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Mohammad Sharif Rajabi
University of Tehran, Iran

Farzin Kalantary
K.N.Toosi University of Technology, Iran

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DEEP EXCAVATION IN AN URBAN AREA: A CASE STUDY

Mohammad Sharif Rajabi
Geotechnical Engineer, University of Tehran
Tehran-Iran

Farzin Kalantary
Assistant Professor, K.N.Toosi University of Technology
Tehran-Iran

ABSTRACT

Due to regulations requiring provision of car park in the typical multi-story buildings in the urban areas and the high cost of land, deep excavation adjacent to existing structures have become common-place in Iran. Limiting lateral as well as vertical displacement of the adjacent structures has proven to be a major geotechnical challenge especially in the coarse grained alluvium of Tehran where determination of geotechnical parameters is tedious.

Often active temporary support methods such as "rigid pad – anchoring" and/or "anchored soldier piles" are used in combination with nailing. However, arriving at the optimum design for such projects for the sake of competitiveness in the typical "design-build" tenders is difficult due multiple choices as well as limited knowledge of geotechnical parameters. Hence accumulation data from case studies is deemed to be very useful.

In this paper, details of a seventeen story building with 20m of excavation in the built-up region of Tehran are presented. The ground water level was initially found to be at the depth of 6m and it was required to lower the water table prior to excavation without any side effects.

Rigorous monitoring and back analysis led to verification of geotechnical parameters as well as design model. The shortcomings of typical site investigations in case of coarse grained cemented soils as well as design procedures are outlined.

INTRODUCTION

Rosha trade complex is located in north of Tehran, Iran. The site area for construction is 1978m^2.It has 17 floors that 7 of them are located below ground level and 10 floors are located above ground level. The totally area of the building is 31319 m^2. In the fig. 1 situation of trade complex is shown.

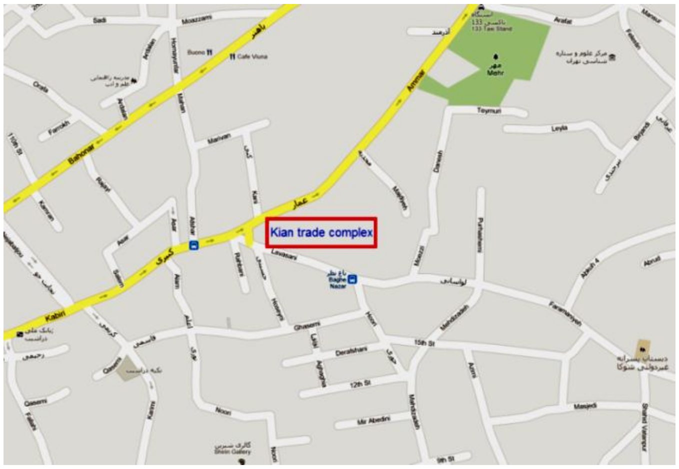

Fig. 1. Rosha trade complex situation

The building, when finished, will be the largest trade complex in Dezashib vicinity. As shown in figure2 the site has five sides (north, east, south-east, south, west), and located between Lavasani and Ammar streets. Depth of excavation is 20m.

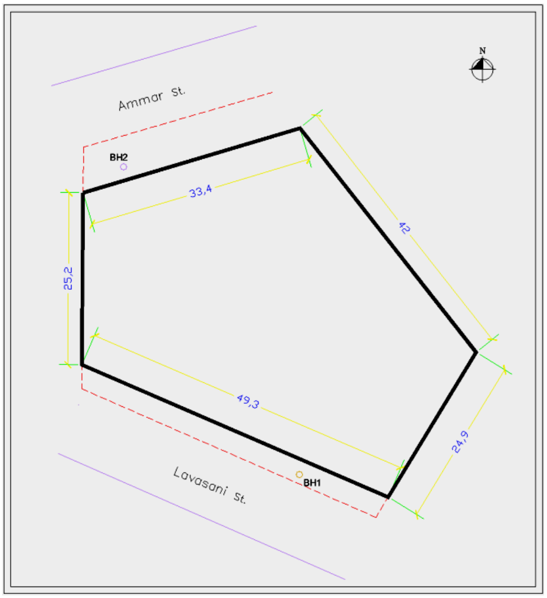

Fig. 2.Site Plan of Rosha Project (Dimensions in meter)

Cost optimization in deep urban excavations has become a major issue for EPC contractors' tender bids. The main concerns in such bids can be summarized as achieving a reliable design, satisfying the required safety factors as well as permissible displacements with minimum cost.

