BUILDING MECHANICS

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PROBABLE METHOD OF CALCULATING THE EFFECTS OF TEMPORARY STATIC-LOADS ON SOIL BRIDGE CONSTRUCTION

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Statement of the problem. The effect of the variation of modulus of the deformation of the sand backfill on the stress-strain state of reinforced concrete vaulted shells under the effects of the temporary static-loads is investigated.
Results. The method based on the statistical tests of the method of probable calculations of the distri-bution of the forces in the vaulted concrete shell of the filled in with soil bridge constructions from the temporary static-loads is proposed. A spatial finite element calculation schema where a stochastic model of the surrounding body of soil appears to be a random field with given statistical characteristics is applied. The results of numerical studies that are based on the exploited for transportation construc-tion are presented.
Conclusions. A minor influence of a scatter of the modulus of deformation on the distribution of normal and bending moments is identified, which allows one to be limited to a deterministic setting the modulus of elasticity of soil backfill while performing strength calculations of reinforced concrete vaulted shells in the elastic medium.

Keywords: soil bridge, thin-walled ferroconcrete arch, probable calculation, sand filling, stress-strained state, bending moments, normal conditions.

Introduction

According to the guidelines (SNiP 2.05.03-84* (SP 35.13330.2011) “Bridges and Pipelines” for strength and deformation calculations of a bridge under construction mechanical characteristics of materials of bearing structures and sandy filling are considered determined.

In fact even well-constructed surrounding arched bridge spans fluctuate considerably. Besides, a wide range of the parameters has acting loads as well as strength and deformation characteristics of the material of a ferroconcrete shell. Considering these fluctuations of the system "shell — elastic environment" is essential as a sandy filling has not only an active pressure on the shell but also resists the deformations of the shell and has a significant effect on its stress-strain.

Therefore there should be no restrictions in stress-strain associated with a wide range of the parameters of the system. This article sets forth a method of investigating the stress-strain of bridges using sandy fillings in a probabilistic manner and looks at a range of the parameters of the stress-strain of a bearing structure considering fluctuations of deformation characteristics of a soil filling.

1. Original assumptions. The parameters determining the fluctuations of the stress-strain of a bearing shell in the elastic environment are grouped if the following are dominant for them:

1. Loading parameters impacting the shell;
2. Geometric and physical characteristics of the arch material;
3. Deformation characteristics of the environment surrounding a bearing shell.

The impact of the first two factors has been studied in detail [1—5]. The influence of the probabilistic character of deformation parameters of the environment on the stress-strain of a ferroconcrete shell has not been sufficiently investigated. It is done here with the use of the method of statistical tests. The massive surrounding the shell is modelled with a continuous stochastic environment with different volumetric finite elements in the form of parallelepipeds and tetrahedrons. Probabilistic character of deformation parameters should be taken into account using two different approaches: the accurate one based on the theory of random fields and the approximated one that uses a simplified stationary model with a constant mathematical anticipation $m(x, y, z) = \text{const}$ and dispersion $D(x, y, z) = \text{const}$.

The accurate approach requires multi-dimensional distributions of deformation characteristics in the surrounding shell of a continuous soil environment: the deformation modulus E, the Poisson coefficient v, adhesion c, angle of the internal friction φ, dilatancy. It is quite challenging to specify a random field using multi-dimensional distribution functions and leads to daunting mathematical and calculation problems. Describing random fields is possible only using the methods of random functions. For the normal law of distribution of the parameters along the environment statistical characteristics of the determining parameters S will suffice:

average $m_s(x, y, z)$, dispersion $Ds(x, y, z)$ and correlation functions $K_s(x_1, x_2, y_1, y_2, z_1, z_2)$ along the typical sections of the field, e.g., along the perimeter of the shell. Generally, even in the assumption on the normality of a random field implementation of the accurate model of the environment is associated with calculation problems and collection of a large amount of statistical characteristics.

