Reliability estimation of reinforced structures under initial data uncertainty

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ABSTRACT The article deals with the approach to reliability estimation based on calculations of internal and general stability of MSEW (GRS), taking into account the uncertainty of the initial data. Uncertainty is taken of such ambiguously defined parameters as: the spread of the values of the strength characteristics (from peak to residual strength) of aggregate soils, the design force in the reinforcing layer, the change in the parameters of the interaction of the reinforcing layer with the soil at the ends of the reinforcing elements and the variety of possible surfaces of collapse. The stability estimation is proposed by a probability calculation using Monte Carlo or Hypercube methods. There are two ways to solve the problem of uncertainty of the initial data: 1) probabilistic estimation; 2) numerical simulation. Both approaches can be applied in practice, but require further development and improvement.

Keywords: MSEW (GRS), peak strength, probabilistic estimation, probability of failure and the reliability index

1 INTRODUCTION

The main parameters of the calculation, which affect the final result of checking internal stability, are the following [1,6]:
- characteristics of the strength of the backfill soil;
- design strength of geosynthetic material;
- parameters of interaction between reinforcing elements and soil.

Angle of friction and soil pressure. Analytical calculation methods do not allow to obtain the magnitude of displacements in the structure. Movements are necessary to evaluate shear de-formations and determine the magnitude of the internal friction angle. For compacted aggregate soils that are in a densified state, exceeding 1-3% of the deformations will lead to a transition from the peak strength to the critical value (residual) [11].

The values of the peak and residual angle of internal friction can take values, for example, for sand, the angle of the internal friction: $\varphi_{pik} = 47^o$; $\varphi_{cv} = 21^o$. Ambiguity of the value of the angle of the soil internal friction entails un-certainty in the value of pressure: active or at rest.

Traditionally, calculations are made for the state of active pressure assuming the presence of small deformations leading to a transition of pressure from the resting state to the active one [5,8].

Another fact that affects the stress state, and therefore the design forces in the reinforcing elements, is the inclusion of the compaction effect [1]. When the compaction technique is applied in the soil, horizontal stresses arise and re-main higher than those in the resting state.

There are analytical methods that allow to determine to some extent the values of displacements or take into account the peak and residual strength (Relative stiffness index method of Ehrlich and Mitchell; combined method D. Leshchinsky). In this paper, we consider the possibility of evaluating reliability in terms of the probabilistic approach.

1.1 *The design strength of the reinforcing element*

In general, the design strength of the reinforcing layer can be determined by two conditions. The first condition is the long-term strength F_{lt}. This is the main criterion that determines the design strength based on the reduction factors, while K_{tot} can take values from 1.8 to 3 [7].

The second condition is the resistance to pulling out F_{pu} (the parameters of interaction between the reinforcing layer and the soil). For reinforcing elements, the requirement of a sufficient length of embedding in the non-movable part is always observed. Graphically the design strength as a variable value is dis-played by the diagram shown in Figure 1. Area I is the strength constraint determined by the first condition; and in region II, where Fpu<Flt is satisfied, by the second condition [2].

