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TECHNICAL NOTE

ANALYSIS OF LENGTHY STRUCTURES RESTING ON MULTI-LAYER SOIL FOUNDATION TAKING INTO ACCOUNT STOCHASTIC BEHAVIOUR OF SOIL

V. GAGIN, P. IVANILOV

Moscow State University of Civil Engineering

1. INTRODUCTION

In order to determine a design reliability, adequate stochastic calculation models have to be developed. For such models it is important to have the possibility of reflecting different action and properties of materials with their probabilistic behaviour. Soil properties, as usual, are extremely non-homogeneous. In modern design practice, the calculations are based on homogeneous multi-layer model of soil. All non-homogeneous effects are covered by safety factors according to limit state design method. The modifications of soil properties due to different processes with time can be taken into account very approximately.

In 1965, in articles [1], [4] the calculation of lengthy structures resting on elastic foundation using probabilistic methods was proposed. Today stochastic models of soil are commonly used in research studies and design of critical structures. The most popular calculation model of foundation is based on the modulus of subgrade reaction theory. The modulus of subgrade reaction and its probabilistic characteristics can be determined directly by field test. As an alternative to the determination of the modulus of subgrade reaction, regular soil properties may be used [2].

In article [2], the model of multi-layer non-homogeneous foundation has been developed. In order to take into account a stochastic behaviour of the soil, a probabilistic model can be developed. Stochastic data for calculation with such a model can be determined by standard soil tests. In this article, the results of studying of the model described are presented.

2. GENERAL ASSUMPTIONS

The model described in [2] has been taken as the base one. The normal law of probabilistic behaviour was used to test the stochastic model. In the stochastic modelling, the Monte-Carlo method was applied. In order to recognize the effects of the model proposed, let us assume that the loads, section and mechanical properties of the structure considered are nonprobabilistic.

3. THE SEQUENCE OF OPERATIONS IN THE ANALYSIS BY STOCHASTIC MODEL

1. Input data: the number of elements, dimensions of structure, structure modulus of elasticity, loads, number of soil layers, soil properties (part of them may be determined as nonprobabilistic), thickness of layers, soil modulus of elasticity E, cohesion factor c, angle of internal friction φ, dead weight of soil γ; for all layers stochastic characteristics can be add.

2. Set of the number of stochastic calculations.

3. Calculation of the first subgrade pressure $[P_1, P_2, ..., P_i, ..., P_n]_1$ as uniformly distributed for a given load.

4. Start of the calculation cycle by number given in point 2.

5. Generation of stochastic values for all soil properties (set as probabilistic in p.1) according to normal law.

6. Start of internal cycle for calculation by model with nonprobablistic parameters [2].

7. Calculation of the structure settlement $[S_1, S_2, ..., S_i, ..., S_n]_k$ for the determined distribution of the subgrade pressure $[P_1, P_2, ..., P_i, ..., P_n]_k$ on the step of the cycle k. During calculation an ultimate pressure for soil R is established, for non-linear calculation the condition of actual pressure $\sigma_{z,i}$ is checked; if $\sigma_{z,i} \geq 1.2\ R_{z,i}$ then at the point i (area) the pressure is fixed as $P_i' = P_i 1.2\ R_{z,i}/\sigma_{z,i}$, and for further iteration it is calculated with P_i'.

8. Calculation of the modulus of subgrade reaction on the step of the cycle k $[C_1, C_2, ..., C_i, ..., C_n]_k$.

9. Static calculation of a given lengthy structure resting on foundation with the modulus of subgrade reaction $[C_1, C_2, ..., C_i, ..., C_n]_k$. As a result we obtain $[S_1', S_2', ..., S_i', ..., S_n']_k$ – the settlements (deflections) of the beam on the step of the cycle k.

