IMPACT OF LINEAR ELEMENTS PROTECTION ON STABILITY OF PIPELINE TRANSPORT SYSTEMS

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ABSTRACT

Protection of individual linear elements (pipelines) is performed using technical, technological and other measures that ensure their operability in the presence of a process of progressive damage, that is, an emergency scenario where the pipelines of the system fail in a random sequence. With the help of the simulation method it is established that the greatest protective effect is observed if a group of pipelines is located near the source of the product, and all unprotected consumers are present in the protected fragment. It is shown that the topology of a «line» or «tree» type is preferable for the protected fragment of the system (simplex).

Keywords: pipeline transport, system, safety, protection, emergency situation, progressive damage, simulation modeling.

Background. *Pipeline transport systems are used to deliver raw materials, semi-finished products and finished products to consumers. In this case, the transported materials can be in a different aggregate state and have different properties [1, 2]. Especially dangerous is the process of delivery of explosive and fire hazardous substances, toxic chemical compounds.*

Possible development of emergency situations in operation of such potentially hazardous facilities is associated with a threat to life and health of personnel, environmental pollution and discontinuance of delivery of the target product to consumers [3]. The scenario of the development of the emergency situation, in which individual linear elements (pipelines) of the system pass randomly into a state of inoperability, will later be called progressive damage [4].

Objective. *The objective of the author is to consider impact of linear elements protection on stability of pipeline transport systems.*

Methods. *The author uses general scientific methods, comparative analysis, evaluation approach, graph construction, modeling.*

Results. *The development of progressive damage at some stage leads to the situation when all consumers are disconnected from the source of the product delivery, and the system loses the ability to reproduce the functional effect even in minimal volumes.*

To prevent the transition of individual linear elements to a state of inoperability, various technical, technological and organizational techniques are used. For example, pipelines are protected against corrosion, hydraulic shocks, seismic influences, overheating, mechanical damage [5–7].

Such protective measures are costly, but they allow increasing the ability of the system to withstand the development of the process of progressive damage and to reduce the possible damage in case of an emergency situation.

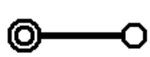
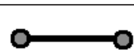
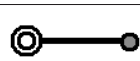
From this point of view, it is important to study the impact of protection of the linear elements of the pipeline system on development of the process of progressive damage to its network structure, which is characterized by the presence of a set of elements as separate subsets G1, ... G5 (Table 1).

Since the protected linear elements do not become unworkable in the course of development of an emergency situation, the protected linear elements maintain further their operability, and the indicator of stability of the network structure $0 \le F_v \le 1$ *means the average share of unprotected pipelines, the transition of which into an inoperable state leads to disconnection from the source of all unprotected consumers of the target product.*

Those consumers of the product are considered as unprotected, whose disconnection from the source in the considered network structure is possible at a

Table 1

Characteristics of linear elements of the pipeline transport system

A linear element of the system that connects one another:	A graphic representation of an element	Belonging to a separate subset	A quantitative composition of the elements of a subset
source and consumer		G1	g_1
two consumers of a product		G2	g_2
individual consumer and a transport node		G3	g_3
two transport nodes		G4	g_4
source of a product and a transport node		G5	g_5

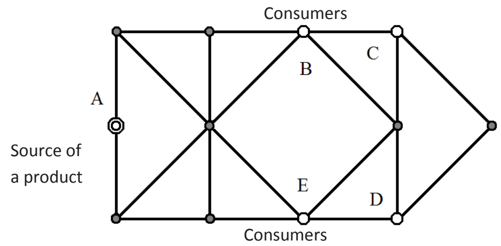
certain stage of development of progressive damage.

Let's define the concept of a simplex as a set of interconnected protected linear elements in the network structure. Suppose that a simplex can have any point elements except the source of the target product. This means that a simplex can contain only linear elements belonging to the subsets G2, G3 and G4.

