Methodology for the integrated assessment of design solutions for foundation pit fences based on the theory of active systems

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Abstract. To automate the selection of design solutions for foundation pit fences, it is necessary to build an integrated mechanism. However, for the real construction projects with various engineering and geological conditions, there are many design solutions for foundation pit fencing that satisfy the calculations for the limiting conditions. A rather difficult task is the issue of optimizing various parameters that must be taken into account when developing a design solution, as well as evaluating various possible options and choosing the most appropriate need from them, not only in terms of cost, but also the safety of residents. The paper proposes a methodology for assessing design solutions for foundation pit enclosures based on the theory of active systems.

1. Introduction
The building envelope, as a complex engineering object, is characterized by a set of parameters that determine the technical and economic indicators of the design solution [1-6]. In the process of evaluating the design solution of the pit fence, the problem arises when choosing the most optimal of them, that is, to determine those solutions with high technical and economic indicators. Thus, we pass to the problem of multicriteria choice. To solve this problem, it is proposed to use modern tools of mathematical modeling, namely, the principles of the theory of active systems associated with the formation of a comprehensive assessment, which reflects all the consumer properties of the object in aggregated form.

The theory of active systems (TAS) is a part of the theory of management of socio-economic systems that studies the properties of the mechanisms of their functioning, due to the manifestations of the activity of participants in the system. The main research method is mathematical (game-theoretic) and simulation. Many efficient management mechanisms have been developed, researched and implemented; the corresponding models and methods are used to solve a wide range of management problems in the economy and society. The results obtained are reflected in numerous publications [7-17]. According to its main approaches and used research methods, the theory of active systems is extremely closely connected with such sections of control theory as: theory of hierarchical systems, theory of control of complex systems, economic and mathematical modeling, project management. The first class of works are monographs containing a complete and systematic presentation of current theoretical results, as well as the results of applied research [7-12]. The second class of work are textbooks aimed at university students, graduate students and students of the continuing education system [13-17]. The third class of works, reflecting mainly theoretical results, are papers in scientific journals (mainly “Automation and Telemechanics”, as well as “Instruments and Control Systems”, “University News”, “Systems Science”, “Mathematical Social Sciences” and etc.)
2. The mechanism for obtaining a comprehensive assessment of the pit fencing

Recently, an approach based on the use of the goal tree has gained wide distribution for constructing generalized estimates of objects of various types.

At the same time, each element (top) of the tree, including the final one, is disaggregated into exactly two sub-elements, that is, the so-called dichotomy method is used. In this case, the aggregation of each pair of elements into the element of the next (upper) level is performed using logical convolution matrices.

The solution to the problem of choosing a design solution for the excavation fence involves the implementation of conflicting goals within the existing resource constraints. In this case, to make a decision it is necessary to use a mechanism for assessing the feasibility of goals.

We will consider the type of building envelope as a complex technical system, the state of which can be estimated by a number of factors or criteria. Let the system being evaluated be described on the basis of a given set of particular criteria by the vector $\mathbf{K} = (K_1, ..., K_I, ..., K_N)$, where $K_I$ is the value of the I-th particular criterion. The task is to work out a comprehensive criterion for choosing a design solution for the excavation fence $f(\mathbf{K})$.

For the task of assessing the choice of the design solution for the foundation pit fence, a binary structure is selected from five enlarged groups of criteria (figure 1):

- $K_1$ - Geological conditions;
- $K_2$ - Hydrogeological conditions;
- $K_3$ - The distance from existing buildings to the pit;
- $K_4$ - Category of existing buildings by technical condition;
- $K_5$ - Cost-effectiveness of the design solution.

![Figure 1. Binary structure for five groups of criteria.](image-url)

The group of criteria $K_1$, describing the geological conditions and the group of criteria $K_2$, characterizing the hydro-geological conditions, are combined into one aggregate criterion of environmental parameters $K_{12}$; the aggregate criterion of the surrounding building parameters $K_{34}$ combines the group of criteria $K_3$ representing the distance to the foundation pit and the group of criteria $K_4$ corresponding to the category of buildings according to the technical condition. Further, these aggregate criteria $K_{12}$ and $K_{34}$ will be combined into a criterion for a comprehensive assessment of $K_0$, and after a criterion for a comprehensive assessment of $K_0$ will be combined with
a criterion of economic efficiency K5, resulting in a criterion of an integrated assessment taking into account the economic efficiency of KOE.

The employees selected a three-point rating scale: rating 1 - “unsatisfactory” (the values of the indicators do not recommend the use of this construction of the foundation pit fence), 2 - “satisfactory” (the values of the indicators allow this construction of the foundation pit fence), 3 - “good” (the values of the indicators are very favorable for the use of this design of the pit fence).

For a three-point scale, the main convolution matrices are presented in figure 2:

\[
M_1 = \begin{bmatrix}
2 & 2 & 3 \\
1 & 2 & 3 \\
\end{bmatrix}
\]

\[
M_2 = \begin{bmatrix}
2 & 2 & 3 \\
1 & 2 & 2 \\
\end{bmatrix}
\]

\[
M_3 = \begin{bmatrix}
1 & 2 & 2 \\
1 & 1 & 1 \\
\end{bmatrix}
\]

\[
M_4 = \begin{bmatrix}
2 & 2 & 2 \\
1 & 1 & 1 \\
\end{bmatrix}
\]

\[
M_5 = \begin{bmatrix}
1 & 2 & 3 \\
1 & 2 & 2 \\
\end{bmatrix}
\]

\[
M_6 = \begin{bmatrix}
2 & 3 & 3 \\
2 & 2 & 2 \\
\end{bmatrix}
\]

Figure 2. Basic convolution matrices.