There might be different simplifications of the accurate probabilistic model of the environment allowing the calculation scheme to be simplified. E.g., one of them is modelling the environment of the shell using a soil environment with elastic bonds with correlated along the perimeter stiffness characteristics. However, such a calculation scheme of the parameters of the elastic environment requires a lot of statistical data on the correlation of the parameters of the environment at different points and thus cannot be implemented as there are not any.

The approximated approach means a constant mathematical anticipation in the environment surrounding the shell $m(x, y, z)$ = const and dispersion $D(x, y, z)$ = const. The correlation of change in the parameters of the environment is not taken into account. Numerical characteristics of random value will suffice in describing the soil environment. In this paper for developing a method of probabilistic calculation, a bridge using sandy filling is presented as a non-linear finite element calculation scheme consisting of a random homogeneous area (Fig. 1).

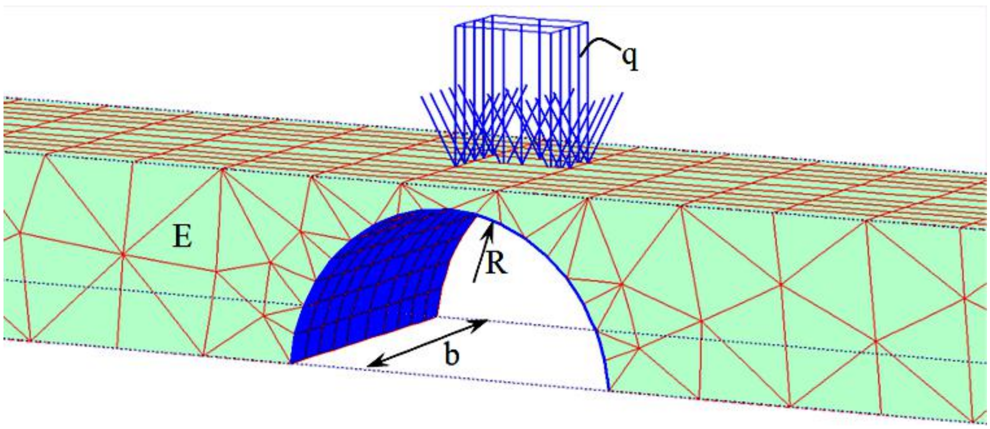

Fig. 1. Spatial calculation scheme of a bridge using sandy filling

In describing the calculation scheme of a bridge using sandy filling, studying probabilistic positions depending on changes in bending moments M and normal forces N in the typical sections of the arch in the most inconvenient loading area will suffice for random specification of the deformation modulus of the soil environment E. It is convenient to use the spatial finite element calculation model of a bridge using sandy filling that we described in detail [1] in *Plaxis* [7] where there are the following assumptions:

1) The material of a bearing shell is linearly elastic;

2) Non-linear properties of the soil massive surrounding the arch bearing structure are accepted in accordance with the Mohr-Coulumb model.

2. Algorithm of a probabilistic calculation of stress-strain. In order to conduct probabilistic calculations, the method of statistical tests was employed. Despite being highly time-consuming, it allows one to obtain viable results considering fluctuations of linear as well as non-linear determining parameters. The essence of the method of statistical testings is that there is a multi-step calculation of stress-strain of the shell under a constant load and constanly changing deformation modulus of the environment. For each calculation option the deformation modulus of the environment is considered random. Since the modulus of deformation of the soil system depends on a variety of factors (granular composition, density, humidity, etc.), we would assume that the distribution of the modulus of deformation in a probabilistic calculation scheme complies with the normal law:

$$P_E = \frac{1}{\sigma_E\sqrt{2\pi}}\exp\left[\frac{(E-m_E)^2}{2\sigma_E^2}\right], \tag{1}$$

where m_E and σ_E are mathematical ancipitation and standard of random deformation modules respectively.

