Regression analysis of the calculation of the organizational and technological potential for the production of cold weather concreting.

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Abstract. Concrete work in the winter and related organizational and technological decisions affect the efficiency of the construction project, both at the stage of technological design and at the stage of work. This work shows a review of research on organizational and technological solutions that affect the quality of monolithic structures in the construction of residential multi-story buildings in the winter. We justified the choice of potential as the most optimal tool that will solve the problems posed in the study. We have identified the main regression coefficients for calculating the second-order regression equation. We performed data processing of production and technological modules and their correlation relationships identified in previous studies. The core matrix of the orthogonal central compositional plan is calculated. Variance of reproducibility has been determined. We have obtained the regression coefficients in this paper. We carried out the significance of these coefficients using the standard error. Further directions for the development of research into the potential of organizational and technological solutions for the production of concrete work in the winter were identified in this article. They were determined by determining the adequacy of this model.

1. Introduction
The Russian Federation has extreme climatic conditions. Despite this, the volume of annually erected monolithic reinforced concrete structures is constantly growing. The construction of monolithic reinforced concrete structures is an all-weather process in this regard. As a result, the construction of monolithic reinforced concrete structures in the winter period entails a number of problems that entail an increase in labor costs, construction costs and violation of deadlines. We proposed earlier to create a tool that assesses the validity and effectiveness of the application of organizational and technical measures in the production of winter concreting. There are a sufficient number of studies on organizational and technological potential. [1-11,14-20]

We described the parameters previously divided into groups, which were obtained according to the results of our studies. Research results have been described in previously published articles. [12,13,21] The compositions of the groups of factors were also refined and adjusted after repeated studies in the form of questioning of experts. They took the following new look: z1 - quality of project documentation, application of non-destructive testing of concrete strength; z2 - module of the surface of the structure, qualifications of workers and engineering personnel.; z3 - timeliness and accuracy of measures to protect concrete laid in the structure, ambient temperature.
The experiment was the next step in the study. The essence of the experiment was to transfer the objects under study from one state to another by setting different parameter values. Further, the regularity of his work was carried out in the form of establishing quantitative characteristics by tracking changes in responses. All parameters (or most of them) change according to some rules in a polyparametric experiment, considered in the theory of experimental design, from experience to experience at the same time. Moreover, the influence of each of them stands out immediately after the processing of this kind of experiment.

The coding results obtained by us will be used at this stage to conduct experiments with already established boundary values of the parameters.

2. Material and Methods

We use a plan in which each variable takes at least 3 different values in the process of constructing a polynomial of the second degree, which has a higher order than linear models. The construction of 2nd order plans can be carried out with different approaches. A complete factorial experiment of the type $3^k$ will be used by us, but the disadvantage of these plans is a large redundancy. Planning is carried out as rationally as possible in accordance with the idea of a step-by-step experiment. This is achieved by adding intentionally selected points to the “core” formed by planning for linear approximation. These plans are called compositional (sequential). Compositional plans make it possible to use the information received as a result of the implementation of the linear plan. Compositional plans make it possible to use the information received as a result of the implementation of the linear plan.

The use of orthogonal central compositional plans is the solution to such problems as the consistent selection of a model. And the core of the full factorial experiment is these tasks. Central compositional plans are widespread at $k < 5$. The concept of “central” means obtaining values symmetrical to the center of the plan. The second-order central compositional plan has the core of the full $2k$ factorial experiment. The use of a full factorial experiment will make it possible to obtain unbiased estimates of the coefficients of the polynomial model.

One point is added in the center of the plan in the “Boxing plans” to the core, which is built in accordance with the full factorial experiment. This point has coordinates $(0,0,...,0)$ and $2^k$ “star” points with coordinates $(\pm \hat{g}, 0, ..., 0), ..., (0, 0, ..., \pm \hat{g})$.

The plan will be the central compositional plan of the 2nd order. And it is built in accordance with these conditions. The total number of plan points during the use of compositional planning is found by this formula:

$$N = N_0 + 2^k + 1$$

where $N_0$ – number of points in the core of the plan.