Due to numerous acceptable combinations of length, spacing and specifications of tie-back elements, many designers use trial and error procedure based on educated guesses. However, more sophisticated mathematical procedures are needed to achieve this task.

Besides introducing an interesting case study, a genetic algorithm to optimize support system is introduced in this article.

The case introduced here is a privately financed commercial complex with 20 meter excavation in the built up area of northern Tehran. The project is located on type C Tehran alluvium that is mostly clayey gravel with high density. However, some of the soil layers encountered in the site consisted of sandy clay with low plasticity. The mechanical properties of the soil layers are provided in table 1.

Table 1.Soil Properties

Depth (m)	Elastic modulus (MPa)	Cohesion (kPa)	Internal friction angle (°)	Specific unit weight (kN/m^3)
0-2	100	10	25	18
2-7	250	20	32	20
7-19	660	40	38	20
>19	1250	150	0	20

The ground water table was initially encountered at a depth of 6m below surface. This was rather unexpected and further investigation showed that an abandoned qanat (subterranean hand-dug water conveyance tunnel) had been blocked by earlier constructions down-stream and the water discharge from the qanat into the area had cause the rise in the water table. Hence one of the initial tasks was to lower the ground water level for the excavation to begin.

In order to lower the ground water table, pumping on permanent bases could be envisaged. However, since skilled qanat diggers were readily available, it was decided to sink a number of inter-connected wells around the site to collect and divert the ground water in to a mildly sloped and newly dug qanat 3 meters below the foundation level.

Due to favorable topography of the area, it was possible to connect the qanat to sewage tunnel some 300 meters downhill. A perspective view of the drainage wells and connecting tunnels are shown in figure 3.

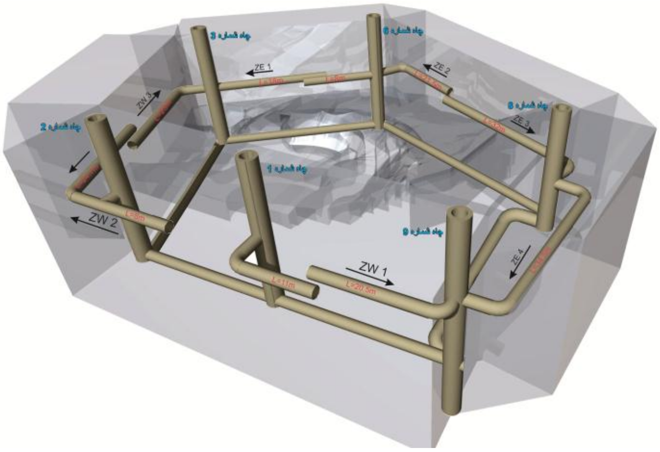

Fig. 3.The layout of drainage wells and the inter-connection tunnels

The art manual digging of wells and qanats in the arid plateaus of central Iran are well-documented. The qanat had always been started from the outlet point and worked up to the desired water table on the foothills. With the aid of electrical pumps it has become possible to start the conveyance system from the so-called mother-well (head-well) downhill.

The above mentioned method was successfully used to lower the ground water level and is now under consideration for another project. Elimination of water from the walls of the excavation allowed typical design procedure to be carried for the project. However, the very ability of the soil to allow such operations is an indication of the cohesiveness or cementation of the alluvium. However, in the coarse grained layers of Tehran alluvium, it is not possible to measure the cohesion with routine sampling and laboratory tests. For this reason the relatively costly insitu shear tests in underground galleries have become common-practice in large excavations. Often, the results of this test make the difference between an optimum design and over-designed support system.