The calculation of the stress-strain of the shell in the elastic and plastic environment using a spatial calculation scheme by means of the method of statistical testings includes the following steps:

— Generation of random modules of deformation E of the bearing shell surrounding the soil environment;

— A non-linear statistical calculation of the stress-strain of the shell using *Plaxis* [7] for a spatial non-linear finite element calculation scheme of bridges using sandy fillings;

— Accumulation of statistical data of the parameters of maximum efforts in the typical sections of the bearing structures for follow-up calculations for different modules of deformation E.

Equalling statistic distributions choosing the most appropriate analytical distribution laws [9]. For numerical calculations along with the normal distribution law we use the general betalaw where density is determined using the formula:

$$f(x) = \frac{\Gamma(C_1+C_2)}{\Gamma(C_1)\Gamma(C_2)}x^{C_1-1}(1-x)^{C_2-1}, (0 < x < 1). \tag{2}$$

In expression (2) for the density of betadistribution there are also special functions $\Gamma(x)$ for which the mathematical software *MathCAD* is employed. Formula (2) suggests that the betalaw has two parameters C_1 and C_2 that have an effect on the graph of the density of the distribution law. The theory [6] shows that at $C_1 > C_2$ distribution has a negative asymmetry and when pac $C_1 = C_2$ that has a negative asymmetry, for $C_1 < C_2$ is a positive asymmetry, for $C_1 = C_2$ distribution has a symmetrical shape. Fig. 2. Shows the graphs of the density distribution that were used to equal the histograms of random efforts in the typicall sections of the arch in the elastic environment.

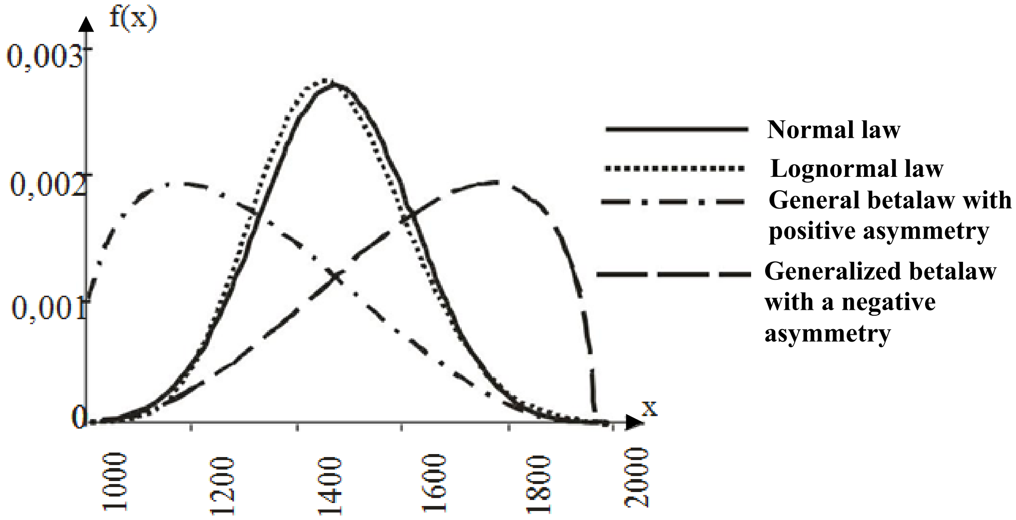

Fig. 2. Density distribution of different laws

The block scheme of the probabilistic calculation of the soil-filling structure under a statistica time load based on the method of statistical testings is presented in Fig. 3. Time loads are modelled equally on a local area of the filling distributed on the surface using random load intensity q (see Fig. 1).

3. Numerical realization of the method of probabilistic calculation of stress-strain. The method will be tested using the example of a model of a bridge using sandy filling with a ferroconcrete arch span structure with the following geometric parameters: the bridge span is 12.0 m, curvature is 6.0 m, arch of the slope is 5.5 m, the thickness of the arch is 0.3 m. Numerica; calculations using the method of statistical testings of the distributed intensity q = 113.6 kN/m^2, applied to the average section along the length. In the initial distribution of the deformation modulus of the soil environment the following parameters are accepted: the range E = 6…52 MPa. The massive out of 200 random values of the deformation modulus distributed according to the normal law (1) with the parameters m_E = 40 MPa and standard σ_E = 10 MPa were obtained by means of numerical generation using *Stadia* software [8] (Fig. 4).

