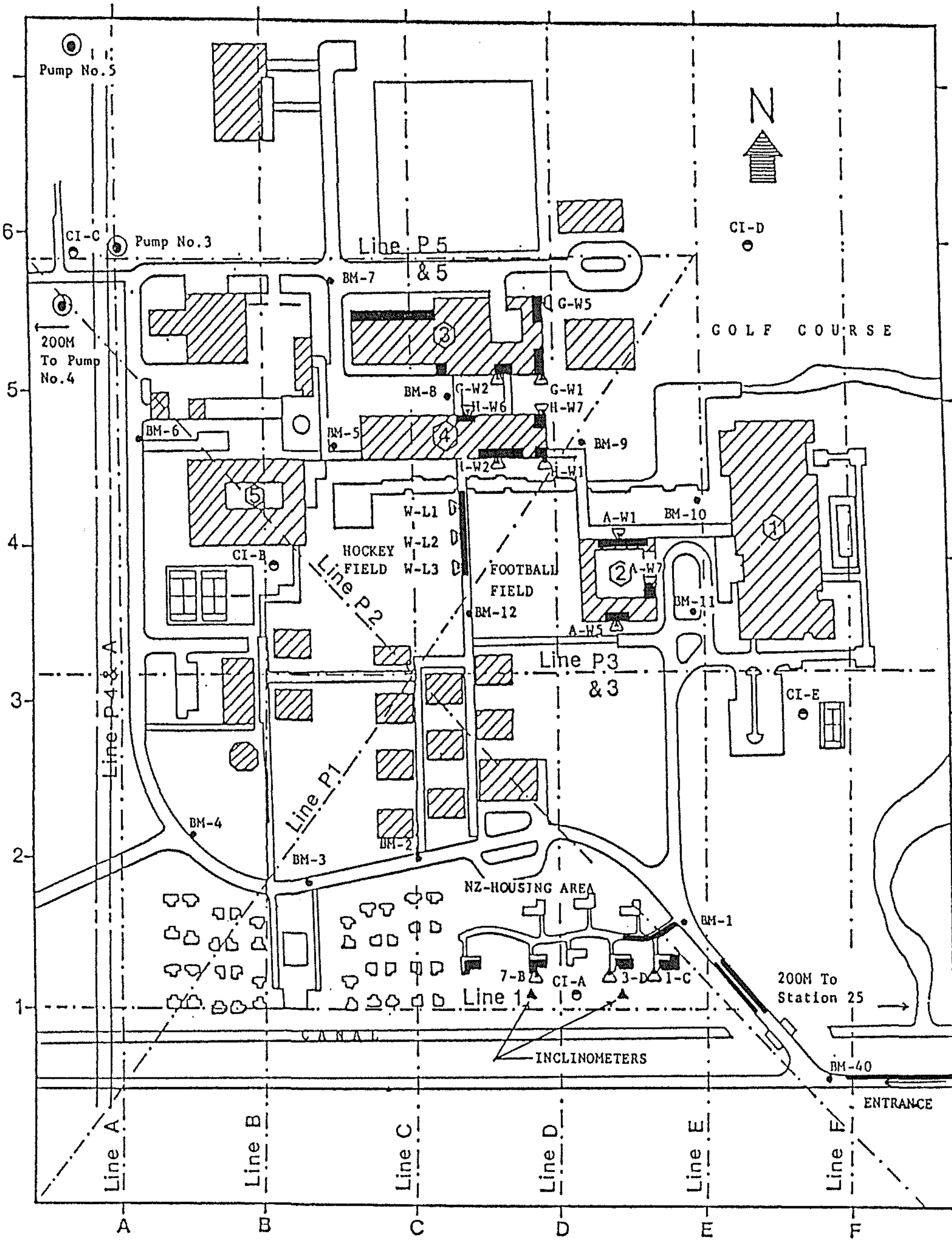
Introduction

The present AIT campus is about 10 years old. Among AIT buildings and structures, there are widespread indications of differential movements (Bergado, 1983b) evidenced by horizontal and vertical cracks of existing buildings, longitudinal cracks on the asphaltic pavements of roadways, cracks on concrete pavements of tennis courts and walkways, lateral movements towards canal excavations, etc. In this paper, field monitoring not only includes the observations of subsidence, horizontal movements, and subsidence effects but also the in-situ testing of the subsoil deposit for possible correlation of subsoil strength with the surface manifestations of subsidence. Most of the results presented in this paper were derived from the work of Apaipong (1984) under the guidance of the other authors.

Field Monitoring Devices

A hundred locations were selected for fixing the steel rulers as measurement points for observation of the settlement of buildings and walkways. The steel rulers are permanently fixed on the walls and columns of the structures. Five new locations around the campus were selected for installation of surface settlement plates for observation of ground subsidence. Their locations are indicated in Fig. 1. Two locations in the NZ Housing Area were selected for installation of inclinometers (Fig. 1) for observations of horizontal ground movements.

