Some Results of Systemic Study of Design and Technological Solutions for Stabilizing Ground Structures

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Abstract. The article presents the results of the application of the system-analysis technique for stabilization of ground structures in the Far Eastern territory of the Russian Federation using the new multifunctional technology "SETCON". These results are presented in two perspectives: on the one hand, it is a generalization of the application of the functional-systemic approach for the development of the design and technological solutions, on the other hand they represent new original technologies that are independent scientific results. Examples of the improved technological solutions are given and proposals on improving the methods of making constructive and technological decisions are made.

1. Introduction

The paper is a summary of the author's many years of experience in improving design and technological solutions for the reconstruction of such objects of the transport network of the region as the roadbed of railways and highways and other ground structures. The results of applying the methodology of systemic study of design-technological solutions to the problems of stabilizing ground structures in the Far East of Russia are exemplified by the new multifunctional technology "SETCON" developed by the author.

In accordance with the methodology of the functional-systemic approach [1] the design and technological solutions are considered as a system that includes such heterogeneous subsystems as design (volume-constructive) solutions of reconstructed objects and methods of their construction. At the same time the main system-forming factor is the result, i.e. the reconstruction of the object in the most effective way in the aggregate of restrictions imposed by the external environment. The result (in the context of the goal) is dynamic due to the constant change in the requirements of the oversystem. Such dynamics gives rise to the technogenesis of the system in the form of the spiral development, when the cycle of achieving the result follows a new cycle at a new qualitative level.

2. The problem of watering the soil for road embankments on permafrost. Search for solutions.

Immediately after the construction of the roads the roadbed becomes a powerful heating source for permafrost due to the high thermal conductivity of the roadbed soils. The intensive processes of permafrost degradation occur due to the violation of water-thermal regime in the system "roadbed-subgrade" [2].

According to the data of modern researches of the roadbed condition in the Eastern site of the Baikal-Amur railway [3] the extent of the deforming and defective roadbed on some sites makes up to 79% of the length of these sites. The main cause of deformation is the flooding of the roadbed due to...
the lack of necessary culverts. Most deformations occur in the sections with logs without such structures and in the approach paths to the existing culvert artificial structures.

The leading transport construction researchers created the basis of the methodology for the development, adoption, and implementation of specific measures to stabilize the roadbed under construction and operation in the cryolithozone [4-7, etc.].

The stability of the roadbed can be ensured due to the removal of water from the body of the roadbed. But under the conditions of low flow it is extremely difficult to cross-flow water due to the small slope of the terrain. The culvert built on permafrost has a negative impact on the temperature regime of the surrounding frozen soil [8]. The construction of the overpass bridge in the condition of the moving trains is problematic because of the need to build a bypass section of the railway. As experience has shown, the most effective design in the areas of poorly secured runoff is a filtering embankment (FE) made from fractionated rocky soil, shown in figure 1 [9]. The size of fractions of stone is from 20 to 70 cm.

![Figure 1. Filter mound (FM) in the roadbed: 1 – railroad embankment; 2 - filter; 3 - insulation top of FM; 4 sand - gravel cushion; 5 – counter dam; 6 - cap; 7 - insulation of the bottom of FM; 8 - depression curve of water flow.](image)

The widespread introduction of these high-performance structures into practice of the reconstruction of the roadbed is constrained by a number of reasons:
- traditional technology of FM construction prescribes laying the stone by hand;
- existing mechanized methods of work are characterized by large losses of expensive rock material and do not provide the necessary quality of construction;
- due to the low productivity of work, it is necessary to organize the movement of trains along the temporary bridge for several days which entails significant economic damage because of the speed limit.

Further consideration of the general approach to the systemic development of the technology will be continued with a particular example of the construction of filtering mounds during the reconstruction of the roadbed.

