Role of engineering geology investigations in deep excavations

Zaman Malekzade

i) PhD, Department of Geology, Payame Noor University, PO BOX 19395-3697, Tehran, Iran

Abstract

In congested urban area it is common to do excavation several meters lower than ground surface to have sufficient space for car parking and electromechanical facilities. Excavation is one of hazardous tasks in the context of civil engineering activities. Geotechnical assessments coupled with engineering geology explorations play important role in reducing hazards associated with excavation. In these excavation works, especially in megacities, concentration on engineering geology aspects of the sites is usually at least or ignored. That is, geological features of the site in addition to the geotechnical properties have to be studied. On the basis of observations, between different case studies, and in one of excavations, this paper presents documented problems encountered governing by presence of a large fault zone. Of these problems are uncontrolled deformation in some parts of the retaining wall and its consequent to damage neighboring buildings, local uprising water table and its effect on the internal and external slope stability. This case study has been done on hard soils that faulting has generated a wide crushed zone with tight fault planes. In this case, it is advised to consider these weak planes in modeling when engineers want to evaluate slope stability safety factor by limit equilibrium analysis and/or calculation of deformation due to excavation by finite element method. These collaborations have to be continued along the excavation implementation because, in these cases, supports with sufficient capacity with the slot excavation (sequential excavation dictated by soil conditions) are needed. That is, two disciplines of geotechnical engineering and engineering geology should support together properly. Therefore, I selected one of problematic project in that there was not such reconciliation between geotechnical and geological data thereby it experienced damage from these defects.

Keywords: engineering geology, excavation, fault

1 INTRODUCTION

Application of geological concepts in engineering tasks is an essential definition of engineering geology but I think it is not all. One of major features that inherited in geology, as a whole, and distinct it from engineering knowledge is “looking up soils and rocks behaviors as a function of geologic time in a wider range than soil and rock mechanics does”. Effects of geo-structures such as faults, beddings, joints and the cementation on the slope stability as post-dated events (after deposition of soil) are as examples. Geologically, these structures and elements considered as continuous elements in the context of discontinuous or discrete medium including soils or rocks. Engineers often ignore these surfaces or elements as discrete surfaces or elements affecting the physical properties especially when he or she models hard soils (behaves as a soft rock) by a finite element or limit equilibrium approaches.

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This paper aims to introduce a case study in which the knowledge and concerns of engineering geology could help to find a better way to solve the problems encountered during a problematic and hazardous task: a deep excavation that eventually failed (Figure 1). This study is done in Tehran (capital of Iran) megacity where civilization does not permit populations to distribute horizontally. That is, in such an area people have to find enough room to emplace mechanical facilities and car parking in underground spaces through the excavation.

2 GEOLOGICAL AND GEOTECHNICAL PROSPECTING

Tehran plain locates between south of Alborz mountain and central Iran depression (Figure 2). It fills with about 1km Quaternary alluvial deposits yielded by erosion of high lands after late Alpine orogenic phase. Sequentially, it is divided by at least four groups: A, B, C and D those are getting younger respectively. Among them “A”, so called Hezar Dareh alluvium, is significantly impressed by late Alpine orogenic events and folded. Therefore, dipping is one of major features for “A” to distinguish it from three other of alluviums those are horizontally underlain by it. Usually, wherever the “A” alluvium is exposed on the ground surface a fault responsible for its exhumation is more probable as it is the case for this case study. Three other alluviums differ from together by age, grain size, density and their geographic extension. As a general role and due to the southward dipping of Tehran plain from foothill to the central Iran plane, grain size of deposits become finer from north to the south respectively.

Seismotectonic studies in this site mapped a predefined thrust fault (Berberian, 1988) dipping south namely “Davodieh” thrust fault passes near (some 500m) the site. Field observation, however, indicates this fault (and/or its branches) exactly crosses the site (Figure 3).

3 DATA

To evaluate the geological feature of the fault some fault plans measured in the area on which the excavation was bare (Table 1). Then, kinematic analysis has been done on the data to discover the fault type as method expressed by Carey (1986). The result shows a thrust faulting with some left laterally strike-slip component (Figure 4). It is noticeable to cite that the fault and its effects have not been studied before implementation of retaining wall. Direction of maximum of in situ stress deduced by the microtectonic analysis is NE-SW.

As stated earlier, the targeted case study is an excavation located central northwest of Tehran with maximum depth of 30m (Atrchian, 2014). Method served for retaining system is soil anchorage. Soil mostly consists of dense to very dense gravel, sand and a considerable part of fines namely GM-GC to SM-SC; according to the USC (unified soil classification) (Figure 5).
Geotechnical study reported a perched water table in variable depths (Figure 5). This is confirmed by GPR (Ground Penetration Radar) by which a high frequency electromagnetic waves send to the undersurface and reflected or refracted by some soil layer (as an absorbing surface) containing higher water content. The surfaces may indirectly imply faults surfaces (Figure 6).

Table 1. Fault planes measurement result. Abbreviations are: A = Azimuth of fault planes, D = Dip of planes, DD = Dip Direction of planes (N = North, S = South), R = Rake of fault slip, RD = Direction of Rake (N = North, S = South, W = West, and E = East), K = Kinematics (D = Dextral, S = Sinisteral, I = Inverse).

| A  | D  | DD | R  | RD | K  |
|----|----|----|----|----|----|
| 352| 70 | N  | 10 | N  | D  |
| 310| 70 | N  | 11 | S  | S  |
| 75 | 60 | N  | 10 | E  | S  |
| 350| 85 | N  | 10 | S  | I  |
| 300| 70 | N  | 50 | S  | I  |
| 250| 50 | N  | 60 | W  | I  |
| 240| 45 | N  | 70 | W  | I  |
| 145| 80 | S  | 40 | N  | I  |
| 300| 65 | N  | 60 | E  | I  |

Table 4. Fault planes measurement result. Abbreviations are: A = Azimuth of fault planes, D = Dip of planes, DD = Dip Direction of planes (N = North, S = South), R = Rake of fault slip, RD = Direction of Rake (N = North, S = South, W = West, and E = East), K = Kinematics (D = Dextral, S = Sinisteral, I = Inverse).