There are three types of existing compression indicators that were installed since 1979 as part of Bangkok subsidence studies (AIT, 1978, 1980, 1981) as station 25 located near AIT campus entrance. These are auger tip, cone tip and deep compression instruments. Both soil compression and pore pressure can be measured by these instruments.



LEGEND: 1. AIT Center
2. Central Administration
3. GTE and SEC Building
4. HSD and ENV Building
5. Library
* Shaded areas are location of damages

Fig. 1 The Map of Study Area, AIT Campus (Scale 1:4,000)

In-Situ Tests

A Geonor vane test apparatus was used to determine the in-situ undrained vane strength. In this test, a measured increasing torque is applied to the shaft connected to the vane until the soil fails by circumscribing a cylindrical surface. Bjerrum (1972) found the disparity between the actual undrained shear strength from the field and the value obtained from the field vane test such that a correction factor should be applied.

The pressuremeter used in this study is the monocell type manufactured by Oyo Corporation. This type employed a 70 cm long probe and consisted of three main components, namely: the probe, the control unit, and the tube. Three main soil parameters were obtained, namely: the horizontal total pressure at rest (Po), the yield pressure (Py), and the limit pressure (Pℓ). In addition, the pressuremeter modulus (Em) can be obtained in the straight line portion of the pressuremeter curve between Po and Py where the soil is in the elastic state. Gibson and Anderson (1961) suggested the equation for Em which indicates the relative compressibility of the cohesive subsoil.

Land Subsidence in AIT Campus

The land subsidence in AIT campus is mainly caused by groundwater pumping for its water supply. The recording of groundwater pumping began in 1980. During the past four years, the rate of groundwater extraction is given in Fig. 2. The depth from which the quantities of groundwater are extracted is about 200 m in the Nonthaburi Aquifer. The use of groundwater supply appears to have increased rapidly in 1982. It is estimated that at present, the pumping rate is about 4000 m^3/day. The locations of five deep wells are shown in Fig. 1.

The AIT campus is situated within the Lower Central Plain of Thailand on a flat deltaic-marine deposit in an area about 40 km north of Bangkok (Fig. 4). The ground elevation is generally about 1.5 m above the mean sea level (MSL) and the groundwater table fluctuates around 1.0 below the ground surface. The subsoil profile (Chalermsak, 1977; Dum, 1977) as shown in Fig. 3 consists of sedimentary deposits forming alternate layers of clay and sand with gravel down to 1000 m depth. The three uppermost layers consist of 2 m thick weathered clay, about 8 m thick soft clay, and about 5 m thick first stiff clay layer.

The pattern of subsidence occuring in AIT campus due to groundwater pumping is of the form of localized ground depressions in open field areas, differential movements in asphaltic and concrete pavements, and differential settlements between structures on shallow foundations and structures resting on deep foundations. The drawdown of piezometric level in the underground results in an increase in the effective stresses in the soil strata. While the total stress is constant, the increase in effective stress corresponding to the decrease in pore water pressure accelerates the consolidation of the clay layer in addition to groundwater depletion of the aquifer. Localized ground subsidence may also be caused by the occurrence of more than normal density of silt and fine sand lenses which serve as drainage paths accelerating consolidation in the soft clay. Another pattern usually occur on ground adjacent to canal excavations is subsidence due to slow lateral movement of the adjacent ground towards the canal. Furthermore, subsidence commonly occurs adjacent to underground drainage systems may be due to erosion of the subgrade sandy material due to leakage at cracks and joints in the drainage channels.