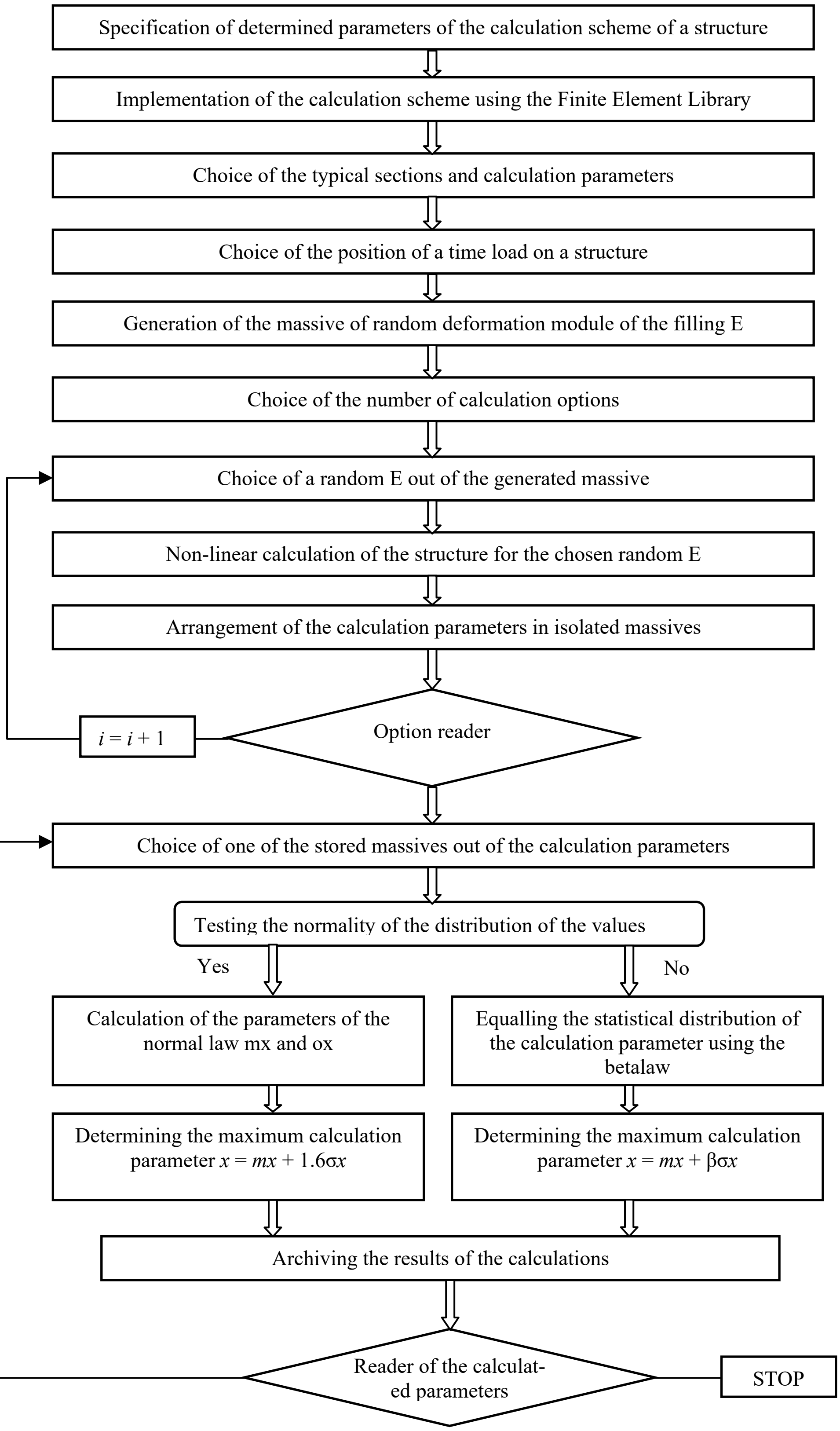

Fig. 3. Block scheme of the probabilistic calculation of a bridge using a sandy filling

For the illustration in Fig. 5 there is a histogram of the distribution of the bending moments in the support section of the arch under a time load placed in the middle of the span of a bridge using a sandy filling that was obtained based on the results of probabilistic calculations.

