Lessons learned from the collapse of the Nicoll Highway in Singapore April 2004

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Introduction

During the construction of Contract C824 of the Circle Line in Singapore, on 20th April 2004 an 80 m long section of excavation, 30 m deep, totally collapsed. The resulting crater was as deep as 15 metres and was more than 100 m in diameter. Six lanes of the adjacent Nicoll Highway subsided by as much as 13 m. 4 men lost their lives.

Public Inquiry

A Committee of Inquiry was established. Public hearings were held from May 2004 until December 2004 and the Final Report was published in 10th May 2005. Ref 1. The Committee decided that there was a host of causative factors. They identified four major causes and fifteen contributory causes.

In February 2004, two months before the collapse, walers between struts and wall panels at a nearby location were found to have buckled. As a consequence the design of the connection between the struts and the walers was changed. Pieces of steel channel section were added to strengthen the connection. Unfortunately the strengthening did not provide adequate capacity. Subsequent laboratory tests on perfectly constructed samples showed about half the capacity. Moreover whereas steel normally strain hardens and has marginally increased capacity after initial yielding, the connection exhibited brittle failure with massive reduction in capacity after first yielding.

Early on 20th April 2004 walers were found to be buckling and attempts were made to reinforce them. However the efforts were in vain and later in the day the whole system of diaphragm walls and 9 levels of strutting collapsed.

The Committee decided that design errors resulted in the initial failure of the 9th level strutting and the ensuing total collapse resulted from inability of the retaining system as a whole to resist the redistributed loads arising from failure of the strutting at the 9th level.

Some of the practical lessons learned

The majority of the soil supported by the diaphragm wall was soft marine clay which would not drain significantly during the works. Therefore it was rightly assumed that the soft clay would be undrained. The computer program PLAXIS allows input of undrained shear strengths directly, Method B, or input of effective stress strength parameters c’ and φ’, whereby the shear strength is calculated using the Mohr Coulomb model with an undrained setting, Method A. The undrained setting, with no change of volume of the soil, results in no change in the isotropic stress, and as a result of adopting a strength criterion with an angle of friction, an over-estimate in the strength of a normally consolidated clay. The manual recommended the use of Method A. Using Method A for this project the computed displacement of the wall is about half of the value obtained by using Method B. The bending moment in the wall is similarly under-estimated.

An essential part of site safety is monitoring the performance of the works. The instrumentation included two inclinometers that were used to monitor the lateral displacements of opposing wall

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panels. From these readings one could compute the convergence between the walls at every strut location. A comparison showed that the rate of convergence between the walls did not match with the monitored forces in the struts showing that the strutting system was progressively yielding weeks before the failure.

From the inclinometer profiles one can determine the radius of curvature at any given time from which it is possible to determine the bending moment in the wall panel. Inclinometer results showed that a plastic hinge developed in the wall panel at the location of the failure some three weeks months before the collapse. The Alarm Level for the displacement was exceeded and it was relaxed twice, without recognizing the distress of the wall panel at the time. Alert, Action and Alarm levels (AAA) of maximum movement are relevant to limiting ground movement and protecting the surrounding ground and adjacent property. Such limits do not relate to the performance of the wall in bending for which a limit on the radius of curvature would be appropriate.

The design required the struts to be pre-loaded to 75% of the design maximum force and locked off. Within one hour after lock-off the load had dropped to only 20% of the required pre-load. The AAA limits were based on not over loading the struts. Because the AAA limits were set with a maximum force commencing at 50% of the design load no warning was issued. Just before the collapse the readings had not exceeded 35% of the design value. Unfortunately, it was not observed at the time that the force in the strut was only 35% of what it should have been. At that stage the total forces provided by all 9 levels of struts on the wall was only 67% of the design value which means that the wall was barely supported. The factor of safety against forwards movement was one and the walls were moving.

Actions Taken

Immediately after the collapse, LTA appointed independent checkers of the design for all then current temporary works, LTA commissioned re-examination of all temporary works under way, and LTA issued revised design principles for temporary retaining walls. Temporary works were to be designed to same standards as permanent works. Building and Construction Authority (BCA) required immediate check on all uses of PLAXIS.

In May 2005, BCA promulgated guidance notes to concerned parties which set out new standards for site investigation, design and construction of deep earth retaining structures. Ref 2.

Major changes are advising that temporary works should be designed to the same standards as permanent works, checked independently.

LTA appointed consultants to perform independent reviews and checks for the completion of the Circle Line and procures instrumentation directly and not via the main contractor.

The office of the Building Control Unit in LTA has been closed and now BCA administers Building Control for LTA construction projects.

References

1 Report of the Committee of Inquiry into the incident at the MRT Circle Line Worksite that led to the collapse of the Nicoll Highway on 20 April 2004. R. Magnus, Er. Dr. Teh Cee Ing and Er. Lau Joo Ming. May 2005. Submitted to The Hon. Minister of Manpower. Singapore.

2 Advisory note 1/05 on Deep Excavation. Commissioner for Building Control, Government of Singapore, 5 May 2005.