Evaluation of Subsidence Effects

Typical damages to land subsidence in AIT campus are found in many places

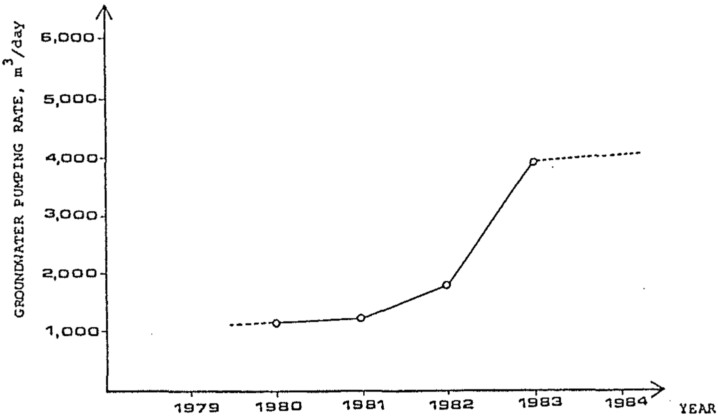


Fig. 2 Groundwater Pumping in AIT Campus

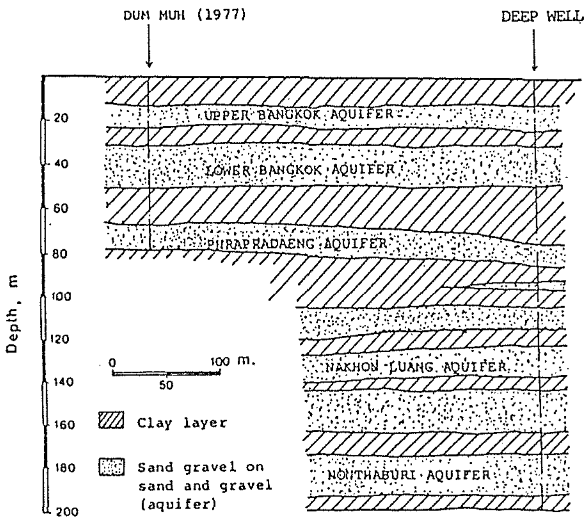


Fig. 3 Soil Profile East-West Section at AIT Campus

as indicated in Fig. 1 in the form of cracks, ground movements, and differential settlements. The subsidence observations were carried out by precision surface levelling with respect to a reference point, the deep compression indicator which is anchored down to 200 m depth. Two runs of precision levelling in interval of 3 months were carried out on the fixed steel rulers on buildings and walkways, surface settlement plates, pavement markers, and compression indicators. The locations of the observed points are indicated in Fig. 1.

Among the existing buildings, the worst damage which necessitated immediate repair occured in the Registry Office in the Administration Building. The floors and walls which directly rest on the ground surface and had not been connected to the tie beams have subsided, separated from the columns,

