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The Effect of mixed foundations on the response of some buildings to excavation

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ABSTRACT: Many of the older parts of Singapore are built over deep deposits of near normally consolidated marine clay. Up to the 1930s buildings were typically founded on footings supported on a dense mass of bakau piles. The bakau piles were typically 3 m to 6 m in length. The typical terraced shophouses of Singapore, built on such foundations, settle with the ground surface. Conservation of large areas of Chinatown and Little India has involved the renovation of many of these shophouses. To meet modern design codes, renovated buildings often have an interior or extension that are founded on deep piles taken to competent bearing strata, while the conserved façade remains on the old, shallow foundations. The paper records examples of buildings on mixed foundations that suffered damage during excavation for the North East subway line in Singapore. The settlements, modes of deformation and final result of excavation near these structures are presented.

1 INTRODUCTION

Many of the older parts of Singapore are built over deep deposits of near normally consolidated marine clay. These deposits can reach 20 m to 40 m in thickness. Up to the 1930s buildings were typically founded on footings supported on a dense mass of bakau piles; for smaller buildings this practice continued at least into the 1950's. Bakau piles are still used today for minor structures, such as drains. Bakau piles are timber, typically 3 m to 6 m in length, and 50 mm in diameter. They are used to provide a uniform mat under the footings; they are not generally taken to firm bearing strata. The typical old, two to four storey, terraced shophouses of Singapore, built on such foundations, settled with the ground surface. Historically, many of these buildings have settled by hundreds of millimetres.

The older shophouses are typically constructed of brick, but from about the 1930s reinforced concrete frames began to be used, with brick infill. Older buildings that have not been refurbished commonly show

significant cracks as a result of historical settlement. Such cracks are, however, easily repaired.

Many shophouses were demolished with the modern development of Singapore. However, over the last 15 years major efforts have been made to conserve shophouses, particularly in the old Chinatown and Little India areas. Conservation has often been limited to preserving the façade of the buildings. The shophouses continue to be used as shops, restaurants, offices and as homes. Upgrading the inside of the building for modern use often requires that deep foundations are introduced, in order to comply with modern design codes. This has resulted in many buildings where part of the structure is on shallow foundations over deep soft clays, while other parts of the building are on deep foundations.

Building on mixed foundations, or terraces of buildings on differing foundations can be exceptionally sensitive to settlement. Unlike buildings on uniform foundations, they are also very sensitive to settlements caused by consolidation. Examples of the behaviour of buildings on mixed foundations, which

were affected by the construction of Singapore's North East Line, are given below.

2 FOOCHOW METHODIST CHURCH

The Foochow Methodist Church is located along Race Course Road (Figure 1). Cut-and-cover tunnels were excavated to a depth of 17.5 m on the far side of Race Course Road from the church (see Figure 2).

The excavation was carried out within diaphragm walls 0.8 m in thickness, supported by 5 levels of struts. A jet grouted slab was formed just below final excavation level (Wen et al 2001). The ground conditions consist of 10 m of fill and fluvial sand overlying near normally consolidated marine clay. At a depth of approximately 23 m below ground surface dense or very stiff to hard Old Alluvium was encountered.

The church proper has three floors. On Sunday each floor is used for separate services, in different dialects. On the east side of the church was a four storey building, used as a kindergarten, and beyond that a three storey building used mainly as a Sunday school. However, the complex appeared to be a single, continuous building.

The first signs of damage occurred before excavation of the North East Line even started. Bored piling was carried out for a private development adjacent to the Sunday school. Although excavation work for the North East line had not yet commenced, instrumentation had been installed in readiness for diaphragm wall construction.

Settlements of up to 15 mm were measured on the Sunday school block, with a differential settlement of 6 mm across the frontage. This settlement caused a significant crack to open up at the junction between the Sunday school and the kindergarten. This crack was wider at the top of the building than the bottom. The crack was negligible at ground floor level, while at the top of the building the width was about 12 mm. The pattern of cracking indicated that the Sunday school

block was rotating away from the rest of the building. The point of rotation was at the junction of the buildings, at ground floor level.

The degree of damage was high relative to the amount of settlement recorded. The amount of damage, and the pattern of damage, indicated that the building was likely to be on mixed foundations, and a detailed assessment of the foundations and building structure was then carried out. The church complex was found to be a mix of structures that had evolved over many years. The original church proper was a two storey structure that had been built in the 1930s, on shallow foundations. The Sunday school block had originally been built as an apartment building in the 1950s, and was founded on bakau piles. In the mid 1990s the church and Sunday school were integrated. This was done by constructing a linking section, used as a kindergarten school in the week. At the same time the church was extended upwards, to provide the third storey, and sideways, on the side opposite to the kindergarten. All of the newer structures, that is the linking kindergarten and the extensions to the church proper (sanctuary area), were founded on piles taken through the marine clay and into the Old Alluvium. No underpinning of the old structure was carried out; in effect, the old church building, on shallow foundations, was wrapped within the new structure on deep foundations.

