The project decisions’ assessment algorithm for the foundation pit fencing based on the Theory of Active Systems

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Abstract. Currently, a lot of new construction is underway in the large cities and megacities territories. Large residential complexes and shopping centers are erected at the sites of former industrial zones and factories. The issue of the accidents in foundation pits arising from the errors in their barriers’ projecting has recently been an acute question. And this is directly related to the fact that construction has to be carried out in very difficult straitened development conditions with the presence of existing utilities and underground facilities. The main designer’s task is the selection of an optimal project solution. Any project decision for the foundation pit barrier is characterized by both the technical characteristics, in particular the materials used, and its construction cost. Therefore, the designer faces a difficult question of the price and quality ratio for this project decision. And it is complicated by the fact that the specific engineering and geological conditions imply the possibility of various project decisions for the foundation pit fencing and the materials corresponding to the calculations results for the limiting states. This paper describes in detail the methodology for assessing the project decisions for foundation pit fencing and the choice of the materials used in barriers’ design based on the active systems theory.

Introduction
Barrier construction is a complex engineering object. In this regard, it is characterized by a set of the parameters determining the technical and economic indicators of the project decision [1 - 4]. In the process of the foundation pit barrier project decision assessment, the problem of choosing the most optimal decision, that is, to determine those decisions which technical and economic indicators are high, arises. Thus, we pass to the multicriteria choice problem. To solve this problem, it is proposed to use modern tools of mathematical modeling, for example, the active systems theory principles associated with a comprehensive assessment reflecting the consumer properties’ totality inherent in the object.

Theory of Active Systems (TAS) is a section of the systems’ management theory belonging to the socio-economic category. The subject of this theory is the properties inherent in the mechanisms of active systems’ functioning. These properties are determined by the activity manifestations for the system subjects. The main research methods are the methods of simulation and game-theoretic (mathematical) modeling. A significant number of control mechanisms with high efficiency has been developed and implemented. Methods and models are used to solve various control problems. These tasks are associated with the management of a wide range of objects - from the technological processes
to the regions and states [5-7]. The solution to such problems requires the need to comprehensively assess the complex socio-economic objects, such as development scenarios, programs, projects, etc. The methodology for the comprehensive assessment formation has been developed at the V.A. Trapeznikov Institute of Control Sciences, Academy of Sciences. It integrates various approaches to comprehensive assessment presented in a significant number of economic activity areas [8-11].

This approach is based on the following idea - in relation to the object being evaluated, a set of parameters should be determined. Using convolution matrices, the parameters should be compared in pairs to each other. Further, also by means of convolution matrices, it is necessary to carry out pairwise comparison of the obtained characteristics for the next level. The specified procedure should be repeated until the only characteristic remains. The resulting characteristics will be a comprehensive assessment of the object.

Methodology for designing a comprehensive mechanism of assessing the project decisions for foundation pit fencing

Let us consider the methodology for constructing an integrated mechanism of assessing the project decisions for foundation pit fencing (Figure 1)

**Figure 1.** An integrated mechanism of selecting the project decisions for foundation pit fencing

A consistent description of the design decision evaluation process consists of two stages.

Stage 1:

- an examination mechanism that provides the opportunity to identify, based on information about the foundation pit fences’ types, the main problems and targets. It is necessary to identify the experts’ opinion through a survey, to process the received estimates. The final decision - the result of the
examination - is determined by the evaluation processing results. It is required to develop a procedure that will be used to process the expert assessments.

- integrated assessment mechanism. This mechanism provides the formation of an aggregated description based on detailed information, various parameters and indicators. The basis of such a description is a limited number of the object’s generalized characteristics. The mechanism provides the design solutions’ assessment for the foundation pit barriers, depending on the technical requirements and characteristics of the built-up area.

Stage 2:
- a “cost-effectiveness” mechanism for the updated assessment development of the project decisions for the foundation pit fencing, taking into account economic efficiency. The main idea of the mechanism is as follows: taking into account the proposed project decisions for the foundation pit fencing, selected in the framework of the previous stage, and the volume of productive resources necessary to implement them, the cost-effectiveness of the project decisions for the foundation pit fencing is determined.

