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SETTLEMENT DUE TO DEEP FOUNDATION CONSTRUCTION
TASSEMENT DU A LA CONSTRUCTION DES FONDATIONS PROFONDES
ОСАДКА В РЕЗУЛЬТАТЕ УСТРОЙСТВА ГЛУБОКИХ ОПОР

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SYNOPSIS. This paper describes a Singapore case history of adjacent ground settlements due to deep excavation for foundation construction. The settlements are shown to be a consequence of various factors such as the soft clay formation, the critical depth of excavation, the method of construction and the time lag in strutting. The pattern of the cracks and the gaps that were observed between the various blocks of the building—City Hall Building, are found to be consistent with the settlements that had occurred.'

INTRODUCTION

In 1966 Singapore began its programme of intensive urban renewal. Being landscarce skyscrapers with deep basements began to make their appearance in contrast to the conventional low storied houses. The construction of the foundations for these skyscrapers brings about a number of problems hitherto little known of in Singapore. Among these problems are the settlements of adjacent structures in congested areas due to deep excavations for basements in soft clay. These settlements have resulted in severe cracks and structural damage to numerous existing buildings. One such structure is the raft-founded City Hall Building adjacent to which a four basement underground car park for a multi-storey shopping complex was built. In the construction contiguous bored piles to depths varying between 60 feet and 90 feet and penetrating through soft marine clay to found at a very stiff clay layer were used. The struttings consisted of the basement floor slabs which were concreted as the excavation progressed. One month after excavation work had commenced numerous cracks were observed in the columns, beams and walls of the City Hall Building. A couple of months later, an investigation was initiated by the Public Works Department, Singapore to determine the causes of the cracks and the extent of structural damage. The investigation revealed that the settlements could be attributed to a number of factors, e.g. the soft clay formation, the critical depth of excavation, the method of construction and the time lag in strutting. The crack patterns and the gaps that were observed between the various blocks of the building were found to be

consistent with the settlements that had occurred. This paper presents the results of the findings.

CITY HALL BUILDING

The 40 year old City Hall Building, 250 feet by 380 feet approximately, Fig. 1, is located at the junction of Coleman Street and St. Andrew's Road. To its left is the pile founded Supreme Court Building and to its north is the Adepfi Hotel whose foundation is unknown. The Colombo Court Shopping Complex lies to its northwest and is separated from the City Hall and Supreme Court by a 36 feet wide service road. The City Hall Building, Fig. 2, is made up of five 4-storied blocks, each block being independent of the other. Block B and E are similar and so are blocks A and C. The construction of the various blocks is generally of reinforced concrete with brick panel walls. The typical foundation, section AA in Fig. 2, consists of columns which are carried down through spread footings to a 9 inch thick reinforced concrete raft-founded on sand at 6 feet below the original ground level. The average dead and live load on the ground is about half ton per square feet.

SOIL CONDITIONS

The soil conditions, Fig. 3, on which the City Hall Building is founded can be described as follows:

0 to 20 feet loose, fine to coarse sand

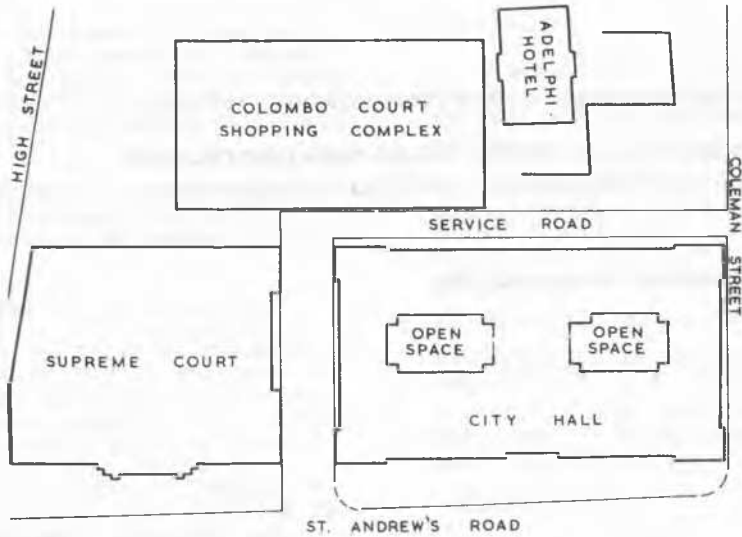


Figure 1 Site plan of City Hall Building

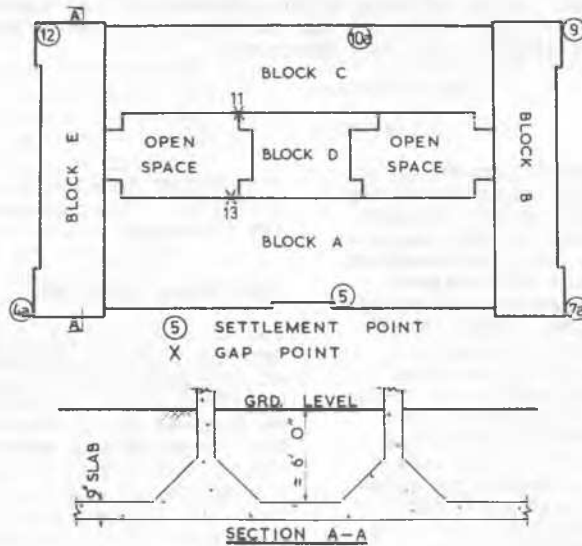


Figure 2 Settlement positions and foundation of City Hall Building

20 to 75 feet very soft to soft blue marine clay

75 to 95 feet stiff to very stiff multi-coloured clay

and the water table is 4 feet below ground level.

The characteristics of the soft blue marine clay is similar to that found in other parts of Singapore (see TAN 1970). The index properties are: LL=100, PL=30, clay fraction=50. The sensitivity varies from 5 to 8. The undrained shear strength is about 1.0 lb/in² and there is a slight increase in shear str-

ength with depth. The bulk density lies between 90 and 100 lb/cu.ft. The average m_v value is high, about 0.1 ft²/ton over the effective pressure range of 1 to 1.5 ton/ft². The undrained shear strength of the stiff clay is about 20 lb/in² and its bulk density is 135 lb/cu.ft.

COLOMBO COURT SHOPPING COMPLEX* - METHOD OF CONSTRUCTION

The Colombo Court Shopping Complex approximately 282 feet by 156 feet, Fig. 3, has a 4'6" lower ground floor and four underground basements each of approximate height of 8'6". *private development

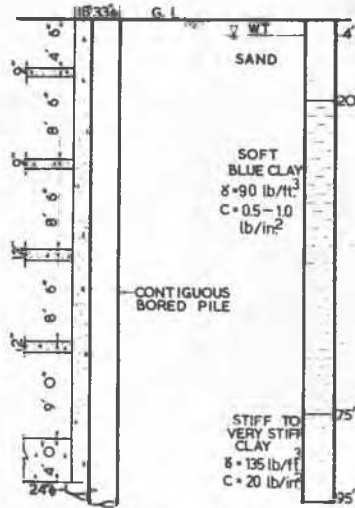


Figure 3 Soil Conditions and Cross Section of Colombo Court Excavation

The fourth basement is on a 4 feet thick floor slab which rests on piles. The total depth of excavation required during construction was 45 feet. To construct the basements contiguous bored piles each of diameter 33", were first placed round the periphery of the proposed site. These piles were embedded about 20 feet into the stiff clay. Next the excavation for the substructure was made to the first basement level. The floor slab which was to act as a permanent strut was cast. The

two operations, excavation and slab concreting, were then repeated for the second basement floor down and subsequent basement floors. The sequence of the construction is shown in Table 1. This 'upside-down' method which utilized strutting from the permanent intermediate basement floors is somewhat similar to that used for construction of the basement for the City National Bank Building in Los Angeles (TOMLINSON 1969).