After reviewing the design of the structure, there were three aspects of particular concern:

- The junction between the old church building and the new parts. A limited provision for differential movement had been allowed for in the design and detailing. Movement in excess of that provided for would result in the two structures becoming locked together. At this point further differential settlement would cause large stresses to develop in the elements connecting the two structures.
- The front façade of the church. The façade of the old church had been extended upward from the second storey level to several metres above the third storey level and had been structurally separated

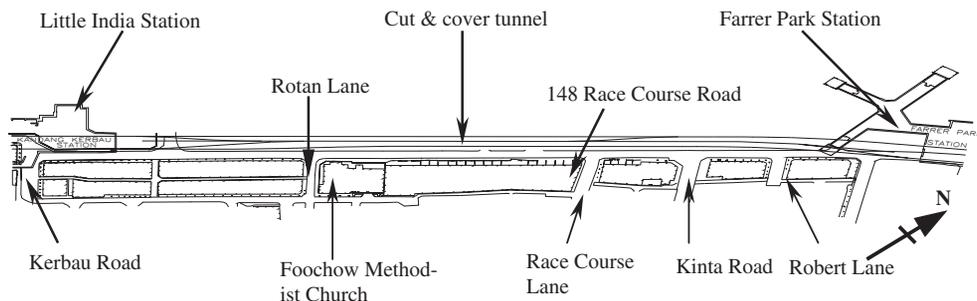


Figure 1. Race Course Road area, showing the location of the Foochow Methodist Church and number 148, Race Course Road.

from the new structure of the church. Some accidental restraint had been provided by brickwork that crossed between the facade and the main structure. Differential settlement would lead to this restraint being broken, with a risk that further differential settlement would cause the façade to tilt forward and perhaps collapse.

- The junction between the Sunday School block and the new structure (kindergarten area). Although some movement joints had been provided at the junctions of structural elements, these joints were only partial. Internal walls and ceilings passed across such movement joints as there were, without any provision for movement. A computer room had been constructed on the flat roof of the Sunday School block, but with its roof cantilevering out from the newly built section. By early September

1998, before excavation for the cut and cover tunnel extended in front of the church, large cracks had appeared in the walls of the computer room and in other walls which crossed the joints between the old and new structures. This occurred because the roof of the computer room was effectively supported by the piled, newly built section, while the rest of the old building rotated away.

The planned excavation was 17.5 m in depth, in soft marine clay of the Kallang Formation. Significant settlement, in excess of 100 mm, was anticipated, despite the provision of a jet-grouted slab at the base of the excavation. The building was clearly exceptionally sensitive to settlement, whether induced by diaphragm wall movement or consolidation. It was decided that it would not be possible to restrict settlement to a level