Based on the hierarchical structure binary treble of the criteria, a comprehensive assessment can be formed. In order to form the indicated assessment, it is necessary to organize a hierarchical structure of criteria. The aggregate assessment of criteria related to the previous level is determined at each level of this structure.

The procedure for the comprehensive assessment development for the project decision choice can be represented as a hierarchical process. Table 1, based on the expert survey of 76 experts, shows the average values of private estimates characterizing the building area for each type of foundation pit fencing (barrier).

**Table 1.** The estimates of the indicators, characterizing the building area for each excavation type

| Type of fencing | Ground wall | Piles’ fencing | Sheet pile fencing | Beam fencing |
|-----------------|-------------|----------------|--------------------|--------------|
| Groups of criteria |            |                |                    |              |
| Geological conditions (C1) | 3 | 3 | 3 | 2 |
| Hydro-geological conditions (C2) | 3 | 2 | 2 | 1 |
| Distance from the enveloping buildings to the foundation pit (C3) | 3 | 3 | 1 | 1 |
| Existing building category (C4) | 2 | 3 | 2 | 2 |
| Cost-effectiveness of the project decision (C5) | 2 | 1 | 2 | 3 |

The modern designer faces a very difficult task, since in modern conditions a wide selection of methods for constructing the foundation pit barriers is used, and each of them has both its advantages and disadvantages. The factors that influence how effective one or the other barrier type use is, are the presence of the surrounding supply lines, structures, buildings, the size and depth of the pit, hydro-geological, soil conditions [12]. In this regard, the experts were asked to evaluate each of the main types of enclosing structures used, depending on the enlarged groups of criteria influences.
A three-point assessment scale was chosen for assessment: rating 1 - “unsatisfactory” (criteria values do not recommend applying this foundation pit barrier construction), 2 - “satisfactory” (criteria values allow applying this foundation pit barrier construction), 3 - “good” (criteria values are very favorable for the application of this foundation pit barrier construction).

Figure 2 shows a tree-form structure that corresponds to the analyzed model.

![Figure 2](image)

**Figure 2.** Binary structure for the five groups of criteria,

where C1-C5 are the local estimates based on the enlarged groups of criteria (Table 1).

It seems natural to first combine the geological conditions C1 criterion and the criterion of hydro-geological conditions C2 into one aggregate criterion of environmental parameters C12. Similarly, we will combine the criterion for the distance from the enveloping buildings to the foundation pit C3 with the criterion for the enveloping buildings’ category according to the C4 technical condition into one aggregate criterion for the C34 enveloping buildings’ parameters. Further, combining the aggregated criteria of the environmental parameters C12 with C34 enveloping buildings’ parameters, we obtain a comprehensive assessment of the project decision for the foundation pit barrier, which ensures the technical characteristics and safety of the development zone. However, the cost of its construction has a very large influence on the choice of the project solution for the foundation pit fence building. Therefore, the foundation pit fencing comprehensive assessment indicator CAE, taking into account the economic efficiency, will be obtained by combining the indicator of a comprehensive assessment of the foundation pit fencing CA with the economic efficiency criterion for the project decision C5.

**The mechanism for obtaining the project decisions’ integrated assessments for foundation pit fencing**

An inherent feature of the hierarchical structure shown in Figure 2 is that, with respect to each of the nodes in this structure, only two estimates are aggregated. This feature is essential. The requirement for a comprehensive assessment is that it should reflect the priorities inherent in the project decision of the foundation pit barrier. The priorities and comprehensive assessment as a whole should be made by the decision makers. In this case, a subjective problem arises. Effective assessment and correlation can only be done by a person in relation to a limited number of options. The optimal number of criteria at each assessment stage is two. A convenient form for presenting the comparison results in the presence of two criteria is the matrix (Chart).

It is necessary to go to the rating scale for each of the criteria, which is discrete. The project decision of the foundation pit barrier should be evaluated using a three-point scale for each of the criteria. On this scale, 1 corresponds to an unsatisfactory assessment (the values of the indicators do not recommend...
the use of this foundation pit barrier construction), 2 - “satisfactory” (the values of the indicators allow this foundation pit barrier construction to be used), 3 - “good” (the values of the indicators are very favorable for the use of this design foundation pit fencing).

