The Back Calculation of Some Existing Slopes to Estimate The Cohesion of a Coarse Cohesive Alluvium

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Abstract: - Most common types of excavations in Tehran is unsupported vertical excavation adjacent to nearby building which the height of them could be as high as 30 to 40 m because the soil is highly cemented in some regions of Tehran. In the presented investigation, slope stability analyses have been used to consider the stability of some unsupported vertical excavations to estimate the minimum (lower bound) cohesion of the soil. Limit equilibrium method, has been used for slope stability analysis.

Test results show the cohesion of Tehran alluvium can be very high and its value varies with cementation degree, unit weight and other parameters. In-situ cohesion, estimated from back calculations, is in a good agreement with cohesion obtained from a number of high quality in-situ direct shear tests.

Key-Words: - unsupported excavation, back calculation, Limit Equilibrium Method, Tehran coarse-grained alluvia, calcite cement

1 Introduction
The city of Tehran is located at the foot of the Alborz Mountain Range, which is basically composed of Eocene pyroclastic deposits (green tuff) and other volcanic rocks. The geology and the morphology of the Tehran region are similar to that for other cities located at the foot of mountains. Tehran alluvium often consists of gravelly sand to sandy gravel with some cobbles and boulders that is dominantly cemented by carbonaceous materials.

The earth slopes and high vertical cuts are frequently observed to be stable for long periods in Tehran coarse-grained alluvium. Figure 1 shows some excavations in the alluvium of Tehran. Stability is often attributed to cementation effects on shear strength of these soils. Tehran is expanding rapidly and in recent years many important projects such as metro and sewage tunnels, deep cuts for highways and foundation are constructed on Tehran alluvium. It is extremely difficult to acquire undisturbed samples using conventional soil sampling techniques from this material. Furthermore, even when samples can be retrieved, as block sample, the result of laboratory strength tests may not be representative of the actual in-situ behavior. Therefore the measurement of cohesion is a challenging task for practicing engineers.

One of the simplest solutions to obtain in-situ cohesion is back calculation. In this paper the procedure and results of estimating of in-situ cohesion of Tehran cemented alluvium on the base of some existing slopes back calculations are presented and discussed.

2 Study Area
The study area consists of the some central zones of Tehran. Modarres highway is located at the north of the region. The area is bounded by the Mirdamad Street to the east, Chamraan highway to the west, and the south by Keshavarz Blvd. Tehran plain starts near the city center with an elevation of 1250 meters above sea level, and stretches over to the southern parts of Rey in a mild slope. The elevation declines in a mild west-east slope. Tehran deposits are the result of river activity and seasonal inundations. Alluviums in these zones include commonly two types, which classified by the age of deposition.

3 Geology of Tehran Alluvium
Tehran alluvium is deposited by frequent flow of rivers and floods from mountains of north of the
Fig. 1. Coarse-grained alluvia of Tehran. (a) A alluvium Darya excavation, 40 m. (b) B alluvium, Kooie Daneshgah excavation, 7 m. (c) C alluvium, Hejab Street excavation, 15 m. (d) D alluvium, Emam Ali Highway [2], 5 m.

City. This alluvium is divided into four series: A, B, C and D depending on the age of deposition [1]. In terms of geological approach, Tehran alluvium is consisting of deposited soils in many alluvial fans. Coarse-grained particles consist of tuff, shale and volcanic rocks. Particle shapes are dominantly sub-angular.

From a geological point of view, cementation process of Tehran alluvium is a secondary event, in a way that the cementation agent has been deposited by groundwater after the base grains had been deposited. Cement materials are often carbonate materials such as calcite [2].

Cementation degree of this alluvium varies in different series and sites. In the 'A' series, it is very high and in the 'D' series, there is little cementation. A vast area of Tehran city consists of 'A' series alluvium. According to the Unified Classification System, they are GW-GM, GW-GC, GP-GM, GM, GC, SW-SM, SW-SC, SM and SC.

4 Field and laboratory operations
Conclusion
The field and laboratory operations were carried out in the following phases, each of which will be described in detail in the paper:

4.1 Observation and Taking Excavation Data in Different Alluvium Types;

A number of exposed trenches and eight excavations were visited by the author during this study. Figure 2 shows the locations of the excavations that were considered in this study. In addition, 45 trial pits excavated in previous researches were used to augment the research findings. The visual observations of the previous studies are summarized in Table 1.

Each study consisted of taking some disturbed samples for chemical tests to specify the amount of cement and its type, determine excavation geometry and type of adjacent building to assign surcharge and its distance from the edge of excavation. The first step in conducting the research was finding unsupported excavations with appropriate height and surcharge. Some excavations were being excavated about 20 to 40 meters, provided access to fresh or slightly weathered cemented alluvium.

Determining excavation geometry performed by by manual instruments and/or theodolite. To take
disturbed samples for chemical tests a little soil were taken from the unweathered soil, under the visible side of excavation.

4.2 Chemical Testing

The main object of the chemical testing is specifying the type and amount of cement of alluvia for each analyzed excavation. Measuring the carbonate cement of soils was first published by Collins in 1906[3]. Collins also devised a special slide-rule to simplify the necessary calculations[3]. In this test a specified amount of soil is treated with hydrochloric acid. The volume of carbon dioxide given off is measured, and is corrected for temperature and atmospheric pressure. The amount of carbonate of the soil is calculated from the corrected volume of carbon dioxide. The method is accurate enough for most engineering purposes.

\[ CaCO_3 + 2HCl \rightarrow CaCl_2 + CO_2 \uparrow \]

Created Gas volume is converted to normal term by Gases ideal law. The use gas volumeter apparatus is shown in Fig.3.