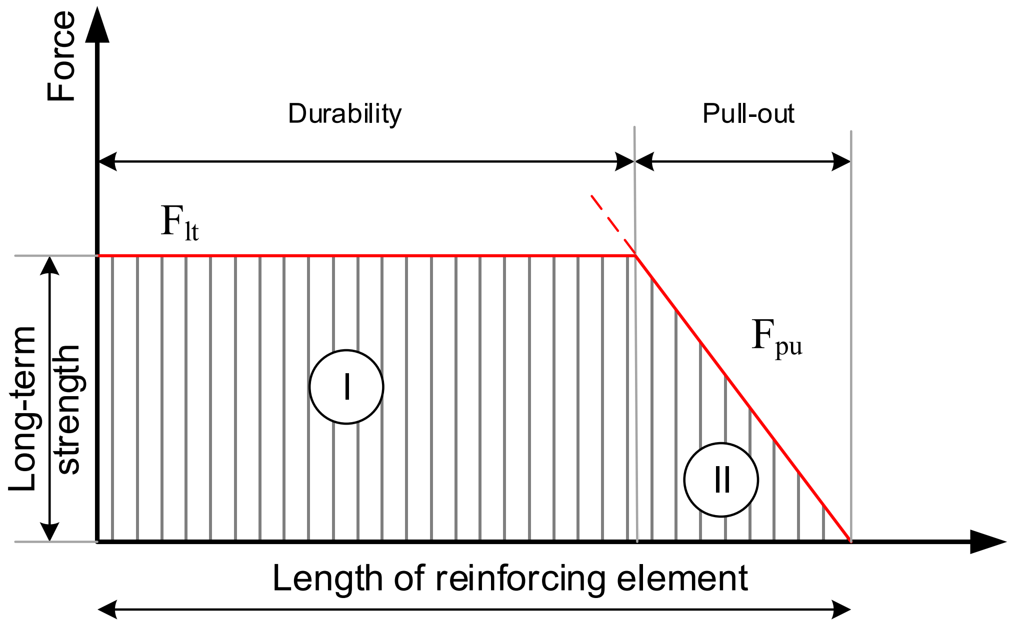

Figure. 1 Design strength parameters for the length of the reinforcing layer

The values of the pulling strength for different types of materials (geogrid, geotextile) can differ according to different data up to 34-44%, depending on the chosen interaction coefficient of soil and geosynthetic material [6].

Figure 2 shows some of the possible combinations of variants of the sliding surface position and its intersection of the reinforcing elements. In this case, each reinforcing element has a different diagram of design strength along the length.

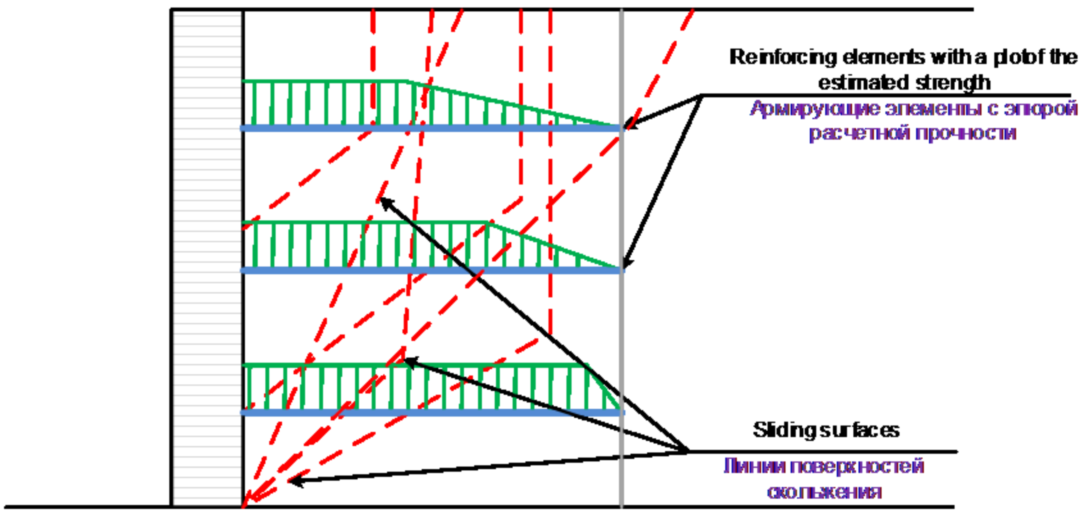

Figure 2. The scheme of an example of possible combinations of the sliding surface position with respect to the reinforcing elements with a design strength

In Russia, we have adopted our own system of strength reduction factors to determine the long-term strength, which consists of 7 factors (K1-K7) [7]. The uncertainty of this parameter depends on the likely impacts of the environment. Thus, on the basis of the expected operational conditions of the structure, ranges of probable changes in the value of the long-term strength Flt can be formed depending on the factors K1, K4-K7 (except for the coefficient of creep K2 and the factor taking into account connections K3).