Table 1 and table 2 contain a description of the corresponding planning matrices for the central compositional plan for $k = 4$. The number of experiments for this plan is equal $N = 2^3 + 2 \cdot 3 + 1 = 15$. Each factor varies at 5 levels: $-\hat{g} - 1; 0; 1; \hat{g}$.

| Table 1. The core matrix of the orthogonal central compositional plan. |
|-----------------------------|-----------------------------|-----------------------------|
| $Z_1$ | $Z_2$ | $Z_3$ |
| -1  | -1  | -1  |
| 1   | -1  | -1  |
| -1  | 1   | -1  |
| 1   | 1   | -1  |
| -1  | -1  | 1   |
| 1   | -1  | 1   |
| -1  | 1   | 1   |
| 1   | 1   | 1   |
Table 2. Additional matrix core points.

| $Z_1$ | $Z_2$ | $Z_3$ |
|-------|-------|-------|
| $\hat{g}$ | 0 | 0 |
| $-\hat{g}$ | 0 | 0 |
| 0 | $\hat{g}$ | 0 |
| 0 | $-\hat{g}$ | 0 |
| 0 | 0 | $\hat{g}$ |
| 0 | 0 | $-\hat{g}$ |
| 0 | 0 | 0 |

Not all columns in a 2nd order plan matrix comply with the symmetry condition. And not all pairs of columns comply with the condition of orthogonality (Table 2). Since, for all lines of the plan $z_{ij}^k \neq 0$.

We will perform the quadratic parameters transformation and in a special way we will select the "g" shoulder size to eliminate the asymmetry and violation of the orthogonality of the central compositional plan.

We need to move from $z_{ij}^k$ to centered quantities $z_{ij}^* = z_{ij}^2 - z_{ij}^k cp$ (the sum of centered quantities is 0) to ensure that the symmetry properties are observed. The average value of $z_{ij}^k cp$ for all $z_{ij}^k$ is the same and equal

$$c = \frac{(N_0 + 2\hat{g}^2)}{N} \tag{2}$$

We are able to transform the quadratic model

$$y = b_0 + b_1z_1 + \ldots + b_1z_k + b_{12}z_1z_2 + \ldots + b_{k-1,k}z_{k-1}z_k + \sum b_{11}(z_{1-1}^2 - z_{1cp}^2 + z_{1cp}^2) + \sum b_{11}(z_{k-1}z_{kcp}^2 + z_{kcp}^2)$$

$$= d_0 + b_1z_1 + \ldots + b_1z_k + b_{12}z_1z_2 + b_{k-1,k}z_{k-1}z_k + b_{11}z_1^* + \ldots + b_{kk}z_k^* \tag{3}$$

where $d_0 = b_0 + b_{11}z_{1cp}^2 + \ldots + b_{k-1,k}z_{kcp}^2 = b_0 + c(b_{11} + \ldots + b_{k-1,k})$

The original and converted models are equivalent. This is characterized by the coincidence in them of all coefficients except zero. Next, we get the planning matrix. The results of the table are not submitted to the article, since they are large. But we will immediately use its results. In this table, the sums of elements for all columns, with the exception of column $z_0$, take the value 0. In the transformed table, the symmetry property is observed. Columns of quadratic terms are not orthogonal for arbitrary values of "$g" despite this. But.

$$\sum_{i=1}^{N}(z_{ij}^2 - c)(z_{ij}^2 - c) = \sum_{i=1}^{N}z_{ij}^2z_{ij}^* \neq 0, \quad k \neq j \tag{4}$$

Orthogonalization of columns, that is, equating $\sum_{i=1}^{N}z_{ij}^2z_{ij}^*$ to zero is done by choosing the value of "$g". This value of $g$ is found from the equation.

$$\sum_{i=1}^{N}z_{ij}^2z_{ij}^* = N_0 \left(1 - \hat{c}^2 \right)^2 - 4c(\hat{c}^2 - c) + (2k - 4)c^2 + \hat{c}^2 = 0 \tag{5}$$

or

$$N_0(2\hat{c}^2)(N_0^2 + 2\hat{g}^2)(N_0) + (2N_0 + 2\hat{g}^2)c + \hat{c}^2(N_0 + 2k + 1) = N_0 - 2\hat{c}^2 + N_0 + \hat{c}^2 \tag{6}$$