3. The development of a new technology
Special requirements to technologies are caused by the need to consider a number of factors significantly complicating the course of work:
- carrying out the construction work in the conditions of train movement;
- the remoteness and dispersion of the plots of the reconstruction;
- lack of scope of work;
- inaccessibility of work sites;
- the need to work in a limited time period;
- lack of production and financial resources.

A comparative analysis of the existing technologies for the construction of FM showed that they all have a number of significant disadvantages in view of solving the technological problem. For the reconstruction and repair of roadbeds and other ground structures the author has developed a special technology, dubbed SETCON (an abbreviation from the Russian words setchatyi (mesh) and konteiners (containers)) [10].

The essence of the SETCON technology consists in the following:

1) The sorted rock is loaded mechanically to special synthetic rope mesh containers (setcons);
2) The filled containers are transported to the construction site by various vehicles;
3) The constructions are mounted from containers using jib cranes or single-bucket excavators.

Thus, the process of construction of the FM, which was so difficult to mechanize, turns into an orderly installation process with a minimum of manual work.

The developed technology was implemented on the Eastern section of BAM (Baikal-Amur railroad) (km 3222 PC 5). The main positive results of the SETCON technology are as follows [3]:

- the complexity of the work is reduced by 1.5-2 times;
- the consumption of the assorted rock soil is reduced by 20-40%; there is no need in a temporary bridge; the fractionated stone has no contaminants;
- the duration of the production process is reduced by 3-4 times;
- the economic losses from restricting the speed of trains in the period of reconstruction are reduced.

Such results of the introduction of the new technology compensate for the increase of the construction cost connected with the payment for the manufacture and delivery of mesh containers.

4. Development of SETCON technology with the method of systemic study of design and technological solutions.

Having considered in retrospect the process of development of SETCON technology it is possible to make some methodological generalizations and identify the sequence of certain procedures and to establish the main driving forces and patterns.

For a technological process as a system, the basic rule is: "the quality level of any process is determined by the quality level of the intermediate stage, which has the worst quality index" [1]. In other words, it is the principle of "weak link". Based on this rule, the evaluation of the quality of the i-th Q_i process will be determined from the formula:

$$Q_i = \min_j (Q_{i,j})$$

where $Q_{i,j}$ are indicators of the quality of the j-th part of the elementary process as a part of the given process i. Therefore, the improvement of the technology after the general analysis was carried out in several directions: with a consistent special analysis of the relevant elements and working out the ways to improve the process.

After testing the SETCON technology in real conditions of construction sites there came a natural process of improvement and development. The process of development of this technology (technogenesis) is evolutionary. The scheme of development of design and technological solutions is presented in Figure 2. Technogenesis of the system is a cyclic process of purposeful improvement and is displayed as a spiral scheme. In accordance with the scheme, the phases of the life cycle of the $G_i-L_i-T_j-R_i$ process are repeated on each i-th round of the development spiral. Here
- $G_i$ is research and problem-setting (goal-setting);
- $L_i$ is identification of obstacles to the achievement of results (limitations to the development);
- $T_i$ is solving the problems on the technical level (technical capabilities as a product of engineering creativity);
- $R_i$ is the result (development of design-technological documentation, legal registration, implementation).

Then, new, extended requirements of the oversystem appear as a rule and the process repeats. Let's fix the main points of our example illustrating the methodological approach.

![Figure 2. The scheme of development of design and technological solutions (the phases of the technogenesis of the system)](image)

During the first cycle ($i=1$), the goal of $G_1$ was to develop SETCON technology for the construction of filter mounds (FM) in the conditions of reconstruction of railways instead of existing traditional technologies (phase $L_1$). The author put forward and formulated the idea of SETCON technology, performed the necessary design and technological studies, obtained a patent for the invention [10] (phase $T_1$). As a result of this work (phase $R_1$), a set of technological documentation for the construction work was developed, the introduction of technology on the real object was made, positive results were obtained.