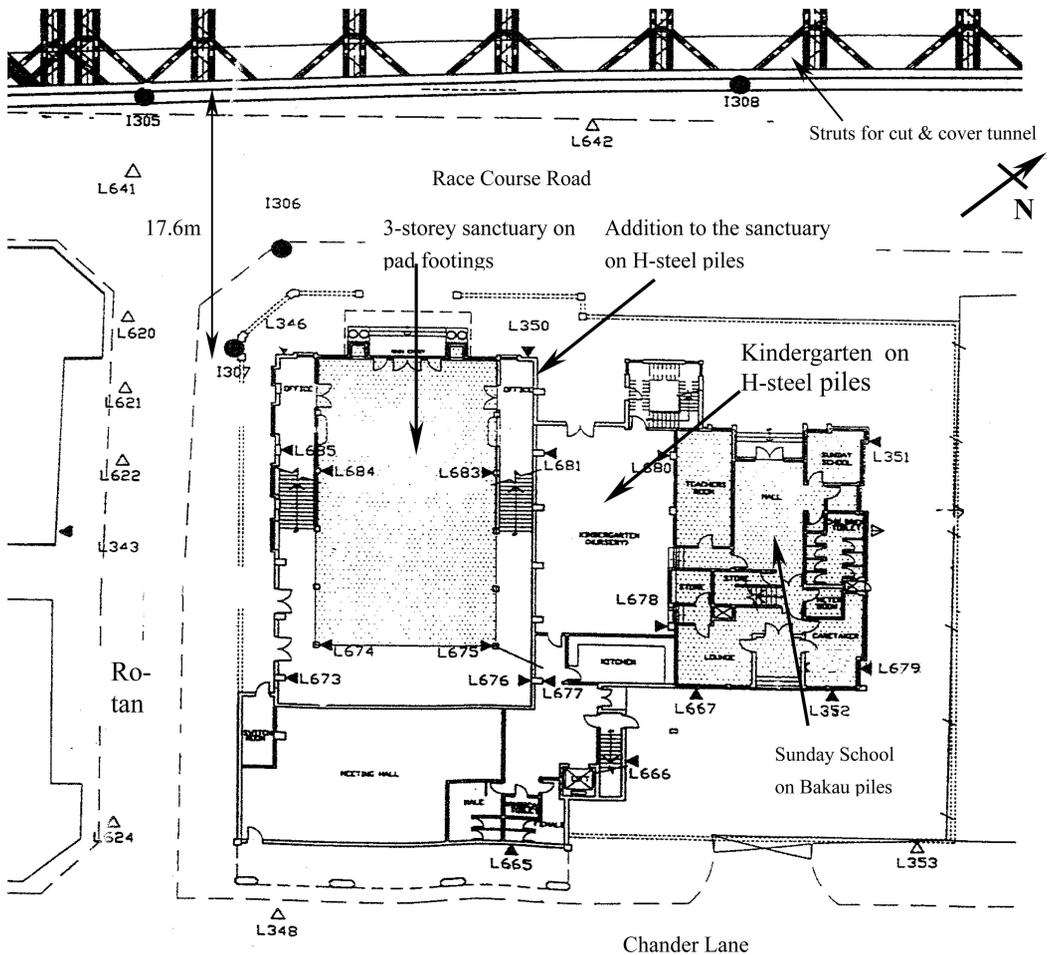


Figure 2. Fochow Methodist Church, showing the location relative to the cut-and-cover tunnels and the various foundation systems within the building.



Figure 3. Fochow Methodist Church during the early stages of the construction of the cut-and-cover tunnel excavation. The façade has been propped, as discussed in the text.

allow the safety of the public to be assured. The primary concerns were with that would the main church structure, including the façade, rather than the Sunday school block where damage was first observed. It was decided to underpin the old church, including the façade, so that it was on uniform foundations. Due to the disruption involved in underpinning, the congregation was provided with alternative premises during the period of the underpinning. The alternative premises had sufficient space to house the kindergarten and Sunday school classes. The Sunday school block was not underpinned. It was planned to allow this block to move during excavation, and repair the damage that occurred. In the end, the church committee decided to demolish the Sunday school block soon after the excavation was complete, and build a larger structure in its place.

Excavation of the cut and cover tunnel in front of the church took place between October 1998 and May 1999. The maximum wall deflection opposite the Sunday school area was only 43 mm, significantly less than the approximately 100 mm predicted, based on the design. However, the maximum measured settlement on the Sunday school block was exactly 100 mm. Based on Nicholson (1987), the maximum settlement should be approximately equal to the maximum wall deflection, to which can be added settlement due to consolidation and wall installation. This would imply that there was about 43 mm of settlement due to wall movement, with the remaining 57 mm mainly due to consolidation. Pore pressures in the Old Alluvium underlying the marine clay dropped by up to 8 mm, which would be consistent with the excavation causing under drainage of the marine clay. Although the maximum settlement of the Sunday school block was



Figure 4. Cracking at the junction of the old sanctuary area and the new building, on the inside of the façade.

100 mm, the side nearest the kindergarten settled by only 14 mm, leading to a differential settlement of 86 mm. The Sunday school block tilted by 1:130, away from the rest of the church complex. This led to massive cracks developing at the junction between the kindergarten block and the Sunday school area. The cracks were repaired on a number of occasions, but overall were up to 50 mm in total width. Internally, ceiling tiles fell and a number of partition walls were severely damaged. Figures 4, 5 and 6 show some of the cracking that had developed by August 1999, three months after the excavation in front of the church was



Figure 5. Cracking at the junction of the Sunday School (old) and Kindergarten section (new).



Figure 6. Cracking at the computer room. The roof is cantilevered off the new structure, the floor is part of the older Sunday School area.

completed. The photographs were taken in areas at the junctions between the old and new sections of the building, where the cracking was most severe.