Consequently, $\hat{c}^2 N = N_0$. Then $\hat{c} = (N_0/N)^{1/2}$. Substitute the value of "$c" in the equation

$$\left(\frac{N_0}{N}\right)^{1/2} = \frac{(N_0 + 2\hat{g}^2)}{N} \tag{7}$$

Having solved the equation, we find the value of "$\hat{g}":

$$\hat{g} = \left(\frac{(\sqrt{N_0} - N_0)/2}{2} \right)^{1/2} \tag{8}$$
For a $2^3$ kernel, the value will be $\tilde{g} = 1,414$. This is necessary to guarantee orthogonality.

Repeated experiments will not guarantee complete coincidence of the results if the previous ones were accompanied by errors. The processing procedure should take into account these circumstances in this regard.

The primary operation in statistical analysis is to determine the variance of reproducibility $S_{\text{repr}}^2$.

This is a quantity that quantitatively describes the random errors of the experiment. Its determination is made according to the scatter of the results of measuring the response $y_{ui}$ at the same points in the plan.

We find the reproducibility variance for the entire experimental design using the formula:

$$S_{\text{repr}}^2 = \frac{1}{N(r-1)} \sum_{i=1}^{N} \left( \sum_{u=1}^{N} (y_{ui} - \bar{y}_{ui})^2 \right)$$  \hspace{1cm} (9)

Where $i = 1,2, ..., r$ – number of retries; $y_{ui}$ - result of individual experience; $\bar{y}_{ui}$ - arithmetic mean of repeated experiments on the line of the plan; $N(r - 1) = f_1$ – number of degrees of freedom; $N$ – total number of plan points.

Estimates of the regression coefficients are determined as follows:\

$$b_i = \frac{\sum_{u=1}^{N} z_{ku} \bar{y}_{u}}{\sum_{u=1}^{N} z_{ku}^2}$$  \hspace{1cm} (10)

$$b_{ij} = \frac{\sum_{u=1}^{N} z_{ku} \bar{y}_{u}}{\sum_{u=1}^{N} z_{ku}^2}$$  \hspace{1cm} (11)

$$b_{ii} = \frac{\sum_{u=1}^{N} z_{ku} \bar{y}_{u}}{\sum_{u=1}^{N} z_{ku}^2}$$  \hspace{1cm} (12)

where $z_{ku}$ – parameter value (vector column); $\bar{y}_{u}$ - arithmetic mean of repeated experiments on the line of the plan; $N$ – total number of plan points; $u$ – plan line.

Coefficient estimation $b_0$:

$$d_0 = \frac{\sum_{u=1}^{N} \bar{y}_{u}}{N}$$  \hspace{1cm} (13)

Then

$$b_0 = d_0 - c \sum_{i=1}^{r} b_i$$  \hspace{1cm} (14)

Checking the regression coefficients for significance using the standard error is a mandatory operation that follows after their calculation:

$$S_b = \frac{S_{\text{repr}}^2}{N}$$  \hspace{1cm} (15)

The statistical hypothesis that the mathematical expectation of a random variable is equal to zero is the basis of verification: the condition $b = 0$ for all coefficients (16-19). Verification is carried out using Student’s $t_{cr}$ test (20). The value from the table is used as the basis for the critical value of $t_{cr}$.

$$t_0 = \left| \frac{b_0}{S_b} \right|$$  \hspace{1cm} (16)

$$t_i = \left| \frac{b_i}{S_b} \right|$$  \hspace{1cm} (17)

$$t_{ij} = \left| \frac{b_{ij}}{S_b} \right|$$  \hspace{1cm} (18)

$$t_{ij} = \left| \frac{b_{ij}}{S_b} \right|$$  \hspace{1cm} (19)

$$t_{0;ij} > t_{kp}$$  \hspace{1cm} (20)

The assessment of the adequacy variance for $N > m$ characterizes the deviations between the results of observations and the values that are formed by the response function:

$$S_a^2 = \frac{1}{N-m} \sum_{u=1}^{N} (\bar{y}_{u} - y_{u})^2, N > m$$  \hspace{1cm} (21)

where $m$ – number of estimated model coefficients; $\bar{y}_{u}$ – average value of observation results at the “u” point of the plan; $y_{u}$ – response value at the same point, predicted by the model.

