Urban Geological Problems in Taiwan

slope stability, subsidence, liquefaction

Moh and Associates, Inc. Member, ISSMGE Dr.Za-Chieh Moh
Moh and Associates, Inc. Member, ISSMGE Dr. Richard Hwang

INTRODUCTION

As population grows and lands become scarce, developments tend to expand to areas in which ground conditions are not favorable, such as hill slopes and swamps. Slope failure and ground subsidence are thus two common geological problems associated with urbanization. Presented herein are the measures taken in the City of Taipei to deal with these problems. Also discussed are the problems faced in design and construction of underground structures. Although the paper only quotes the City of Taipei as examples, some of the problems discussed are nevertheless fairly common to other urban areas on Taiwan.

PROTECTION OF SLOPELANDS

The Taiwan Island is located at the convergent boundary between the Philippine Sea Plate and the Eurasian Plate and was extruded from the ocean as a result of tectonic movements of these two plates. Therefore, the geology of the island is very fragile with steep terrain and numerous faults. Furthermore, the island is on the path of typhoons and experienced 3 to 5 typhoons, on an average, annually. Heavy storms induced by typhoons and tropical cyclones often resulted in large landslides in summers and autumns. Slopelands takes up about 55% of the total area of the city of Taipei and landslide is thus a serious concern for the citizens of Taipei. The problem of landslide in the suburbs of the city is becoming increasingly serious as a few fetal accidents occurred in recent years. The failure of a hill slope, which was previously stabilized by ground anchors, during Typhoon Winnie of August 1997, for example, destroyed four 5-story apartments and took 28 lives. A recent study shows that there are 24 communities which were identified as vulnerable to landslides and debris flows. As a precaution, the city government evacuated the one most vulnerable in January 2002 permanently and resettled the residents somewhere else. This task is to continue on other communities to minimize the potential loss due to landslides and debris flows.

To be better prepared, the city government has established databases using the GIS systems to compile geological information, such as terrain, faults, abandoned mines, etc. and records of landslides, debris flows, etc. with the aim of developing a regional hazard mitigation program. Satellite images were studied to identify old landslides and traces of debris flows. Based on the results obtained, environmental sensitivity maps were prepared. These maps are useful for the government to regulate future developments on slopelands and can also be used by various agencies to conduct planning of infrastructures.

The problems associated with developments on slopelands are by no means limited to landslides, replacement of vegetation with pavement has reduced the ability of soils to retain water. Although the unprecedent rainfall was partially responsible, the worst-ever flooding in the city in Typhoon Nari in September 2001 was caused by the rapid convergence of surface water into rivers. The flood, up to 10m in depth, covered nearly one third of the city and took 82 lives. All the underground sections of the rapid transit systems were submerged in water and it took 3 months for the operation of the rapid transit system to be back to normal. Although the city government had already raised the levees along the Keelung River to a level corresponding to floods with a 200-year return period, the street drainage systems could only cope with floods with a 5-year return period. The situation was worsen by the fact that 8 pumping stations stopped working as their cooling systems were submerged. Of these stations, the Yu Chen Station is the largest pumping station in the Southeast Asia and is capable of draining a full size swimming pool in 8 seconds. Soon after this station was submerged, the flood level in the city quickly rose. To prevent similar events from happening, the fences surrounding these pumping stations have been raised to a height of, up to, 8m above the ground.

GROUNDWATER DRAWDOWN AND GROUND SUBSIDENCE

Ground subsidence was once a major problem in the Taipei Basin due to excessive pumping of groundwater from the underlying Chingmei Gravel which is a thick water bearing layer existing at a depth of 40m below the surface and was the sole source of water supply for the entire Taipei Basin for years. The piezometric level in the Chingmei Gravel was a few meter above the ground surface at the turn of the 20th century and dropped to a level of 40m below the surface in the 70's. As a result, the ground settled by, as much as, 2.2m in the city central of Taipei. Fortunately, the population in those days was small and buildings were mostly 6 stories or lower and were supported on compensating foundations. Furthermore, subsidence was wide spread and was rather uniform. Therefore, it caused very few foundation failures, if any. Elsewhere, ground subsidence has become a major problem in

總經理 莫若楫博士 亞新工程顧問股份有限公司
副總經理 黃南輝博士 亞新工程顧問股份有限公司

costal areas of Southern Taiwan in recent years because of excessive pumping for drawing water for fish farming. Although the areas which are now experiencing subsidence are not as populated as the city of Taipei, the subsidence does cause serious concern in the engineering society as the High Speed Rail which is now under construction is to pass through these areas.