10. Determination of the discrepancy $\Delta_i = 2|S_i' - S_i|/(S_i' + S_i)$; if $\max[\Delta_1, \Delta_2, ..., \Delta_i, ..., \Delta_n]_k \leq 0.03$ then the cycle is completed and the calculation of moments can be started. If $\max[\Delta_1, \Delta_2, ..., \Delta_i, ..., \Delta_n]_k > 0.03$ then $k = k + 1$ and the cycle continues from the point 11. In areas where actual pressure is fixed as P_i', the discrepancy is determined as $\Delta_i' = |1-1.2\ R_{z,i}/\sigma_{z,i}|$; for the areas with subgrade reaction 0 discrepancy is not calculated.

11. Calculation of new subgrade pressures $[P_1, P_2, ..., P_i, ..., P_n]_k$ using $[C_1, C_2, ..., C_i, ..., C_n]_k$ and $[S_1', S_2', ..., S_i', ..., S_n']_k$. If $S_i' \leq 0 \Rightarrow P_i = 0$. Continue from point 7.

12. Storing of stochastic data from each stochastic calculation.
13. Data processing and statistical estimation of the results.

4. EXAMPLE

As an example let us consider the T-beam with point load as it is presented in figure 1. The beam is made of linearly elastic material with the module of elasticity E_b = 30 GPa. Nonprobabilistic characteristic of the soil is given in the table 1. As it is shown in article [2], vertical pressure reaches its maximum value around the footing of the beam. So, the deformation of soil (and the changes of soil properties) in top ought to be taken into account with all probabilistic factors. Let us consider the stochastic behaviour of the beam due to probabilistic changes in the layer *N*1. Some variants of stochastic behaviour are presented as follows:

Table

Mechanical properties of soil layers.

No. of layer	E (MPa)	C (kPa)	φ (grad)	γ (kN/m^3)
1	10	14	15	18
2	20	16	25	19
3	25	12	30	18

Variant 1. We can conclude, based on data from [2], that the thickness of layer may greatly influence the mode of beam deformation. Let us consider the probabilistic changes of the thickness of layer 1. The average of the thickness distribution is 1 m, and the standard is 0.2 m. The number of stochastic calculations equal 450.

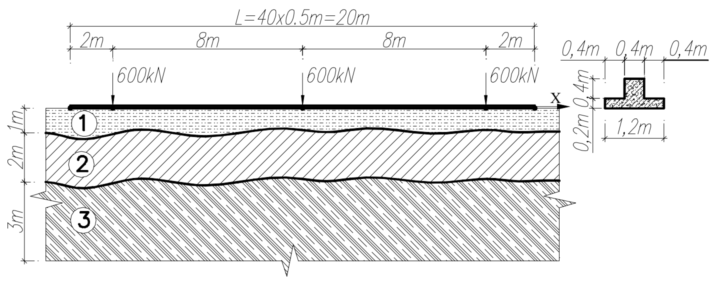
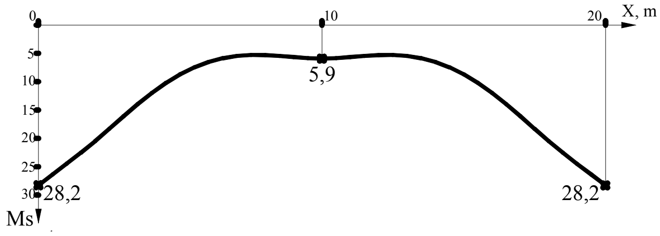


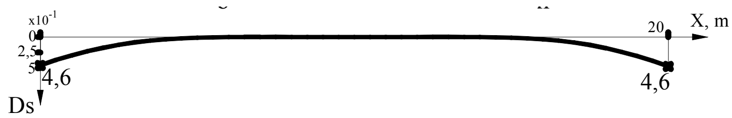
Fig. 1. Calculation model and position of layers

The results of the calculation for variant 1 are presented in figure 2 as the lines of statistical estimation.