Prospects for the growth of freight traffic on BAM exacerbated the problem of the roadbed, opening the 2nd cycle ($i=2$). Taking into account the system of planning the repair work on the railroads of Russia there was set goal $G_2$, namely the improvement of the SETCON technology for the organization of the construction work in a single complex with capital repairs of the railway.

On this cycle obstacle $L_2$ was formulated as the problem of reducing the duration of the interruption in the movement of trains for the organization of repair work in a single complex with major repairs of the way.

At the creative stage of the formation of technical capabilities ($T_2$) the improvement of internal elements of SETCON technology was carried out. There was performed a functional-systemic analysis of the integrated process with the application of the principle of the "weak link" (p.1). For improving the technology the following elements were identified: 1) SETCON combining the quality of the object and the tool; 2) working operations for the installation of FM and intra-site movement of building materials.
As a result of the work with the first element there were designed setcons of different shapes and sizes for the rational use under various conditions [11].

For the elimination of losses of time on auxiliary operations there was found the following decision: to use the one-bucket excavator as the hoisting-and-transport car instead of mounting cranes [12]. The reduction in the time of the main process was up to 40%. In addition, the reduction of the construction cost was achieved by reducing the amount of auxiliary work reducing the cost of mechanization.

As a result of R_3 there was developed regulatory and technological documentation. Full-scale tests have yielded positive results: the construction of the filtering embankment for a 6-hour "window" on the BAM was a confirmation of the ability to perform the reconstruction of the roadbed in a single complex with major repairs of the way.

During the completion of the 2nd cycle for the Russian Far East, new large-scale tasks of reconstruction of the transport system of the region were identified [13]. The possibility of using the technology as a multi-functional one on the third round of the development spiral (i=3) predetermined the goal of G_3, i.e. to extend the use of the SETCON technology for the construction of other special structures made of rocky soil (fortifications for slopes, shore protection structures, etc. [14,15]). The obstacle for performing this task was the lack of opportunities in the rocky quarries of the region to produce the required amount of the rock soil of required fractions. Thus, more than 1 million m³ of such material was required to build structures from fractionated rocky soil for the construction of the Amur-Yakutsk railway, but due to the lack of quarry capacity the design solutions had to be changed. Thus, L_3, restrictions on the performance of rock quarries, determined a new requirement for the development, which on the third cycle of technogenesis stimulates the search for technological opportunities T_3, i.e. the improvement of the accompanying processes. The author is currently working in this direction.

As a result, this technology has become multifunctional. There are the following grounds for this claim. First of all, as the core of this technology setcons combines the following functions:
- a) production and support equipment (shipping containers);
- b) industrial equipment while installing the structure;
- c) serving as a constructive-technological block after installation.

Setcons can be used once, becoming a part of the design, and repeatedly as a tooling for working operations.

Second, the technology can be used for implementing reconstruction activities with various effect on the object (the construction of the filter embankments; laying the rock in tight spaces; reinforcement of fastening structures made of rock).

5. Conclusion
The methodology of systemic development of design and technological solutions allows us to assert the following:
- When considering the progress of design and construction processes from the standpoint of systemic approach the technogenesis process goes through certain phases of development under the influence of the external environment (oversystem);
- The result (in the context of the goal) is dynamic due to the constant changes in the requirements of the oversystem (environment), usually towards increase, development, and empowerment. This dynamics generates technogenesis of the system in the form of a spiral development, when the cycle of achieving the result is followed by a new cycle on a new qualitative level;
- The development of the technological system makes it possible to significantly expand its capabilities. For example, in the considered case, the SETCON technology has become multifunctional.

The proposed spiral model, without claiming to be an absolute theoretical novelty, is a reflection of the real activity of the author, and therefore can be useful from a practical point of view. Some
generalizations and examples will be useful in the design of both structures and construction processes for their construction, although as can be seen from the above these elements are inextricably linked into a single system. The illustration of the systemic study of design and technological solutions for the stabilization of ground structures gives the designers an example for the application of this technology in other areas of construction.

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