SETTLEMENTS AND CRACKS

About a month (November 1969) after excavation had begun at the Colombo Court site, a series of cracks and gaps were observed at the City Hall Building, in particular, Block E (cracks) and Block D (gaps). As a result a number of tell-tale glass were fixed to the walls and measurements taken of the width and length of cracks and gaps. Subsequently, in April 1970, when the cracks became more pronounced and numerous, settlement readings at various points were also taken. The positions of some of the gap and settlement points are shown in Fig. 2. The plot of the amount of settlement against time since the excavation commenced for points 4a, 12, 5, 10a, 7a and 9 is presented in Fig. 4. It is observed that the settlements of the building are high at points (12, 10a, 9) nearest to the excavation and low (4a) further away. They are practically zero at points 5 and 7a. The amount and rate of settlement increased as the excavation deepened and tailed off as the construction of the final fourth basement approached completion. The rate of settlement was greater than that expected from consolidation settlement which had been very conservatively estimated as less than 0.1 inch per year. The above observations suggest that the consolidation settlement is unlikely to be a major contributor to the observed settlement but

Colombo Court Redevelopment

Table 1

	LOWER GROUND FLOOR*		1st BASEMENT*		2nd BASEMENT*		3rd BASEMENT*		4th BASEMENT*	
	Date Start	Date Complete	Date Start	Date Complete	Date Start	Date Complete	Date Start	Date Complete	Date Start	Date Complete
EXCAVATION	18/10/69**	4/3/70	18/10/69**	4/3/70	2/3/70	26/5/70	21/5/70	31/7/70	10/8/70	6/10/70
FLOOR SLAB CONSTRUCTION	23/2/70	13/4/70	7/1/70	13/3/70	16/5/70	29/6/70	13/7/70	5/9/70	6/10/70	18/12/70
DEPTH OF EXCAVATION	15'-6"		15'-6"		9'-0"		9'-0"		9'-6"	

* EXCAVATIONS FOR THE LOWER GROUND FLOOR AND 1ST BASEMENT WERE CARRIED TOGETHER.

** EXCAVATION OVER AREAS DIRECTLY BEHIND THE CITY HALL DID NOT COMMENCE UNTIL DECEMBER 1969.

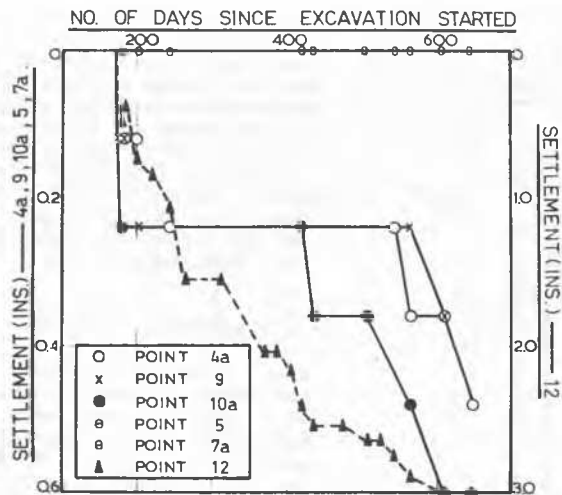


Figure 4 Settlement - time curves

rather the excavation work. This could be seen by examining the factors (PECK 1943, 1969) associated with deep excavation, which if not properly taken account of, would result in excessive settlement. The first of such factors to which scant attention had been accorded in the construction of the basements of the Colombo Court Shopping Complex, is the critical depth of excavation. This critical depth is the depth before which the first strut must be inserted in order to minimize any excessive adjacent ground settlement (PECK 1943). A conservative estimate of the critical depth for the construction in question showed that the first strut should be inserted before the excavation reached a depth of 10.5 feet. Referring to the dates shown in Table 1, it is seen that the first strut (permanent floor slab) was at a depth of about 13 feet below ground level and not at 4 feet 6 inch as indicated in Fig. 3. Hence the critical depth had been exceeded and excessive adjacent ground surface subsidence would result as had been observed. The second factor is the time lag between excavation and strut insertion, the shorter the delay, the lesser would be the adjacent ground settlement. For the Colombo Court excavation it was noticed that, Table 1, the date of completion of the first basement excavation was 4th March, 1970 and that of the floor slab which would act as a permanent strut was 13th March, 1970 - a time lag of 9 days. This delay was made worse by the additional time necessary for the floor slab concrete to cure and mature before it could become effective as a strut. Similarly there was a considerable time delay for the second basement (more than one month), third basement (more than one month) and fourth basement (more than two months). Further it was noted that before the floor slab became completely effective as a strut, excavation for