The number of degrees of freedom of the variance of adequacy $f_2 = N - m$. 
The mathematical model is considered adequate if the ratio of the variances of reproducibility and adequacy is less than the critical value of Fisher.

\[ F_p = \frac{s^2_{\text{eff}}}{s^2_{\text{repr}}} < F_{cr} \]  

(22)

We compose a polynomial second-order regression equation:

\[ y = b_0 + b_1 z_1 + b_2 z_2 + b_3 z_3 + b_{12} z_1 z_2 + b_{13} z_1 z_3 + b_{23} z_2 z_3 + b_{122} z_1^2 + b_{222} z_2^2 + b_{333} z_3^2 \]  

(23)

We need to ensure that the responses satisfy certain requirements in order to maintain the correctness of the analysis and the correctness of the processing of the experiment. The quantitative nature of the responses, expressed in numbers, should be attributed to these requirements. We can use such a technique as ranking or “ranking approach” if there is no corresponding method for quantitative measurement of the research result. The rank is a subjective quantitative assessment of the result of the experiment, based on the following types of scales: two-point, five-point. One response value must correspond to a predefined list of parameter values. It should be accurate to the experimental error in this case.

**Rank approach - a method of expert assessments in a given situation.** Four expert groups were involved in scoring from 1 to 100 for each of the 15 points on the plan.

We use formulas (16-19) to determine the regression coefficients.

\[ b_1 = \frac{-11.87}{10.95} = 1.08 \]

We search for coefficients in the same way, \( b_2; b_3 \),

\[ b_{12} = \frac{-38.13}{8.00} = -4.77 \]

We are looking for odds \( b_{13}; b_{23} \),

\[ b_{11}^2 = \frac{15.67}{4.36} = 12.47 \]

We are looking for odds \( b_{22}^2; b_{33}^2 \).

| Table 3. The values of the regression coefficients. |
|-----------------------------------------------|
| \( b_0 \) | 51.21 |
| \( b_2 \) | -3.08 |
| \( b_{12} \) | -4.77 |
| \( b_{23} \) | -0.08 |
| \( b_1 \) | -11.87 |
| \( b_3 \) | -6.50 |
| \( b_{13} \) | 1.17 |
| \( b_{11} \) | 3.59 |
| \( b_{33} \) | 0.63 |

We will use the formulas (16-19) to check the significance of the coefficients of the regression equation (table 3). Values \( S_p = 1.22 \); \( t_{cr} = 2.050 \).

The condition \( t_{0.05} \( t_{xp} = 2.050 \) is not satisfied for the coefficients \( b_{12}, b_{13}, b_{23}, b_{24} \). We will not use these coefficients further. The final regression equation is as follows:

\[ y = 51.21 + 22.56 z_1 + 13.47 z_2 + 6.25 z_3 + 12.47 z_1^2 + 10.14 z_2^2 + 8.66 z_3^2 \]  

(24)
3. Results

The construction of a mathematical model is one of the main tasks posed by the authors of this work. This mathematical model will allow you to find the best organizational and technological solutions in the production of concrete work in the winter. The found regression coefficients and the results obtained will allow us to approach one more step to the solution of the question posed. This article is the basis for the quantitative assessment of the organizational and technological parameters of a construction project. The adequacy of the mathematical tool is justified in this paper. Identifying the dependence of all combinations of organizational and technological solutions with the results of an expert survey and linking the obtained coefficients of parameter weights to the created mathematical apparatus is the next step. This will make it possible to qualitatively assess the quantitative values of calculating the potential of organizational and technological solutions for the production of concrete work in the winter.

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