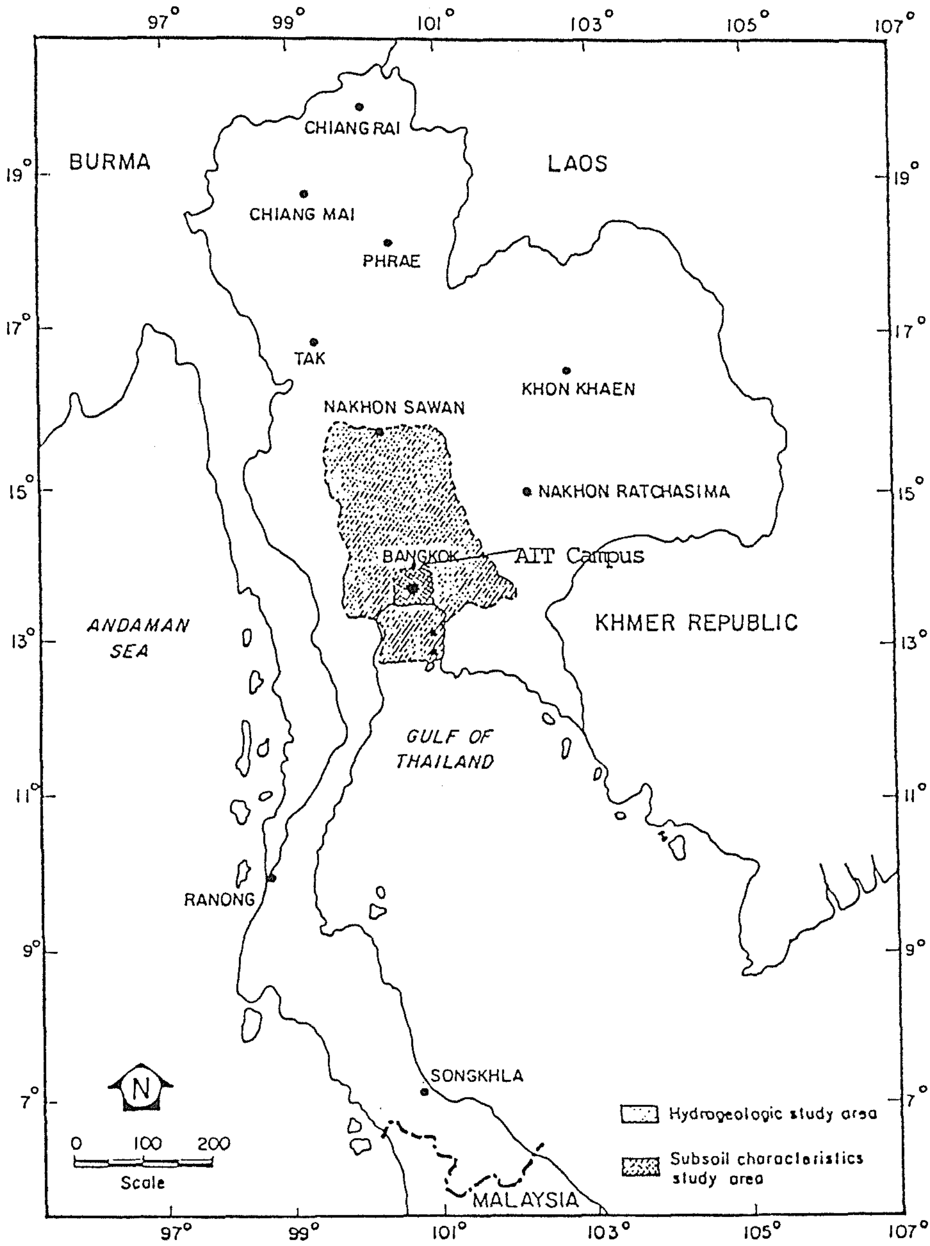


Fig. 4 Map of Thailand Showing AIT Campus and Areas of Previous Subsidence Investigation due to Well Pumping (After AIT, 1980).

and cracked. A detailed case study on the rehabilitation of the Registry Office was done by Bergado (1983a). In other parts of the Administration Building, differential settlements as plotted in Fig. 5 produced cracks in the first floor walls while the columns which are supported by pile foundation showed negligible settlements. Among the observed points as indicated in Fig. 1, a maximum settlement of 0.67 cm was measured in 3 months period.

The other damages can be seen in the Academic Buildings, namely: SEC and GTE Building and HSD and ENV Building. Both buildings show cracks in the first floor walls (Fig. 10a, b) due to differential settlements with a maximum of 2.40 cm in 3 months as plotted in Fig. 6 and Fig. 7 on observed points indicated in Fig. 1. The horizontal and vertical cracks are evident in the weakest portion of the walls such as lines of mortar joints. Measured settlements of the columns on piles were negligible.

The walkway between the Hockey and Football Fields (see Fig. 1) registered differential settlements as plotted in Fig. 8. A maximum settlement of 4.30 cm was measured in 3 months period. The larger settlement registered in this area may also be caused by erosion of the sand subgrade below the walkway due to rain water run-off.

The NZ Faculty Housing Area also suffers structural damages due to subsidence of the surrounding ground relative to the houses which are supported by piles. The sidewalks are cracked forming scarps around the houses (Fig. 11a, b) and the servant's quarters which directly rest on the ground are sinking with a maximum measured settlement of 3.94 cm in 3 months period which occur in House No. 1 (point 1C). Some of the settlements are plotted in Fig. 9a and 9b on points indicated in Fig. 1. Most of these damages occur in the houses adjacent to the canal.

In the asphaltic pavements, longitudinal cracks are found near the side slopes. The cracks of the concrete pavements in the tennis courts are found in random pattern. BM1 to BM12 whose locations are shown in Fig. 1 were used as observation points on the pavement (nail on pavement) around the campus. By interpolation, the Central AIT campus pavements have average settlement of about 0.5 cm in 3 months period.

In open fields, localized depressions can be observed in Football and Hockey Fields, Golf Course, and surrounding areas in Student Villages. The resulting subsidence measured in 5 surface settlement plates has an average of about 2.0 cm in 3 months period. It is also observed that the settlement of the point near the pumping well as indicated in Fig. 1 registered higher settlement.

Compression of the Soil Layer

Soil layer compressions were observed from shallow compression indicators at 10 m and 20 m depths and deep compression indicator at 200 m depth. Located near the AIT campus entrance, these instruments were installed during previous research work (AIT, 1978). The results of the recent measurements are tabulated in Table 1. In the period of 3 months, the observations indicated a compression of 2.28 cm in the top 10 m (soft clay layer) and a compression of 2.34 cm in the top 20 m. Considerable compression occured in the soft clay layer. The compressions in the upper 10 m and in the upper 20 m of subsoil are more or less similar in magnitudes. This large compression in the upper soft clay layer may cause the large differential settlements occurring in the AIT campus. The magnitude of subsidence below 20 m down to 200 m depth was relatively small. The measured compression was 0.19 cm in 3 months period.

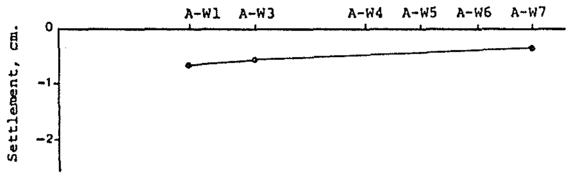


Fig. 5 Settlement of the First Floor Walls, Administration Building (See Fig. 1)

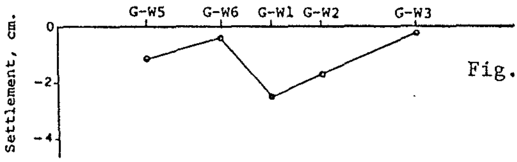


Fig. 6 Settlement of the First Floor Walls, GTE & SEC Building (See Fig. 1).