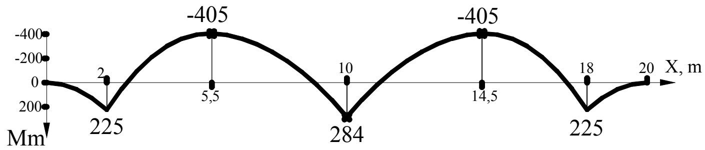
a) Average of distribution of settlements, mm



b) Dispersion of settlements, mm^2



c) Average of distribution of bending moments, kNm



d) Dispersion of bending moments, $(kNm)^2$

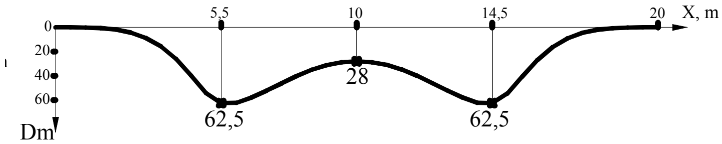


Fig. 2. Results of calculation for variant 1 as lines of statistical estimation

According to the lines of statistical estimation, the changes of layer thickness affect the settlement of the beam ends. However, in the middle of the beam, this influence of layer thickness changes is negligibly little.

Variant 2. Here we consider probabilistic changes of the cohesion factor of layer *N*1. The cohesion factor has influence on non-linear calculation [2]. The average of the distribution of cohesion factor is 14 kPa, and the standard *k* equals 2.1 kPa. The number of stochastic calculations are 450.

The results of the calculation for variant 2 are presented in figure 3 as the lines of statistical estimation.

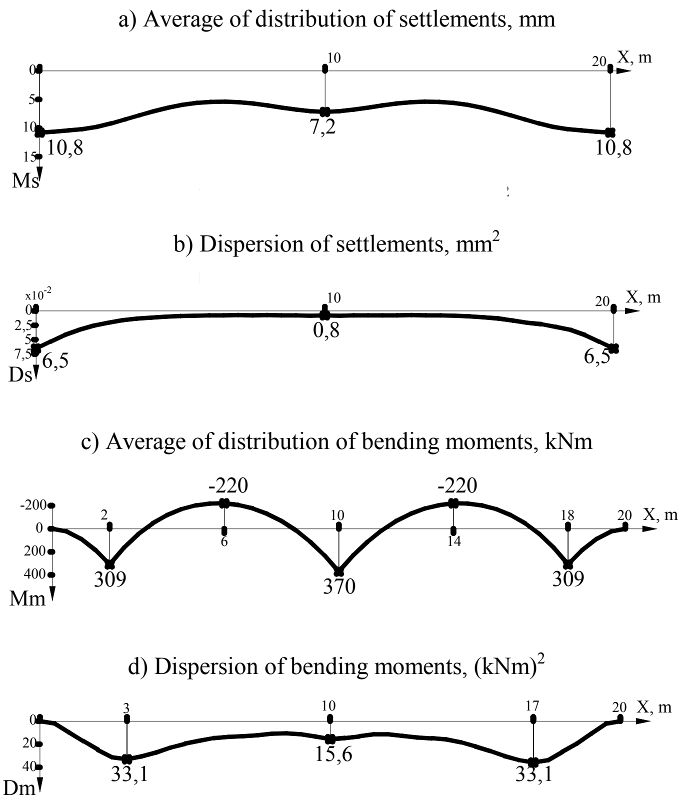


Fig. 3. Results of calculation for variant 2 as lines of statistical estimation

It is the same as in variant 1 where the changes of cohesion factor affect greatly the settlement of the beam ends. Dispersion of the settlement is wider than in variant 2. The curve representing the average of bending moments has different shape than that in variant 1 (figures 2, 3 c).

5. SUMMARY

1. The method presented may be used for the analysis of lengthy structures resting on multi-layer soil foundation with stochastic behaviour.
2. Stochastic behaviour assumed for some parameters as well as the thickness of layer and cohesion factor may affect the design reliability.
3. The changes of the thickness of layer and the cohesion factor considerably affect the settlement of beam ends.

LITERATURE

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