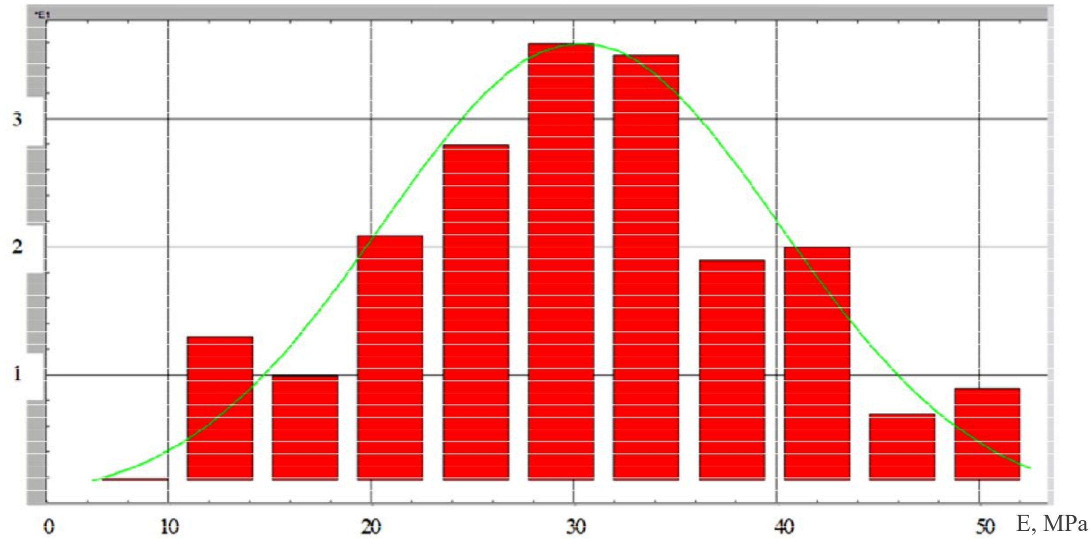

Fig. 4. Initial distribution of random modules of deformation of the soil filling generated according to the normal law