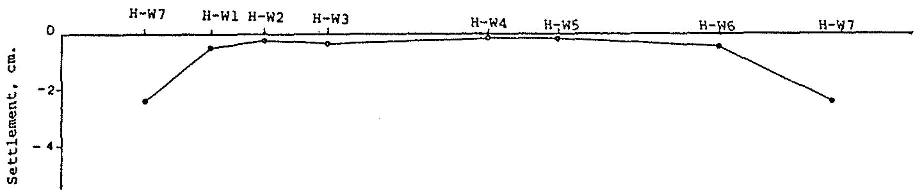


Fig. 7 Settlement of The First Floor Walls, HSD & ENV Building (See Fig. 1)

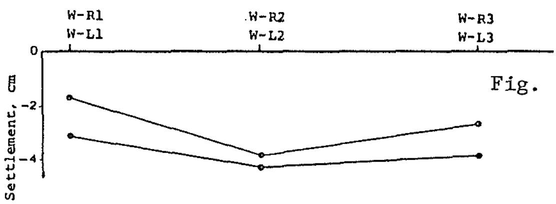


Fig. 8 Settlement of the Walkway Between Hockey and Football Fields

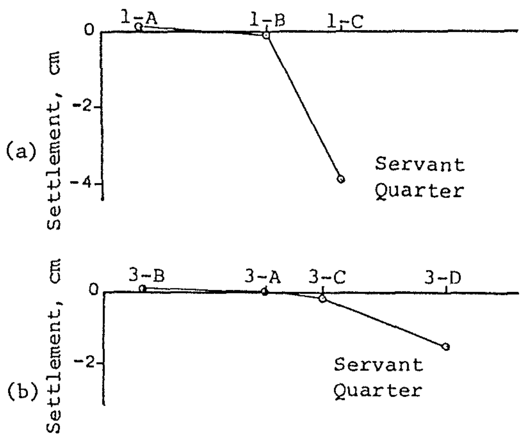


Fig. 9 Settlement in NZ Housing Area
a) House No. 1
b) House No. 3

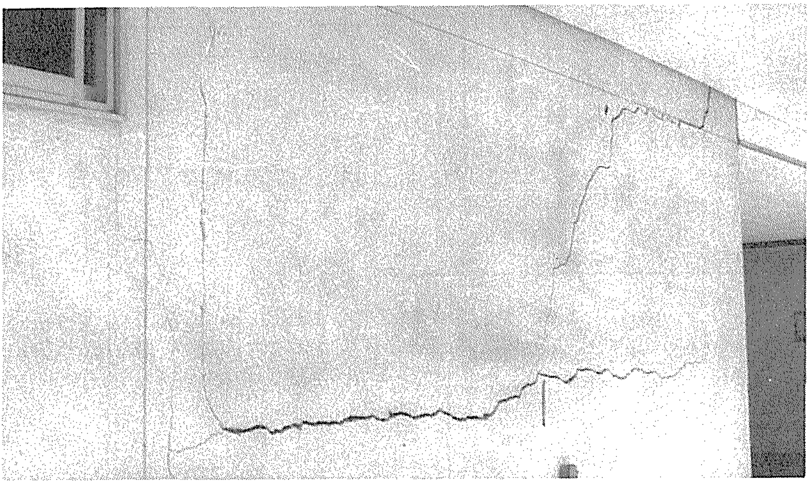


Fig. 10a Cracks in the First Floor Walls in ENV and HSD Building

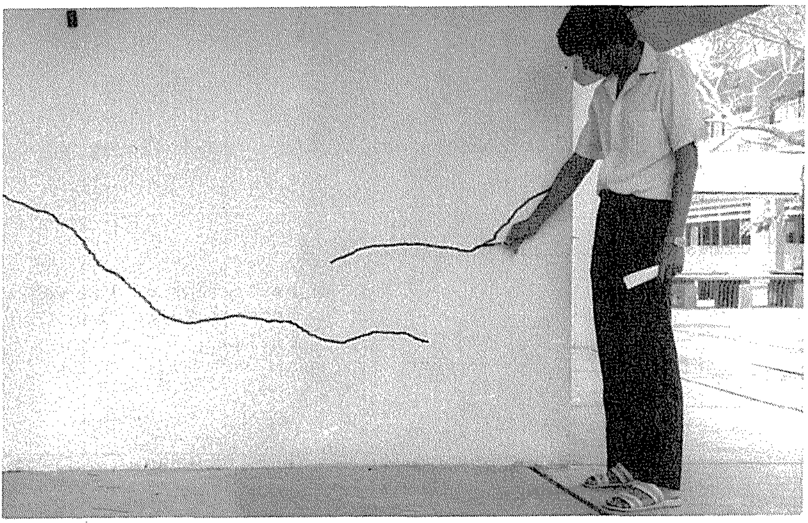


Fig. 10b Cracks in the First Floor Walls in SEC and GTE Building

Monitored Subsidence Correlated with Subsoil Conditions

Table 2 lists the locations, settlements, and types of damages. It can be seen that the area where damages occur registered large settlements.