Let us consider the mechanism for evaluating the project decision starting from the second level of the hierarchy (to convolve the aggregated criteria of the environmental parameters $C_{12}$ with the parameters of the enveloping buildings $C_{34}$, into a comprehensive assessment of the project decision for the foundation pit fencing). That is, we will consider the hierarchical structure for three criteria for evaluating the project decision of the foundation pit barrier. Figure 3 shows an example of the aggregated criterion “environmental parameters” convolution the with the aggregated criterion “environmental parameters”.

![Figure 3. The convolution matrix of C12 and C34 criteria](image)

As already noted, this matrix reflects a comprehensive assessment of the project decision for the foundation pit barrier, since in case of an emergency with the enveloping buildings and the environmental parameters, both criteria will be of priority. In case of a satisfactory situation with the environmental parameters, priority will be given to the indicator characterizing the enveloping buildings’ parameters. In this case its priority is due to the following. If there is a satisfactory estimate of the existing building’s parameter and a good estimate of the environment parameter aggregated criterion, the condition will be considered as satisfactory. In turn, with a satisfactory assessment of the environmental parameters and good parameters of the t buildings, the condition will be assessed as good.

Based on a comprehensive assessment of the project decision for the CA foundation pit fence, it is possible to form a convolution matrix. This convolution matrix allows comprehensively evaluating the project decision of the foundation pit fence, taking into account economic efficiency (CAE). Figure 4 provides an example of such an assessment.

![Figure 4. The convolution matrix of the C5, CA criteria](image)

The priority system in this case is changing. If the evaluation score is good, priority will be given to the economic performance indicator. If the indicators’ values are satisfactory, the priority is the project decision’s comprehensive assessment indicator. In a situation where the situation with the project decision effectiveness indicator in economic terms and the integrated assessment indicator is critical, both indicators will be of priority. Boundary states are possible, separating good and satisfactory,
satisfactory and unsatisfactory statuses. Their definition may be different. Figure 5 presents the scheme for the comprehensive assessment development, taking into account the project decision’s effectiveness in economic terms.

![Diagram](image_url)

**Figure 5.** Development of a comprehensive assessment based on the project decision’s effectiveness for the foundation pit fencing in economic terms (CAE)

On the basis of the convolution treble of criteria, any type of fencing and its effectiveness in economic terms can be evaluated, and the optimal option is determined. In relation to the given evaluation example, the vector \( x = \{x_{12}, x_{34}, x_5\} \) is used to describe each of the options. The vector’s components determine the estimates according to the criteria.

In relation to the binary structure of 5 criteria groups (Fig. 2), the vector \( x = \{x_1, x_2, x_3, x_4, x_5\} \) will be used to describe each of the options, including five components, respectively.

**Discussions and Results**

The developed technique has the following main features:
- flexibility of the assessment system, the ability to work with both qualitative and quantitative variables;
- ease of use for the subject specialist, intelligibility of the process physical meaning;
- even if the set parameters vary slightly, the point estimates of the project effectiveness for the foundation pit fencing, obtained using the methodology, will significantly differ;
- the proposed mathematical model provides the ability to conduct the project decisions’ comprehensive assessment for the foundation pit barriers and a comprehensive assessment taking into account economic efficiency according to the specified criteria for each type of structure and compare the estimates obtained among themselves.

The technique is original and has no analogues.

**Summary**

To develop a comprehensive evaluation and a comprehensive assessment taking into account the project decisions’ economic efficiency for the foundation pit barriers, an appropriate algorithm including two
stages: a mechanism for the project decisions’ comprehensive assessment for the foundation pit fences, which allows evaluating project decisions of foundation pit fences depending on the technical requirements and characteristics of the construction area as well as the cost-effectiveness mechanism for the project decisions’ updated assessment development for the foundation pit barriers taking into account economic efficiency, has been developed. Based on the developed algorithm, the methodology for evaluating the project decisions when choosing the foundation pit fencing has been developed.

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