To classify the soil in point of earthquake engineering purpose accordance with UBC-97 and finding some of dynamic properties 3 geophysical down hole tests have also been done. The results (Figure 7) are in agreement with geotechnical studies: soil with average shear wave velocity of more than 370 m/sec comparable to Group Sc soils in the UBC-97 Code.

Fig. 3. Site location with some of information including fault zone shown by dashed-lines with triangles those tips indicate the dip of the fault. The dash-dot lines are GPR sections and BH and DH are Bore Holes and Down Hole tests locations. The dash lines define the boundary of the site.

Fig. 4. Southward view of the site showing fault planes in small scale (inset of the figure) and large scale depicted by red lines with arrows implying sense of movement. Bedding is shown by parallels black lines. Upper left hand side of the figure presents the results of fault kinematics analysis by which a thrust fault with NE-trending maximum principal stress ($\sigma_1$) detected. Locations of two other stress axes are shown. In lower left hand side, the figure demonstrates the histogram of discontinuities mostly oriented in NW-SE direction in similar manner of bedding planes.

Fig. 5. An N-S trending cross section of soils layer deduced by 4 boreholes logs. Water table and fault surfaces added to show the effect of fault planes on water table that is proposed as perched water table.

4 DISCUSSIONS

In developing countries most of the reason for failure is due to construction (Chen et al., 2007) but investigations errors seem to have significant role to do an excavation properly. It impresses the functions of other participants such as supervisor
and owner. In the case study the effect of fault and its consequent has not been studied well. Effects of presence of fault on urbanization facility could be discussed in different points of view.

Firstly, they are categorized to active and inactive fault. As they are displaced quaternary alluvium (~2 Ma) so we can conclude the faults are younger and active. The active faults are able to produce an earthquake thereby it induce a high acceleration on structures due to near field effect, foundation to suffer rupture, and settlement due to high amounts of vibration are some of consequences of presence of fault in or near the site.

Secondly, the non-seismic aspects of presence of the fault could also be viewed since the fault has significant effect on physical soil and rock properties in the sense of change of water table due to creation of water barriers (the impermeable fault materials), the presence of large volumes of high pressure water trapped behind the barrier results in squeezing or flowing ground conditions (Hoek, 1999) fault planes with different orientations leading to local or general slip surface through the faults planes, change of water flow direction toward excavated area (Figure 8) due to change of permeability coefficients in accordance with the distribution of fault planes. Considering the fault planes in different attitudes it is probably that the soil modeling should also be suffered some changes for example from an ordinary Hardening soil or Mohr-Coulomb model in finite element method to jointed rocks model in a discrete element methods or micromechanical models (e.g., Resende, 2012). This may especially the case for hard soils those are compacted or cemented as the soil being in the study area. It is worth to note, if the fault planes have cohesion and friction less than those are for non-faulted sediments so the results may dramatically unfavorable.

As with the other civil works, the modeling, at best, is not sufficient but use of supports with sufficient capacity, the slot excavation as a constructional procedure and monitoring play important role to prevent uncontrolled deformation.

Fig. 6. first two sections (a and b) are north – south GPR section showing effect of fault planes in southward conducting of water (shown in circles) and two other (c and d) are east–west section depicting concentration of water in center of the excavation by east-west trending of fault planes. The darker lines are reflective surface representing fault and/or soil dipping layers.

Fig. 7. p- and s-waves velocity versus depth(m) in two Down Hole tests implying a dominated seismic bed rocks (hard soils) in depths more than 10m.
5 CONCLUSION AND REMARKS

The aim of this paper is not to find the cause(s) of the failure of this excavation but rather it tends to highlight some geological considerations that help an excavation to move in a safe road. This is the case where a blind fault zone is exposed by the excavation. Strictly speaking, the geological structures change the bulk properties of soils and rocks that are not discovered by random laboratorial or even small scale field examinations such as plate load test. Engineering Geology, based on geological observations and some of analytical approaches built in this course of applied science, can help engineers to see more cautious these favored factors. The field observation shows a fault zone passing through the site and impressed a considerable width of the site. The fault planes are mainly oriented in NW direction dipping northward (Figure 4). Some of younger and less compacted soil accumulated in front of the fault, reported as top soil (Figure 5) may be a colluvial deposits reflected by the fault activities. Kinematical analyses take this as a thrust fault. On the other hand, this is confirmed by GPR where reflected or refracted electromagnetic waves are interpreted as the surfaces with the same attitudes that the observations at the surface do. The GPR test result also shows a convergent water flow toward the fault zone conducting by the faults planes (Figure 8). Although the seismic activities of an active fault is a serious concerns of an engineer in an urban project, the non seismic aspects of presence of fault that is more concentrated by this study are remarkable. Finally, this study suggests, especially for the stiff or hard soils, the analytical approaches chose for evaluating of deformation and, in some extend, for limit state equilibrium should also treat the anisotropies induced by discontinuities planes. In this case fault planes with slickenside and beddings planes in different directions may have different physical and elastic parameters such as elastic modulus, water permeability, cohesion and friction angle that impress the deformation and failure mode of an excavation.

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