Another feature of Russian standards in determining the long-term strength - different reliability factor, which has the following values: $\gamma_b = 1.40$ [8]; $\gamma_b = 1.75$ [2]: $\gamma_b = 1.25$ [7].

Thus, based on the uncertainty of the values of such variables as: φ - angle of internal friction of the backfill; F - strength parameter of the reinforcing lay-er; strength reduction factors: К1 - К7; in combination with a different position of the slip surface, a probabilistic estimation of the stability of the reinforcement system can be performed. The calculation scheme is presented in Figure 3.

In addition to the seven listed parameters, the probabilistic estimation may include other parameters: loads, seismic forces, fluctuations in groundwater level, etc.

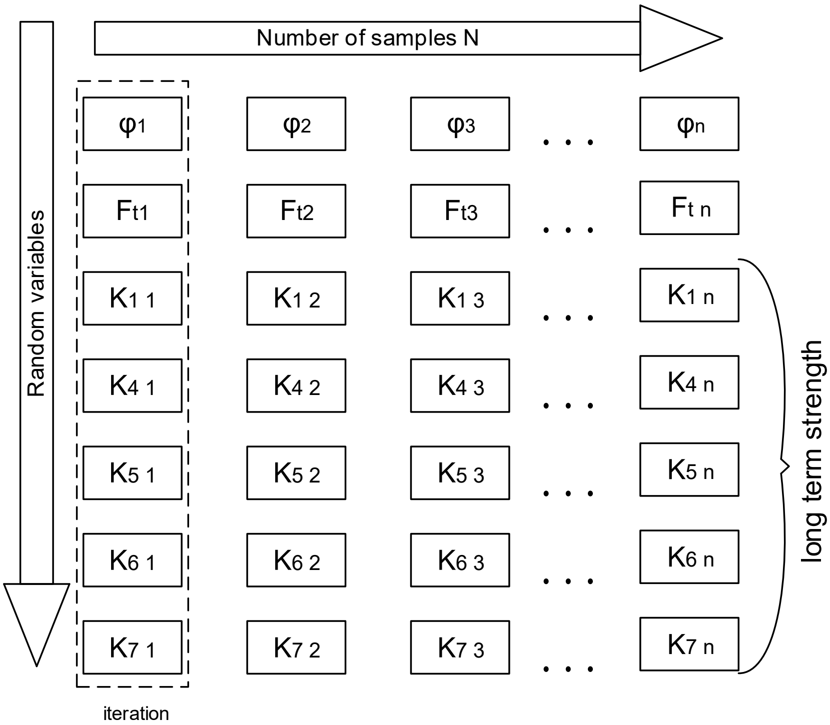

Figure 3 General scheme of iterative probabilistic calculation with indeterminate parameters

2 PROBABILISTIC ESTIMATION

This method implies the use of possible ranges of change in design parameters as initial data. For calculation, it is necessary to use professional geotechnical programs (for example, Rocscience Slide and Slope/W form GeoStudio), which have powerful tools for optimizing the position of the sliding surface [3].

The results of probabilistic reliability analysis are presented as an example in Fig. 4