the next basement level had begun. This is shown by the date of commencement of the second basement (2nd March, 1970) and the date of completion of the first basement floor slab (13th March, 1970). Likewise the same applies to the third basement (date excavation commenced 21st May, 1970, date second basement floor slab completed 29th June, 1970) and fourth basement (date excavation commenced 10th August, 1970, date third basement floor slab completed 5th September, 1970). It is also noted that the bottom fourth basement is in the soft marine clay. This means the tendency for the base to rise during excavation is greater than otherwise. These factors, as discussed above all contribute to the observed excessive adjacent loss of ground. These excessive settlements are clearly shown by the settlements measured at points 4a and 9, which were five times the maximum depth of excavation away. (Note that the maximum quoted by PECK (1969) for three or more basements is only four times). It is also noted that the settlement at point 12 (3 ins.) is less than that (6.5 ins.) which could be estimated from PECK'S (1969) graph. This is because all the settlement readings were taken some six months after settlements had begun and hence the observed settlements would be less than that which had actually occurred.

In Fig. 5 the crack patterns on the first floor beams (Block E) facing the open space are presented. The photograph shows clearly that the columns at the extreme right had settled more than that at the middle left. This middle left column had in turn subsided more than that at the extreme left. These differential settlements had given rise to excessive tensile stresses at the bottom of the concrete beam (nearest to extreme right column) and at the top (nearest to the middle column) and hence the cracks pattern resulted.



Figure 5 Crack patterns on beams

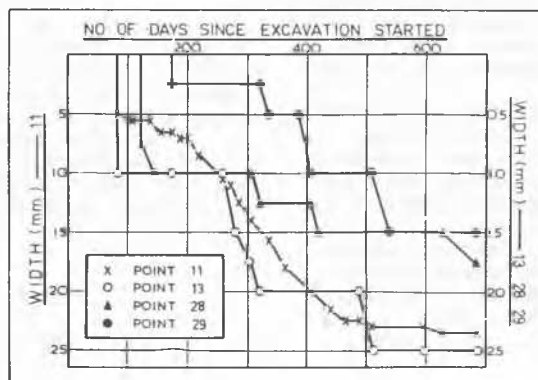


Figure 6 Crack and gap widths against time curves

The same observation applies to the span between the middle and the extreme left column and also to the beams of the two upper floors though not shown. It is interesting to note that the crack propagations were consistent with the differential settlements observed, Fig. 4, where point 12 settled more than points 4a.

The plot of crack width against time for points 28 (first floor) and 29 (second floor) of Block E is given in Fig. 6. The same figure also shows the third floor gap width for point II (between Block D and C and point 13 (between Block D and A) against time. The crack and gap widths increased with time i.e. with deepening of excavation, and became st-

eady and constant when the basement work was almost completed. This behaviour agrees with that observed for settlements, Fig. 4, indicating again that the excavation work is mainly responsible for the cracks and gaps. It is interesting to note that the gap width for point 11 is consistently greater than that for point 13. This suggests that Block C settles more than Block D, which of course is so since Block C is nearer to the excavation. This inference is again in agreement with the settlements observed.

In the above discussion we have confined ourselves to the cracks and settlements of City Hall Building. It is however of interest to note that some cracks, though not measur-

ed, were seen to have occurred in the nearby Adepfi Hotel. No perceptible cracks had been reported in the Supreme Court Building. This is probably because the Supreme Court Building is on piles.

CONCLUSIONS

The movements of the surrounding soil towards a deep excavation are responsible for the subsidence of the adjacent ground surface. The magnitude of the settlements depend on the type of soil, the method of construction and depth of the excavation. In the case of the City Hall Building it has been shown that the construction of the deep basements for the Colombo Court Shopping Complex is responsible for the cracks and settlements observed. These cracks and settlements are accentuated by the substructure being built in poor soil conditions and bad workmanship.

ACKNOWLEDGEMENT

The work described is published with the permission of the Director of Public Works, Republic of Singapore. The author is grateful to the Chief Executive Officer, Housing and Development Board for permission to reproduce Figure 3 and Table 1.

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