Based on the subsoil vane shear strength profiles (Fig. 12 and Fig. 13) on line C and Line D as indicated in Fig. 1, the areas of large subsidence coincide with weaker subsoil. The vane shear strength profiles are more variable and the presence of a weaker layer pockets (shear strength $\leq$ 2.5 t/m^2) within the soft clay layer is more pronounced (Fig. 15). Line C extends from the NZ Housing Area through the Football and Hockey Fields to

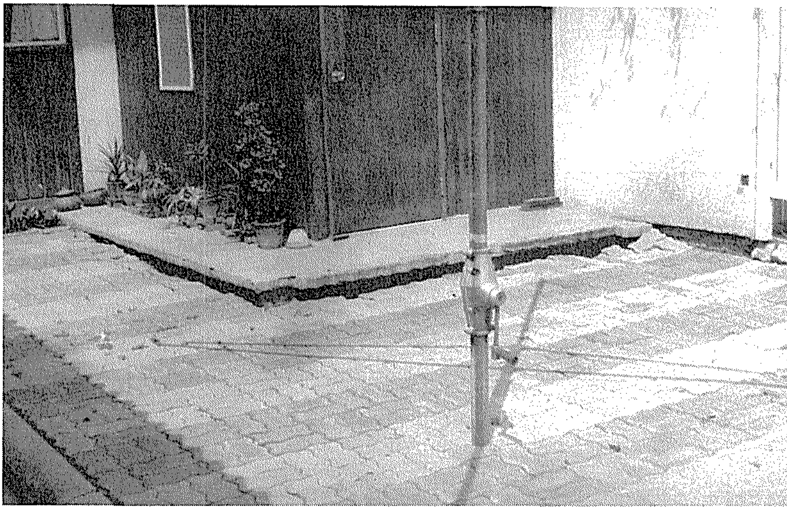


Fig. 11a Damage of Sidewalk at NZ Housing No. 1

Fig. 11b Damages of Sidewalk at NZ Housing No. 7

the Academic Buildings. Line D pass through the NZ Housing Area through the Registry Office in the Administration Building to the Academic Buildings. All of these areas have evidences of large subsidence either structural failure or ground depressions. The existence of weaker layers in the soft clay are also confirmed from the results of the pressuremeter tests. The areas where evidences of subsidence occur coincide with the presence of thick, compressible layers with pressuremeter modulus, Em, below 25 kg/cm^2. Figure 14 shows the profile of Em values on line P1 indicated in Fig. 1. The damages are listed in Table 2.

Table 1 The Summary Results of Compression of Soil Layer

Compression Indicator	Period (months)	Depth Interval (m.)	Compression (mm.)
CI-1 to CI-2	3	1-10	22.80
CI-1 to BM	3	1-20	23.40
CI-1 to CI-4	3	1-200	25.29
CI-2 to BM	3	10-20	0.60
CI-2 to CI-4	3	10-200	2.49
BM to CI-4	3	20-200	1.89

Table 2 Settlement and Damages of Structures, AIT Campus

Location (refer to Fig. 1)	Type of Structure	Settlement in 3 months (mm.)	Type of Damage*
Walkway			
WR1-WL1	Column	15.45	a,b
WR2-WL2		5.45	a
WR3-WL3		12.43	a,b
ENV & HSD			
HW1	1st floor wall	5.46	c
HW2		2.42	c
HW6		4.45	c
HW7		24.15	c,d
GTE & SEC			
GW1	1st floor wall	24.67	c,d
GW2		11.39	c
GW3		3.39	c
GW5		11.93	c
Admin			
AW1	1st floor wall	6.86	c
AW5		5.54	c
AW7		3.90	c,d
NZ Housing	Servant Quarter		
1-C	wall	39.44	e
3-D		11.49	e
7-B		7.73	e

* Note: a = Cracks in roof beam
b = Cracks in column
c = Cracks in the first floor wall
d = Separation between wall and ceiling
e = Separation between column or wall and pavement.