Due to the existence of three multi-story buildings on the perimeter of the site, an active support system was required to limit the displacements to an acceptable level. This has been achieved by anchored-solider piles under the buildings and ordinary anchors on other sides. The support system was complemented with soil nails in between.

The stability of the excavation was controlled by Geo-slope software and the displacements were calculated by Plaxis software. Some details of the procedure and the results are provided in following pages.

DESIGN OF STABILIZATION SYSTEM

Two criteria were considered in designing of excavation wall stabilization system. First, limit equilibrium method thatinvestigates the equilibrium of the soil mass tending to slide down under the influence of gravity. Transitional or rotational movement is considered on assumed or known potential slip surface below soil mass. This method is based on comparison of forces (moments or stresses) resisting instability of the mass and those that causing instability (disturbing forces). Two-dimensional sections are analyzed assuming plain strain conditions. This method assumes that the shear strengths of the materials along the potential failure surface are governed by linear (Mohr-Coulomb) relationships between shear strength and the normal stress on the failure surface. Analysis provides a factor of safety, defined as a ratio of available shear resistance (capacity) to that required for equilibrium. If the value of factor of safety is less than 1.0, slope is unstable. Results (factor of safety) of particular method can vary because method differs in assumptions and satisfied equilibrium conditions. Functional slope design considers calculation with the critical slip surface where is the lowest value of factor of safety. Locating failure surface can be made with the help of computer programs using search optimization techniques. In this project, GeoStudio 2007 software was used for evaluation of limit equilibrium condition. Fast of circular and polygonal slip surfaces provides the lowest factor of safety. External loading, stabilization forces (i.e. anchors, nails and piles etc.) also was added. The software uses solution according to various methods of slices, such as Bishop simplified, Ordinary method of slices (Swedish circle method/Petterson/Fellenius), Spencer, Sarma, etc. FHWA was opted as a technical note for Allowable Stress Design (ASD) and 1.35 was chosen as external minimum safety factor.

The second method that was used to evaluate excavation stability was finite element method. The finite element method (FEM) (its practical application often known as finite element analysis (FEA)) is a numerical technique for finding approximate solutions of partial differential equations (PDE) as well as integral equations. The solution approach is based either on eliminating the differential equation completely (steady state problems), or rendering the PDE into an approximating system of ordinary differential equations, which are then numerically integrated using standard techniques such as Euler's method, Runge-Kutta, etc. In this project PLAXIS 8.2 software was used to predict the lateral and vertical movement of adjacent buildings and streets. This method analysis is crucial where adjacent structures are sensitive to vertical and lateral displacement, for example next to a building.