M1 - matrix of the maximum favorable outcome. Of the two ratings, the big one is always chosen;
M2 - matrix of moderate favorable outcome;
M3 - matrix of the maximum adverse outcome. Of the two ratings, the smaller one is selected;
M4 - matrix of moderate adverse outcome;
M5 - matrix of absolute preference for one indicator;
M6 - matrix of preference for one indicator.

When forming matrices of logical convolution of matrices, the requirements for building envelopes and the features of the building area were taken into account.

3. Results and discussion

We will offer a comprehensive mechanism for choosing design solutions for foundation pit fencing. Table 1, based on an expert survey of 76 experts, shows the average values of private estimates characterizing the building area for each type of foundation pit fence.

|                | Wall in the ground | Pile fence | Sheet Piling | Beam fence |
|----------------|--------------------|------------|--------------|------------|
| Geological conditions (K1) | 3                   | 3          | 3            | 2          |
| Hydrogeological conditions (K2) | 3                   | 2          | 2            | 1          |
| The distance from existing buildings to the pit (K3) | 3                   | 3          | 1            | 1          |
| Category of existing buildings by technical condition (K4) | 2                   | 3          | 2            | 2          |
| Cost-effectiveness of the design solution (K5) | 2                   | 1          | 2            | 3          |

Using the developed methodology, the following problem was solved. There is a territory for the construction of an apartment building in Moscow, it is necessary to choose a design solution for the foundation pit fence, providing a comprehensive assessment of “good” at minimal cost.

We will analyze in detail the mechanism for evaluating the design solution of the foundation pit fence using the example of the wall in the ground design.
Estimates K1 and K2 are collapsed using the matrix M2 (figure 3), estimates K3 and K4 - using the matrix M4 (figure 4).

```
 3 2 3 3
 2 2 2 3
 1 1 2 2
 K2
 K1
```

**Figure 3.** The convolution matrix of the estimates K1 and K2.

This matrix reflects the state of environmental parameters, taking into account the choice of the design solution for the wall in the ground fence.

The convolution matrix of the estimates of the distance to the pit and the category of buildings by technical condition are presented in figure 4.

```
 3 2 2 3
 2 1 2 2
 1 1 1 2
 K1
 K3
```

**Figure 4.** The convolution matrix of the estimates K3 and K4.

This matrix estimates the parameters of the surrounding buildings, taking into account the choice of the design solution for the wall in the ground fence.

Aggregated criteria for assessing environmental parameters and surrounding building parameters are collapsed using the M1 matrix (figure 5), the resulting convolution matrix for a comprehensive assessment of the design solution for the foundation pit enclosure of the wall in the ground is shown in figure 5.

```
 3 3 3 3
 2 2 2 3
 1 1 2 3
 K12
 K34
```

**Figure 5.** The convolution matrix of the estimates K12 and K34.

The convolution of the obtained comprehensive assessment with the criteria of economic efficiency is minimized using the M3 matrix (figure 6), as a result of which we obtain an integrated assessment of the design solution for the foundation pit fence taking into account the economic efficiency of the KOE.

```
 3 1 2 3
 2 1 2 2
 1 1 1 1
 KO
 K5
```

**Figure 6.** The convolution matrix of the estimates KO and K5.
Using the data from figures 5-6, we get: KO = 3, KOE = 2. A comprehensive assessment of “good”, economically this project is rated as “satisfactory” one.

The table 1 shows the graphical diagrams of the formation of comprehensive assessments of the choice of design decisions presented in figures 7-10.

**Figure 7.** The flowchart of the procedure for determining a comprehensive assessment and integrated assessment, taking into account economic efficiency for the design solution of the fence wall in the ground.

**Figure 8.** The flowchart of the procedure for determining a comprehensive assessment and integrated assessment, taking into account economic efficiency for the design solution fencing from piles.
Figure 9. The flowchart of the procedure for determining a comprehensive assessment and integrated assessment, taking into account economic efficiency for the design solution sheet piling.

Figure 10. The flowchart of the procedure for determining a comprehensive assessment and integrated assessment, taking into account economic efficiency for the design solution of a beam fence.
We write the measurement results in the table 2:

**Table 2. Comprehensive assessment and cost-effectiveness of types of structures.**

| Fencing type                        | Wall in the ground | Pile fence | Sheet Piling | Beam fence |
|-------------------------------------|--------------------|------------|--------------|------------|
| Comprehensive assessment (KO)       | 3                  | 3          | 2            | 1          |
| Integrated assessment taking into account economic efficiency (KOE) | 2                  | 1          | 2            | 3          |

Thus, the most preferable design solutions for the foundation pit fence are a wall in the ground and a pile fence. However, a pile fence is a more expensive option. Therefore, for this object it is better to use foundation pit fence rather than a wall in the ground.

Having a convolution tree of enlarged groups of criteria that affect the choice of foundation pit fencing, you can evaluate any option and its economic efficiency and choose the optimal one.

4. Conclusions

This technique is rather efficient. Conducting engineering surveys at the conceptual phase of the feasibility study requires a lot of money to maintain a group of geotechnical specialists to assess the technical condition of the built-up area. Engaging third-party specialists requires a number of procedures such as selecting contractors, conducting a tender and execution of the contracts, etc. In addition, this assessment technique is necessary for a young specialist, since he designs safe objects only after years of professional experience. Therefore, this technique will help reduce errors made during design and the severity of their possible consequences.

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