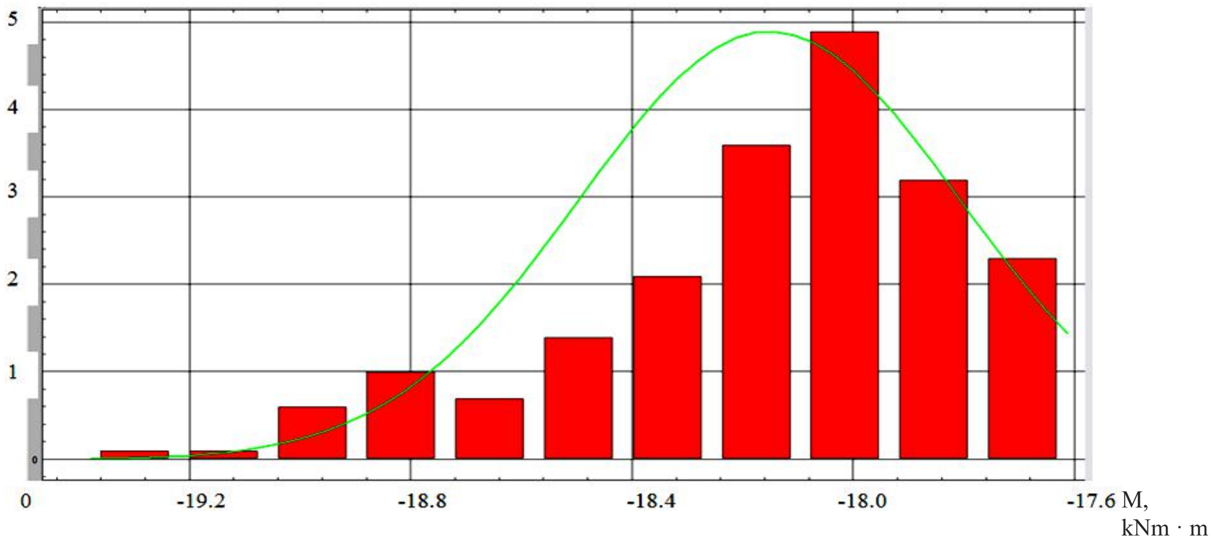

Fig. 5. Histogram of the distribution of the bending moments in the support section of the arch from a time load positioned in the middle of the span of a bridge using a sandy filling

The following conclusions were made based on the results of the numerical calculations:

1. A range of normal efforts in the support section of the arch as well as that in the fourth of the span is in good agreement with the normal law of the distribution only for a clutch section.

According to the same law, the bending moments in the clutch of the span in the fourth of the span are distributed;

Fluctuation of the normal efforts in the clutch section of the arch is considerably different from the normal law. Identical deviation from the normal law is characteristic of the bending moment in the support section of the arch;

2. If a deviation of the bending moment in the support section of the arch has a negative asymmetry and values, large mathematical expectations of the value, have high probabilities, i.e. normal conditions in the clutch section of the arch have a positive asymmetry, large mathematical anticipation of the value, have low probabilities.

The use of the obtained data on the effect of a range of the deformation modulus *E* on the calculation efforts S_p in the typical sections of the arch depends on the distribution law of certain efforts S_i. If this factor is normal, the expression for a specific degree known in the reliability theory can be employed:

$$S_p = m_s + \beta \cdot \sigma_s, \tag{3}$$

where β is the correction number of the standards. With a specific degree $P = 0.95$ this parameter is accepted to be $\beta = 1.64$.

For deviations of the distributions of the evaluated parameters on the normal law the calculation efforts were calculated using fractiles of the chosen betadistribution using the mathematical software *MathCAD*.

The results of computing the calculation parameters of the efforts in the typical sections of the arch for the investigated example using the above calculation algorithms are listed in Table.

Table

Data on the probabilistic calculations of efforts in the typical sections of the arch

Effort	Section of the arch	Calculation characteristics				
		Mathematical anticipation	Standard	Variation coefficient	Distributuion, asymmetry	Calculation value
Normal effort, kN	Support	–348.5	1.79	0.51	Normal $K_a = -0.249$	–349.3
	Fourth of the span	–267.7	1.32	0.48	Normal $K_a = 0.399$	–274.4
	Clutch	–447.8	0.54	0.18	Betalaw $K_a = -1.008$	–447.9
Bending moment, kNm	Support	–18.2	0.35	1.9	Betalaw $K_a = -0.906$	–18.8
	Fourth of the span	8.1	0.81	10	Normal $K_a = 0.399$	9.4
	Clutch	–40.4	0.90	2.2	Normal	41.9

Conclusions

The analysis of the results of the probabilistic calculations of the efforts in the typical sections of the arch listed in Table resulted in the following conclusions:

1. A deviation of the moments for most characteristics of the sections of bridges using a sandy filling considering fluctuations of the deformation module of the soil filling is insignificant, which is important for considering possible defects and damage [5]. Even with the variation coefficient of the deformation module v_E = 31 % a deviation of normal efforts in all of the sections does not exceed 0.5 % and the fluctuation of the bending moments in most loaded by bending and clutch sections is 1.9—2.2 %. It is only in the fourth of the span where the bending moments are considerably lower that the variation coefficient is 10 %.

2. While conducting strength calculations of the arch ferroconcrete shells in the elastic environment, determined specification of the elasticity module will suffice.

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