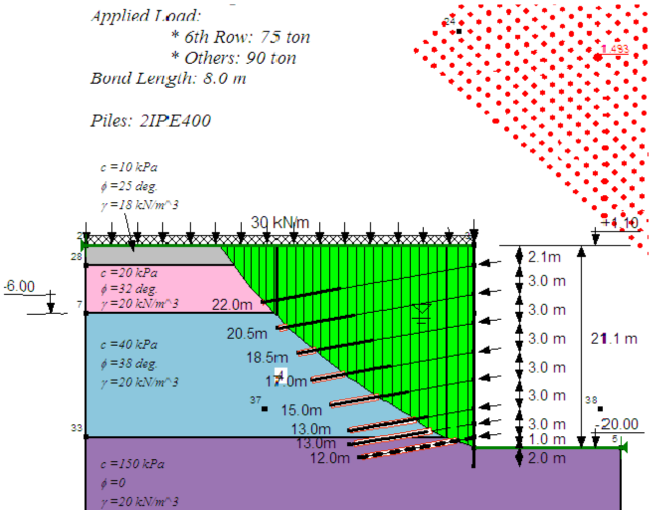

Fig.4. West wall limit equilibrium design using GeoStudio2007

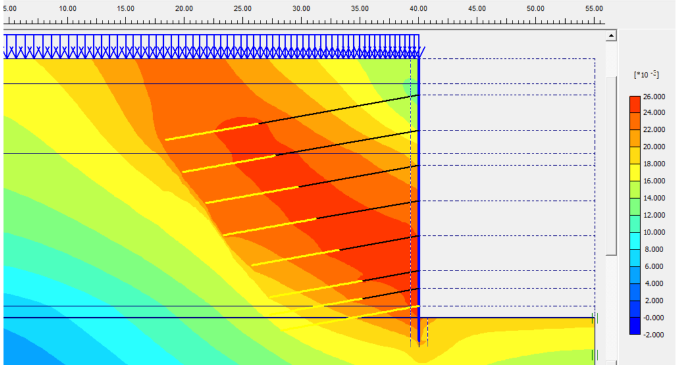

Fig.5. West wall finite element design using PLAXIS

A trial optimization process for the soil nail was also carried out using the Genetic Algorithm. Other optimization processes such as the Particle Swarm Optimization are also under investigation. A brief review of these methods and overall proposed procedure is presented in the following section.

LITERATURE REVIEW

Several studies have been done for calculating the optimum layout of soil nailed walls. Ponterosso et al (2000) produced a GA solution for the cost optimization problem of reinforcement layout for reinforced soil slopes. In their study, the solution incorporates different types of reinforcement within a single slope. The GA described is implemented with the aim of optimization the cost of materials for a preliminary layout of reinforcement soil embankments. Patra et al (2005) reported a generalized method of computer based optimum design of soil nailed slopes. Besides the nail length and diameter optimization, the process of critical slip surface calculation could be an objective which can be achieved by Genetic Alogrithm. Zolfaghari et al (2005) and Jianping Sun et al (2008) and McCombie et al (2002) have done several studies by GA for obtaining the critical slip surface.

OPTIMAZATION PROCESS

Genetic algorithm is a form of evolutionary search that makes use of operators that mimic the natural world. The most commonly used operators are selection, reproduction, crossover and mutation. The solution (or potential solution) of a problem are coded in such a way that they can be thought of as forms of genetic material (DNA). A population of solution is generated randomly and the “fitness” of each individual is assessed by reference to the Fitness Function for that particular problem. The more fit individuals then have a greater chance of reproducing and thus promoting their fitter characteristics through to the subsequent generation(s). Reproduction takes place by swapping part of the ‘DNA’ from two individuals. In order to ensure that no potential solution has zero probability of occurring, the mutation operator can, according to a user defined probability, randomly alter any small element of a solution.

Before starting of length and diameter calculation, the first step is calculation of critical slip surface. The method which is used for calculation the factor of safety (FS) is simplified bishop method (limit equilibrium method). The program which calculates the FS of a slope has been developed in MATLAB software and by using the GA toolbox of MATLAB software, the critical slip surface which has the minimum factor of safety (FS_{min}) can be calculated. As it was described earlier, several studies have been done for this part of calculation, so by passing this part of calculation, the part which is more important than the previous part begins.

Optimization of the soil nail arrangement for an initially determined critical slip line shall almost always affect the position of the critical slip line. Carrying out both optimizations simultaneously will require excessive computer time. So instead it was decided to break up the procedure into two steps. Calculation of critical slips surface and FS_{min} by GA.

1. Calculation of optimum nails length layout by GA for the calculated slip surface from an initial estimation.
2. Calculation of critical slip surface and FS_{min} by GA for the nail layout which has been obtained from the previous step.
3. Should the minimum factor of safety be altered, the new slip surface with the minimum factor of safety is put through the soil nail optimization process. Otherwise the process is terminated.

