# Reliability analysis of nailing method in the stabilization of urban excavation - A case study of an Excavation in Tehran

**S. Ghaffarpour Jahromi[1*], N. Shabakhty[2], P. Tajik[1]**

[1] Faculty of Civil Engineering, Shahid Rajaee Teacher Training University, Tehran, Iran.
[2] Faculty of Civil Engineering, Iran University of Science and Technology, Tehran, Iran.

## ABSTRACT

**Soil nail walls are being used to support vertical excavations below ground level to construct one or two basements. Also, the variability of in-situ soil properties has a significant influence on the stability of the soil nail walls. Conventional methods of slope stability analysis are usually based on limit state analysis and factor of safety criterion. These methods do not take into account the uncertainties. In the present study, global stability, soil-nail pullout failure and nail tensile failure are chosen to study. Cohesion, unit weight and angle of internal friction of soil and ultimate bond strength along the soil nail and yield strength of nail are modeled as random variables. Computations of reliability are performed using MATLAB and RT software. For better understanding, a case of soil nail wall constructed to support a vertical excavation in Tehran is considered for the study and its stability is evaluated for three failure modes. This research aims first to analyze the reliability of nailing walls and validate it using the Monte Carlo simulation method. In addition, the effect of correlation between soil parameters and distribution of random variables on the reliability index was investigated. By sensitivity analysis, the importance of variables in the reliability index was investigated. Then, the reliability index changes were evaluated with respect to the safety factors. Finally, changes in the reliability index were studied by changing the length of nails and the diameter of the nails. According to the assumptions, the correlation between the soil resistance parameters does not have much effect on the pullout mode if the general failure and pulling modes of the nails have a significant effect and should be taken into account in analyzes, as well as the type of distribution of variables affects the reliability index and the choice of distribution type is important.**

## KEYWORDS

**Reliability index, Monte Carlo simulation, Types of rupture, Excavation, Uncertainty, Correlation.**

[*] Corresponding Author E-mail: Saeed_ghf@sru.ac.ir

## 1. Introduction

The use of the nailing method has more than fifty years of experience in reinforcement and stabilization of excavation and earth and rock slopes. Design in this method is inevitable due to the uncertainty of input variables and reliability analysis. The effect of different variables in analysis based on probability theory can be investigated using appropriate functions. Uncertainty means not having accurate and sufficient information on a subject. In all matters relating to engineering sciences, there are uncertainties that must be considered in order to obtain an acceptable result. Uncertainties in geotechnical engineering are very noticeable due to the heterogeneity of materials, laboratory and field errors, as well as insufficient knowledge and information in accurate analysis and modeling. Therefore, analysis of geotechnical problems due to the nature of various variables causing errors and uncertainties should be considered.

Jingyu et al. (2016) evaluated the internal and external stability of reinforced soil walls with reliability analysis. They used point estimation and the Monte Carlo method to calculate the reliability index, which showed that internal stability functions are the most effective limit function. Random variables were internal friction angle, soil specific gravity, base friction and reinforcement tensile strength [1]. Wang et al. (2017) evaluated the internal and external stability of reinforced soil only in a static state, which showed that the internal friction angle is the most effective parameter and other random variables were soil gravity, surge load, tensile strength and base friction. The correlation between random variables was also examined in this study [2]. Lin et al. (2017) analyzed the reliability of the nailing system in the case of slip rupture in multilayer soils. The results of this study showed that stiff clay is more likely to be damaged than dense sand [3]. Yuan and Lin (2019) developed the limit equilibrium method in the analysis of nailing stability. The results of their research showed that the reliability in the limit equilibrium method is much higher than the usual methods and the soil shear strength has the greatest impact on the reliability index. Also, the standard deviation in variables has a large effect on the reliability index [4]. Hu et al. (2020) evaluated the calibration of two types of models in estimating the tensile strength of rebar and the analysis of the internal stability reliability of nailing systems. The results of this study showed that conventional design models are not satisfactory due to the presence of random variables and have many errors for economic design [5]. Johari et al. (2020) investigated the reliability analysis of excavations using a random finite element method. The results of this study showed that there is a large correlation between total displacement and lateral deformation. Among the reliability indicators, at least one case is related to rebar rupture. Also, the highest row of rebar had the most critical confidence indicator. The slip surface in different rebars level was variable, which means that the uncertainty of soil parameters has the greatest impact on the coefficient of safety against tensile strength [6].

## 2. Methodology

In this research, by examining different variables such as internal soil friction angle, soil gravity, reinforcement strength, overhead and wall base friction, excavation reliability is analyzed. In this research, analysis has been done by writing a computational program in MATLAB and RT software based on reliability theories. In this study, the required geotechnical data from the report of a project located in Tehran (Daroos Pasdaran) have been used. According to the report, the soil layering is dense and homogeneous clay sand that characteristics of shown in Figure 1. Geometric and technical specifications of the nailing system of this project are given in Table 1. The arrangement of the rebars on one side of the excavation is schematically shown in Figure 1.