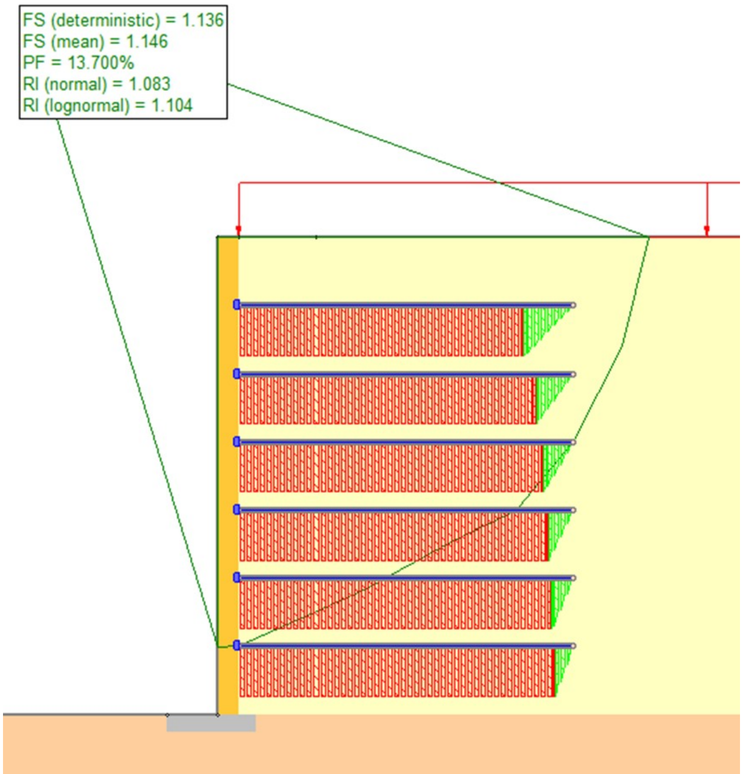

Figure 4 Example of results of probabilistic calculations

The calculation automatically determines the type of collapse (one-part or two-part wedge with the exit of the surface beyond the reinforcing layers). The features of the programs allow to perform a completely automatic search for the sliding surface without any initial restrictions (auto rfine search).

Probabilistic calculations are performed iteratively each time in two stages:

1. Using the Monte-Carlo or Hypercube method, the calculated values (parameters defined as a random variable) are extracted from the probability distribution of the input data;
2. On the basis of the set of selected parameters, the usual stability analysis is carried out.

The result of the probabilistic estimation is the obtaining of the cumulative curve (the integral of the normalized probability density function), shown in Figure 5. The first result is the probability of failure of the structure and the further calculation of the reliability index β, which determines how much un-certainty of the input parameters affects the calculation results.

In this example, the probability of failure is 13.7% (Fig. 5).