The above process is shown in figure 6:

Usually after 3 or 4 times of try and error the desired nail layout which has the FS_{min}in the allowable range is achieved. It should be noted that during the GA process the program forces the GA toolbox to use the values of nails length which increase from bottom to top. It means that, whenever the solution reaches the value of nails length which nails on the top have length less than bottom nails, the program consider a penalty for this layout (solution has a penalty), in this way such these layout can be omitted (solution omitted). Another penalty function is considered in the program, it works in a way that if a solution reaches to a condition which FS_{min}does not meet the allowable value (FS near to 1.5), the program forces the GA toolbox to omit this kind of solution too. By introducing these two penalty functions the GA process can reaches to the final solution in an appropriate way. The program works in a way which the differences between nails length which are close to each other are not more than one meter. Also because of practical difficulties in sites, the nail inclination for vertical wall is considered to be 15 degree. It should be remembered that the fitness function which is a key part of GA is sum of all nails length.

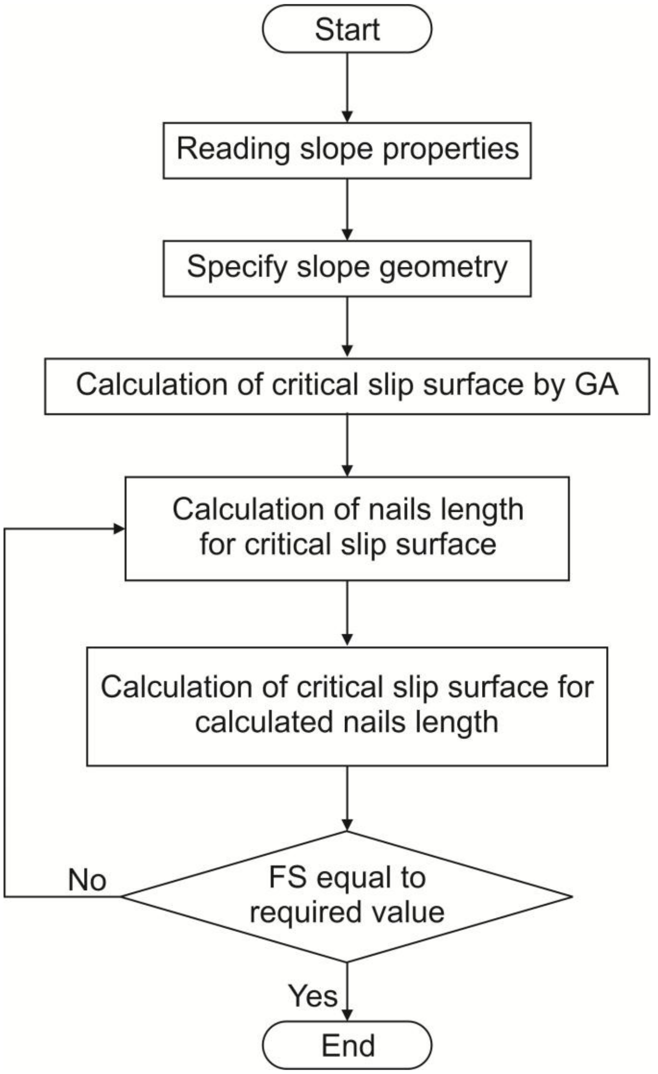

Fig. 6. The process of calculating the nail length by GA

SUMMARY AND CONCLUSION

Soil nailing or anchoring system is a good method for stabilizing excavation especially when blend with soldier pile system. In this project usage of this stabilizing system improved excavation resistance for failing. Wall movements were less than the limiting values set for the projects at all monitoring points, and the wall movements were acceptable. This limitation of movement is contributed to favorable soil conditions over most of the site, high quality construction, and the exceptional quality control and quality assurance measures instituted by the field engineers.

The wall had been designed for 19m depth at first. But after reaching to -19.00 meter depth, the landlord decided to increase the depth of excavation up to -20.00 meter. By the use of nailing and anchoring method and because of such a flexible method, it was possible to extend the excavation.

Fig. 7.Excavated and Stabilized walls of Rosha Trade Complex

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