## 3. Results and Discussion

The study of excavation stability is one of the problems for geotechnical engineers; that due to the heterogeneous nature of the soil and the uncertainty of variables is not possible to express the stability reliability with a single number and with certainty. In this research, the reliability analysis of the stability of urban excavations by the nailing method was investigated. Variables in this study for reliability analysis include adhesion and internal friction angle of soil, soil gravity, slurry-soil bond strength and fracture capacity of rebar. The average coefficient of variation and type of probabilistic distribution are shown in Table 2.

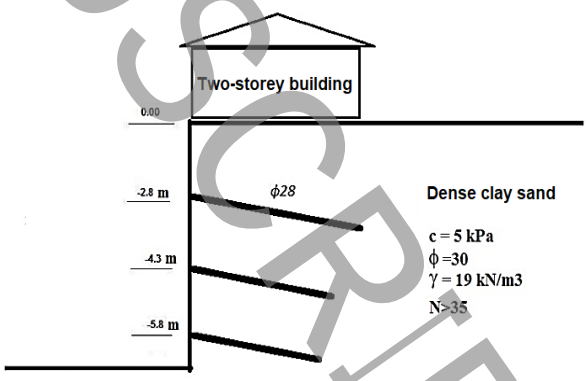


**Figure 1. Section of the nailing of Daroos project**

**Table 1. Nailing data of a project in the Daroos area of Tehran**

| Variable | Symbol | Unit | Value |
|---|---|---|---|
| Wall height | $H$ | $m$ | 7.8 |
| Rebar diameter | $D$ | $mm$ | 28 |
| Borehole diameter | $D_{dh}$ | $mm$ | 125 |
| Overload | $Q_T$ | $kPa$ | 20 |
| Rebar yield strength | $f_y$ | $kPa$ | 400 |
| Horizontal distances of rebars | $S_h$ | $m$ | 2 |
| Vertical distances of rebars | $S_v$ | $m$ | 1.5 |

**Table 2. Statistical characteristics of variables [25-20]**

| Variables | Symbol | Unit | Average | Coefficient of variation | Probabilistic distribution |
|---|---|---|---|---|---|
| Adhesion | $C$ | $kPa$ | 5 | 30 | Continuous logarithmic distribution |
| Internal friction angle | $\varphi$ | $Degree$ | 30 | 9 | Continuous logarithmic distribution |
| Soil gravity | $\gamma$ | $kN/m^3$ | 19 | 5 | Continuous logarithmic distribution |
| Slurry-soil bond strength | $q_u$ | $kPa$ | 125 | 15 | Continuous logarithmic distribution |
| Rebar rupture resistance | $f_y$ | $MPa$ | 400 | 11 | Continuous logarithmic distribution |

## 4. Conclusions

The most important achievements of this research can be summarized as follows:

- Variables affecting the reliability and stability index of the nailing system include internal friction angle, adhesion, soil gravity, slurry bond strength, arrangement and distance of rebars, diameter and tensile strength of rebars and overhead that affect external and internal wall stability.
- In the study of overall stability, the correlation between different soil variables has an important effect on the reliability index, so the correlations c-φ, γ-φ and c-γ have the most impact, respectively.
- The most important variable affecting the overall rupture of the slurry-soil bond strength.
- The correlation between adhesion and the internal friction angle of the soil increases the reliability index of rebar elongation and overall rupture.
- Changing the distribution function of variables from logarithmic to non-logarithmic decreases the reliability index in total rupture and tensile rupture of the rebar, but increases in extrusion, which indicates that the type of distribution function of variables has a greater impact on internal stability.
- Total fracture sensitivity analysis showed that adhesion, internal friction angle and slurry bond strengths are the resistant factor and the specific gravity of the load factor.

## References


[1] C. Jingyu, N. Zhihong, Z. Lianheng anf L. Wei, Case Study on the Typical Failure Modes and Reliability of Reinforced-Earth Retaining Wall, Electronic journal of geotechnical engineering, 21(1) (2016) 305-317.

[2] L. Wang, M. Powers and W. Gong, Reliability Analysis of Geosynthetic Reinforced Soil Walls, In Geo-Risk, Geotechnical Risk Assessment and Management. GSP 285 (2017) 91-100.

[3] P. Lin, J. Liu and X. Yuan, Reliability analysis of soil nail walls against external failures in layered ground, Journal of Geotechnical and Geoenvironmental Engineering, 143(1) (2017) 40-56.

[4] J. Yuan and P. Lin, Reliability analysis of soil nail internal limit states using default FHWA load and resistance models, Marine Georesources & Geotechnology, 37(7) (2019) 783-800.

[5] Y. Hu, P. Lin, C. Guo and G. Mei, Assessment and calibration of two models for estimation of soil nail loads and system reliability analysis of soil nails against internal failures, Acta Geotechnica, 15 (10) (2020) 1-28.

[6] A. Johari, A. Hajivand and S. Binesh, System reliability analysis of soil nail wall using random finite element method, Bulletin of Engineering Geology and the Environment, 79(6) (2020) 2777-98.