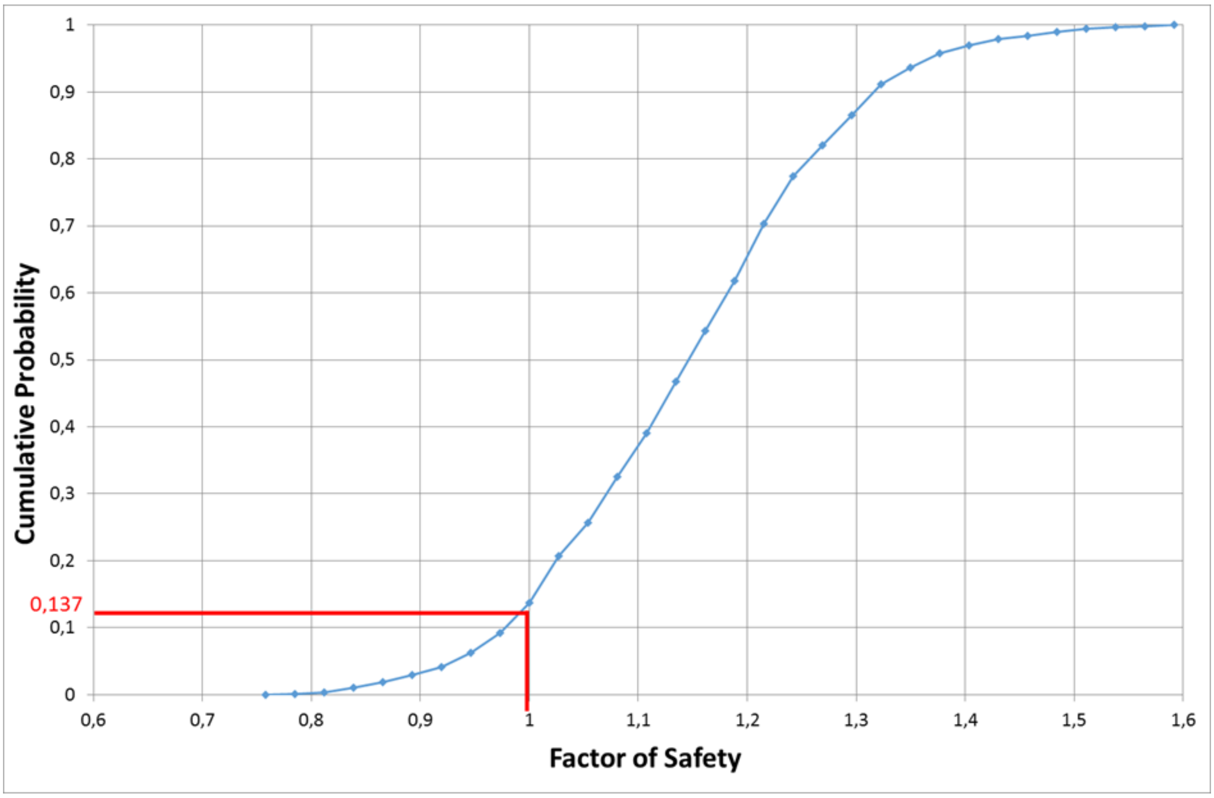

Figure 5 Cumulative probability distribution function (risk curve)

According to EN 1990, the β-index can be used for the classification of the reliability level, in the designation of which the known or assumed statistical variability of the effects and design resistances are considered, as well as the uncertainty of the calculation model:

$$\beta = (SF - 1)/\sigma_{\kappa}$$

where - σ_k is the standard deviation of the stability factor (SF).

For the example considered, SF = 1.14; σ_{κ} = 0,1346 then the reliability index β=1. The average level of consequences (CC2) is adopted. The value of the reliability index should be at least 3.8 (RC2 for a 50-year base period). Thus, according to EN 1990, the simulated construction is unreliable.

3 NUMERICAL MODELING

One of the main tasks of the calculation of reinforced structures is the need to determine the maximum tensile forces in the geosynthetic material. The methods of limiting equilibrium used are limited and do not provide a reliable estimation. These methods do not consider soil compaction technique and stiffness (elongation under load) of the reinforcing elements.

In addition, the position of the potential fracture surface is unknown, since the soil is in a state far from the conditions of the limiting equilibrium. In many cases, the traditional approach gives an excessive margin of the strength of the reinforcing layers.

Numerical modeling methods (for example, finite elements method - FEM) allow to determine the displacements and more realistic stresses in reinforcing layers, but it is very complex and requires high qualification of geotechnics and availability of sufficient and complete initial data. First of all, it is necessary to understand the mechanics of critical states of soil [4].

The essence of this approach is the use of constitutivity soil models, which are universal and allow to estimate the various ground conditions depending on the trajectories of loading.

The constitutivity models, depending on the entered value of overconsolidation ratio (OCR) or pressure from the compaction technique (POP) constitutive models, allow to define a stress state as a overconsolidated (OC) or a normally consolidated (NC) and choose the appropriate strength: peak or critical.

One of the main programs that allow to perform such calculations is the geotechnical software Paxis. There is the opportunity to specify the nonlinear behavior of «Geogrid» element that is intended for modeling of geosynthetic materials and the opportunity to consider creep in the latest version (2017) of the Plaxis program [9].

The numerical modeling gives the possibility to make a calculation taking into account not only geosynthetic materials creep [10], but also soils creep.

The rheological behavior of «Geogrid» element is based on the theory of the idealized creep of geosynthetic materials and the theory of Kelvin-Voigt. It is necessary for calculations to set the stiffness under short term tension and stiffness along the isochrone of calculation time and a specific parameter of retardation time.

CONCLUSION

Reliability analysis in engineering conventionally represents the uncertainty of the system state variables as precise probability distributions and applies probability theory to generate precise estimation s of e.g. the probability of failure or the reliability.

A factor of safety is really an index indicating the relative stability of a construction. It does not imply the actual risk level of the construction, due to the variability of input parameters. With a probabilistic analysis, two useful indices are available to quantify the stability or the risk level of construction. These two indices are known as the probability of failure and the reliability index.

The capabilities of modern software allow to use both analytical and numerical software to assess the reliability of structures with the increasing number of influencing factors.

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