After preparation of sample and drying it, it weighed to 0.400gr and placed in reaction flask. The amount of acid required will range from 10 ml for soil containing little calcareous matter to 15 ml for highly calcareous soils. Water level should be fixed before mixing soil and acid. Moving elevation bottle up and down until the water level in burette exactly coincides with the zero mark (V1). The temperature is measured. Carefully remove reaction flask so that the acid in the cylinder spills over the soil sample. Shake the flask well (being careful not to break or crack acid container).
The water level in burette decreases and secondary volume is obtained (V2). Differences between V2 and V1 indicate the volume of CO2 gas.

Fig 3. Gas volumeter apparatus

5 Back-calculation Analysis
When a slope fails or it is about to fail, it can provide a useful source of information on the conditions in the slope at the time of the failure as well as an opportunity to validate stability analysis methods. Because the slope has failed or it is about to fail, the factor of safety is considered to be unity (1.0) at the time of failure. Using this knowledge and an appropriate method of analysis it is possible to develop a model of the slope at the time that it failed [4]. The model consists of the unit weights and shear strength properties of the soil, groundwater, and pore water pressure conditions and the method of analysis, including failure mechanisms. Such a model can help in understanding the failure better and be used as a basis for analysis of remedial measures. Earning one term having another terms or the process of determining the conditions and establishing a suitable model of the slope from a failure, is termed back analysis or back-calculation.

The simplest back-analysis is one where average shear strength is calculated from the known slope geometry and soil unit weights. This is accomplished by assuming a friction angle of zero and calculating a value of cohesion that will produce a factor of safety of 1. This practice of calculating an average strength expressed as cohesion can, however, lead to erroneous representations of shear strength and potentially unfavorable consequences [5].

To determine minimum cohesion needed to provide the stability of unsupported excavations, stability analysis is performed by Limit Equilibrium Method. For this purpose Simplified Bishop Method is employed.

Bishop's Simplified method considers normal interslice forces with no shear and satisfies only the overall moment equilibrium.

This method uses a General Limit Equilibrium formulation in the factor of safety computation. Figure 4 shows critical slip surfaces for one analyzed excavation. The Simplified Bishop procedure assumes a circular slip surface and horizontal forces between slices. Moment equilibrium about the center of the circle and force equilibrium in the vertical direction for each slice are satisfied. This procedure is more accurate than the Ordinary Method of Slices, especially for effective stress analyses with high pore water pressures.

6 Discussion
As mentioned above, 8 unsupported excavations were studied by author in Tehran alluviums. The characteristics, result of back calculation analysis and chemical testing of mentioned excavations are summarized in Table 2. The results are shown in three major columns. In the first major column the height of excavations, surcharge conditions and alluvium types are presented. In the second major column, the range of internal friction angle according to Rieben classification and Table 2 is presented. In third major column, the percentage of carbonate cement of alluvia and the cohesion of the alluviums which were excavated are presented by chemical testing and back analysis calculations.

The effect of water and faults should be considered by engineering judgment to reduce the value of engineering properties.

Fig.4. Liquibrium Limit analysis. considering factor of safety=1.0, the minimum effective cohesion is 90 kPa for Darya excavation
Table 2 could be generalized for A and C alluviums in Tehran, but it should be considered that it is necessary to study further excavations for full pragmatism. Table 2 could be used to determine geotechnical properties for A and C alluvia but there are not enough data available to include B and D alluvia in the system.

In most cases B and D alluvia have very coarse and fine particles. Geotechnical investigations of fine-grained particles are possible by conventional geotechnical investigation methods, but investigation of coarse-grained soils is difficult because of the very coarse-grained noncemented structure and heterogeneous nature.

### 7 Comparison

Estimated cohesion in present study (Table 2) in compare with previous studies illustrates some difference between the result of in situ direct shear tests and back calculated cohesions. This difference is due to more than unity safety factor for some excavations which not to fail.

A comparison in carbonate cement percentage shows the amount of carbonate cement in A alluvia is very high than C alluvia. To extend these results to other A and C alluvia, more excavations are required in these alluvia.

### 8 Conclusion

Coarse soils are challenging materials in ground investigations because undisturbed sampling and most in situ tests are inapplicable. It is also very expensive to take large samples or to undertake large in situ tests for small to medium-sized construction projects. In-situ cohesion, estimated from back calculations, is in a good agreement with effective cohesion intercept obtained from a number of high quality in-situ direct shear tests. Hence, back calculation of existing excavations is a simple method to estimate the cohesion of soils.

Only one strength parameter (\(c, c'\) or \(\phi, \phi'\)) can be calculated by back-analysis.

One of the benefits of back-analyses is that many of the same errors exist for both the back analysis and the redesign. Thus, there are compensating effects and the net result of the errors is diminished or removed entirely. Caution must also be exercised, however, because neglect of three-dimensional effects will cause back-calculated shear strengths to be too high, and if comparable three-dimensional effects do not exist for the slope redesign, the results may be on the unsafe side.

A new applicable classification for some unsupported excavations has been presented for Tehran A, C alluvia. Most regions located at A, C alluvium could have similar geological formations and the alluvia could be similarly back analyzed. An approach similar to that presented here could be used to add cohesion to another A, C alluvia.

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