CONSTUCTION PROBLEMS

In the late 60's, the government banned the use of groundwater as water supply. The piezometric level in the Chingmei Gravel recovered at a rate of 1.5m per year in the beginning and this rate of recovery reduced to a current rate of 0.5m per year. It is now only a couple of meters below the surface. Although it is highly unlikely for it to return to its original level, it will not be a surprise if the piezometric level in the Chingmei Gravel does recover to the ground level. The recovery of the piezometers level in the Chingmei Gravel stopped ground subsidence but, on the other hand, reduces the factor of safety against blow-in and makes deep excavations more difficult than before. It also reduces the factor of safety against floatation and it is expected that some of the light structures with deep basements may suffer some sorts of floatation problems if the piezometric level in the Chingmei Gravel does go back to the ground level.

The presence of the Chingmei Gravel has indeed caused serious problems during constructions in the past. In fact, all the major accidents during the construction of the Initial Network of the Taipei Rapid Transit Systems were due to piping which started as minor leakages and soon became uncontrollable as the water paths connected to the Chingmei Gravel. The most costly accident occurred when opening was made on the diaphragm wall of a working shaft for the shield machine to enter during the construction of the Panchiao Line. Groundwater ran into the shaft from this opening and the shaft had to be flooded to balance the water pressures on the two sides of the wall for the purpose of stopping the inflow. As a result, two shield machines and three sections of tunnels were submerged in water. It was later found that water came from an abandoned pipe which was once used to draw water from the Chingmei Gravel, presumably, for irrigation. The situation would not have been so bad if there were not a piece of timber right next to the pipe. Although the ground surrounding the opening had previously been treated by jet grouting, the integrity of the treated ground was disturbed as the shield machine arrived and stirred this piece of timber.

Large pieces of timbers (drift woods) were responsible for the difficulty encountered during excavation of a section of tunnel in the Chungho Line. The progress of the tunneling was reduced to less than 1m per day and a sinkhole was created in front of the shield machine because the volume of soil got into the chamber and removed from the chamber exceeded the volume of the ground excavated by the shield machine. Ground treatment had to be carried out in front of the machine for workers to go out of the chamber to remove the obstacles. Timbers do not have to be large to be problematic. A small piece of timber (about 5cm in diameter and 20cm in length) somehow intruded into one of the injection holes on the cutter of a shield machine used for driving one of the tunnel sections in the Tuchen Extension of the Panchiao Line and, as a result, lubricant could not be injected to lubricate the soil to be excavated and the progress of the tunneling was reduced to less than 1 m per day. Similarly, ground treatment had to be carried out in front of the machine for workers to go out of the earth chamber to remove the obstacles.

LIQUEFACTION

The devastating Chi Chi Earthquake, with a magnitude of 7.6 (Richter Scale) of September 21, 1999 was the biggest earthquake in the century with its epicenter on the island. It took more than 2,434 lives and destructed nearly 100,000 buildings. Subsequent to the earthquake, the design code was revised based on the recorded ground motions. This has drastical impacts on the seismic design of structures because the design ground motions are substantially stronger than those adopted before. One of the most difficult issues to face, as far as geotechnical engineering is concerned, is soil liquefaction during earthquakes. Take the central city area of Taipei for example, subsoils contain mainly sand silts with low consistency and liquefaction would occur, theoretically, once peak ground acceleration exceeds 0.18g. A peak ground acceleration of 0.23g is now assigned and liquefaction becomes inevitable. The design of tunnels of rapid transit systems against liquefaction becomes rather complicated and difficult. Any countermeasure against liquefaction would be bloodily expensive and unjustifiable but its omission is equally difficult to defend. This issue deserves a serious consideration because design ground motions tend to become stronger and stronger as more and more earthquakes occurred. A methodology is now in demand to evaluate the cost of mitigation and the benefits gained.

CONCLUSIONS

Geology and geotechnical engineering are important elements to be considered in urbanization because ignorance of either of these two elements might lead to serious consequences on environment and during constructions. Furthermore, liquefaction is likely to become a common concern in many cities and methodology is desired to evaluate the cost-benefit of mitigation programs to arrive at reasonable and, at the same time, cost effective designs.