3 NUMBER 148, RACE COURSE ROAD

Number 148 Race Course Road is located about 130 m from the Foochow Methodist Church. The

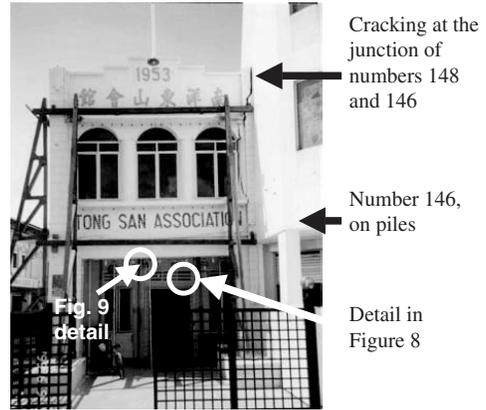


Figure 7. Number 148, showing the severe cracking at the junction with number 146, Race Course Road.

excavation depth, wall type and general excavation arrangement were the same as that at the church.

Number 148, Race Course Road is a two storey shophouse that is used by the Tong San clan association (Figure 7). The structure dates from 1953, and is founded on bakau piles. At some point in the 1990s the building was renovated. Included in the renovation was replacement of the 2nd storey floor with new concrete slabs. A series of steel frames was inserted into the masonry building to carry these new floor slabs. However, there was no record of any strengthening of the foundations. In the mid 1990s the adjacent shophouse at number 146 Race Course Road was demolished, and a new four storey concrete structure erected, founded on piles taken through the marine clay and into the Old Alluvium. In the construction of the adjacent building, half of the old brick party wall was removed. A thin separating membrane was applied, against which the new building was cast. However, the roughness of the old brick wall meant that there was a significant degree of interlock between the two buildings.

The excavation in front of 148 Race Course Road was carried out through 3 m of fill, 4 m of an upper fluvial sand layer, 8 m of upper marine clay, extending into a 4 m thick intermediate fluvial sand layer. Below the excavation was 11 m of lower marine clay, overlying the Old Alluvium. The total depth of soft deposits was 30 m.

The maximum settlement of No. 148 due to excavation was 107 mm. This settlement was measured on the corner of the building facing the excavation and adjacent to Race Course Lane (see Figure 1). The opposite side of the building was held up due to the rough interface with number 146. Although the settlement on this side of the building was not measured, it can be assumed that there was little or no settlement, due to the support of the adjacent, piled building. As



Figure 8. Cracking of the front of the building due to racking.

a result there was a differential settlement of about 100 mm across the front face of a building with a width of about 5 m, giving a differential settlement of about 1:50. The maximum settlement at the rear of the building was 58 mm. The depth of the building was approximately 30 m. The differential settlement between the front and back of the building was 49 mm or about 1:612. Across the building, at the back, the differential settlement was about 50 mm, with or 1:100.

The effect on the building of the differential settlement was severe damage. Figure 7 shows the front face of the building, with significant separation cracking at the junction between number 148, and the neighbouring number 146. Figures 8 and 9 are close ups of the lower part of the front façade, showing severe cracking of the block work over the doors due to racking of the building. There was similar, but less severe, separation and racking cracking in the other cross walls.

The diaphragm wall deflection was 65 mm. This deflection, which was relatively low for the ground conditions, was achieved through the use of a jet grout slab placed at the level of the base of the excavation. The wall deflection would have caused about 60% of the total settlement experienced, with the remainder mainly due to consolidation. There was a gap in the diaphragm wall at the intersection of Race Course Road and Race Course Lane, due to a major utility at this point. Excavation through the upper sand layer, and particularly, into the intermediate sand layer resulted in both leakage and loss of ground.

Several other shophouses along Race Course Road experienced almost as much settlement as number 148, in the range of 70 to 100 mm. Shophouses that were on their original, bakau pile, foundations suffered



Figure 9. More details of the cracking of the front of the building.

little damage as a result of the settlement. The extensive damage at number 148 was mainly due to the large differential settlement across the face of the building. Even though the building itself was on consistent foundations, the way that the next door building had been constructed resulted in one side of the building being rigidly supported while the other side was free to move.

4 OTHER CASES

There has only been space here to present two cases of damage to buildings on mixed foundations. A third case is presented in Shirlaw et al (2003). There were a number of other cases of damage to buildings on mixed foundations during the construction of the North East line. The majority of the buildings that suffered significant damage during construction of the line were on mixed foundations.

In order to minimise the risk of damaging buildings on mixed foundations, the first step that is required is to develop a good understanding of the current foundation system. However, this is not always easy. Many of the older buildings in Singapore have been through two or more major renovations, but the records are not always available.

Buildings on mixed foundations can be so sensitive to settlement (as in the example of the Foochow church) that it is simply not possible to control the movements due to excavation to a level that would avoid significant damage. This sensitivity can be reduced or eliminated by cutting apart the sections on

different foundations, or by underpinning the building so that the foundation response is relatively uniform.

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