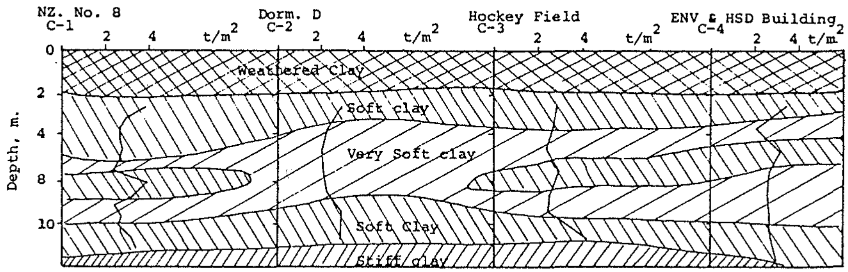


Fig. 12 Vane Shear Strength Subsoil Profile Along Line C (see Fig. 1)

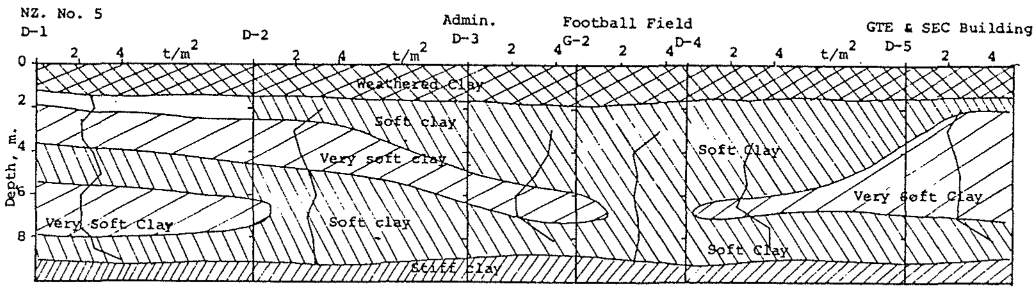


Fig. 13 Vane Shear Strength Subsoil Profile Along Line D (see Fig. 1)

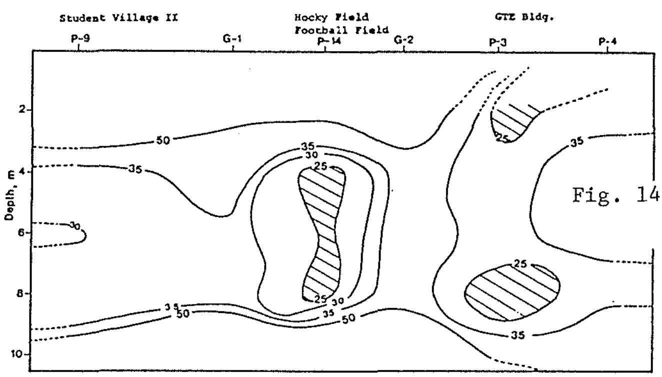


Fig. 14 Profile of Pressuremeter Modulus, Em in the section A1-E5, AIT Campus (Line P1)

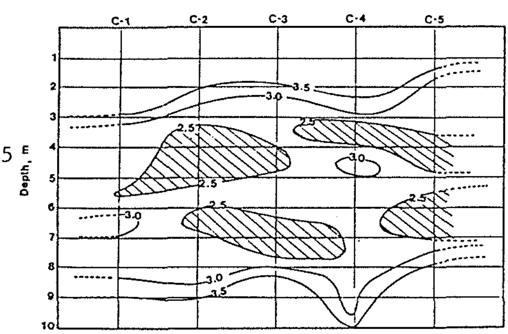


Fig. 15 Profile of Undrained Shear Strength along Section C1-C5 from Field Vane Shear Tests (Line C)

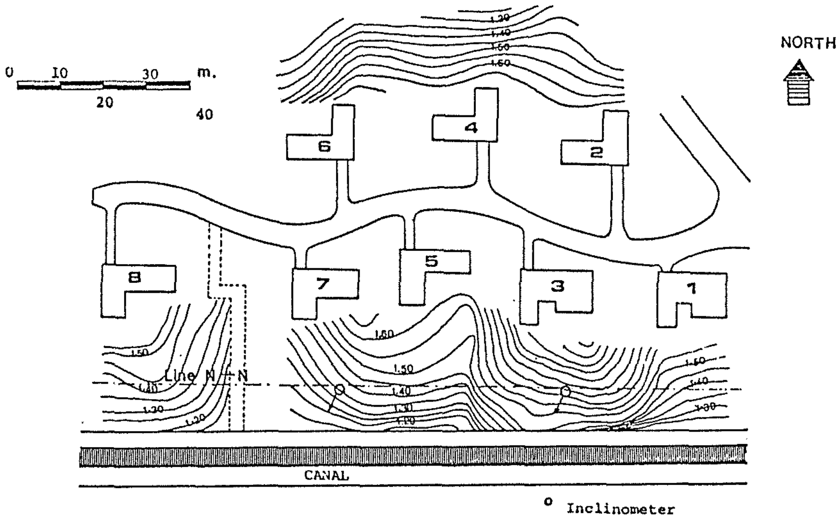


Fig. 16 Contour Elevation at New Zealand Housing, AIT Campus

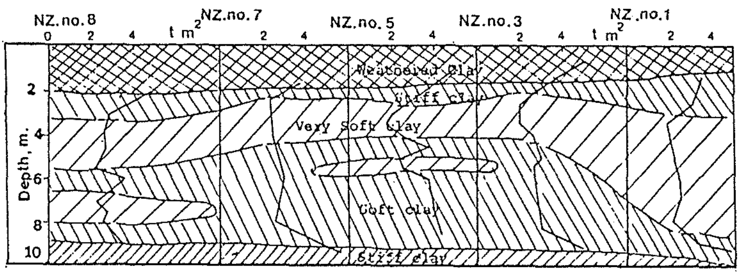


Fig. 17 Soil Profile along Line N-N at New Zealand Housing, AIT Campus

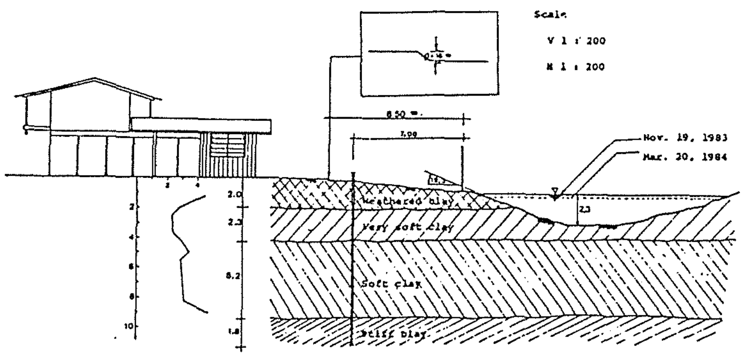


Fig. 18 Soil Profile and Inclinometer Location at NZ Housing, No. 3

Localized ground depressions occurring in open fields and highly loaded areas may also be caused by the presence of silt and fine sand lenses known to exist in the Rangsit soft clay that may serve as drainage paths accelerating subsidence due to well pumping from the leaky aquifer. Figures 12 and 13 show complicated shear strength profile than other areas in AIT campus. May be the density of silts and fine sand lenses in these areas is more than the others.

However, not all settlements are due to the weak subsoil and well pumping. Settlements are also caused by the erosion of the sand fill beneath pavements in areas near drainage trenches and underground sewers. The erosion occur in the subgrade through cracks in the concrete and through construction joints.

The subsidence in the NZ Housing Area as discussed previously may be caused mainly by slow lateral movements of the ground towards the adjacent canal. In three months period, the horizontal ground movements measured from inclinometers in the vicinity of House No. 3 and No. 7 were 1.13 cm and 0.55 cm, respectively, with locations and resultant directions indicated in Fig. 16. Soil profile through line N-N (Fig. 17) shows weaker layer with undrained vane shear strengths $\leq 2.5\ t/m^2$ in the soft clay at depths of 3 to 4 m. As shown in Fig. 18, the loss of lateral support as a result of the canal excavation may caused the slow lateral creep of the ground due to either the relative displacement of the upper weathered crust over the weaker subsoil or the slow squeezing of the weaker layer underneath the weathered crust.

Conclusions

From the results of this study, the following conclusions can be drawn.

In three months period, the average ground surface settlement is about 2.0 cm with maximum values near the pumping well. The average settlement on the pavements in Central AIT Campus is about 0.50 cm in 3 months period.

At the NZ Housing Area, a maximum settlement of 3.94 cm (in 3 months) was measured in the servant's quarters which unlike the houses are not on piles. Maximum settlements in three months period of 2.5 cm, 2.4 cm and 0.69 cm were measured in the damaged walls of the SEC and GTE building, HSD and ENV building, and Academic building, respectively. The walkway between the Hockey and Football Fields registered a maximum settlement of 4.39 cm in 3 months period.

Compressions of the subsoil showed that in the top 10 m and 20 m of the subsoil, compressions of 2.28 cm and 2.34 cm were measured, respectively, while compressions of the deep layers were relatively small.

The evidences of subsidence in the form of damages to existing structures and depressions of the surrounding ground can be correlated with the presence of low strength and very highly compressible zone in the soft clay underneath their corresponding locations. This large settlements in the damaged areas may also be caused by the higher than normal presence of silt and fine sand lenses that may serve as drainage paths resulting in an accelerated consolidation of the soft clay. However, settlements of pavements may also be due to the erosion of the sandfill in the subgrade.

The all around subsidence of the surrounding ground in the NZ Housing Area is mainly caused by either a slow horizontal movements of the surface hard crust over the very soft clay towards the canal or the slow squeezing of the soft clay towards the canal.

The present rate of groundwater pumpage is 4000 m^3/day. The well pumping for water supply in AIT campus is done in the Nonthaburi Aquifer at 180-200 m depth.

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