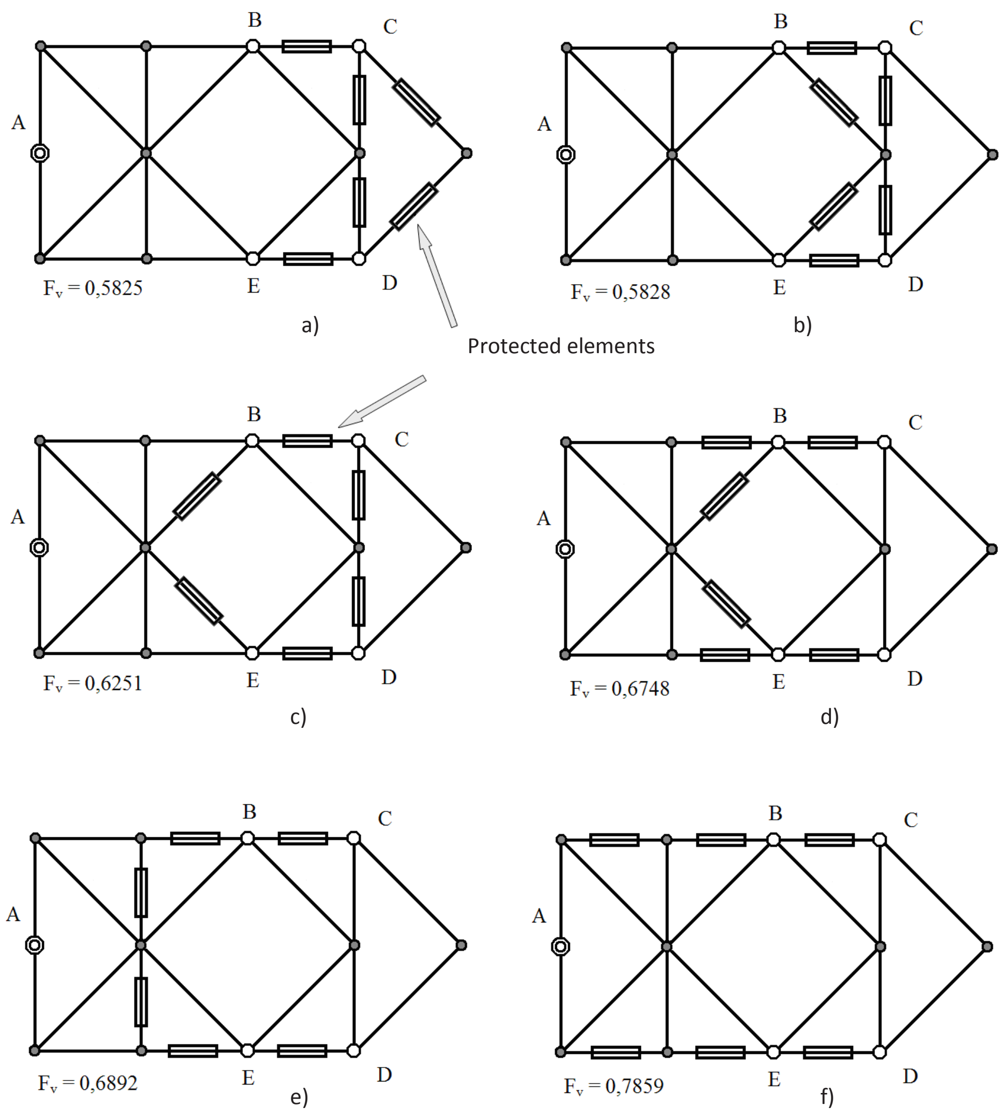
The characteristic of a simplex is the dimension, that is, the number of protected linear elements in its composition. It is obvious that the simplest simplex of dimension 2 arises from the protection of two successively connected linear elements.

A correct comparison of the properties of network structures with protected elements is possible only if the objects to be compared have the same number of unprotected linear elements, unprotected product consumers, as well as a simplex of the same dimension or several simplexes with the same total dimension.

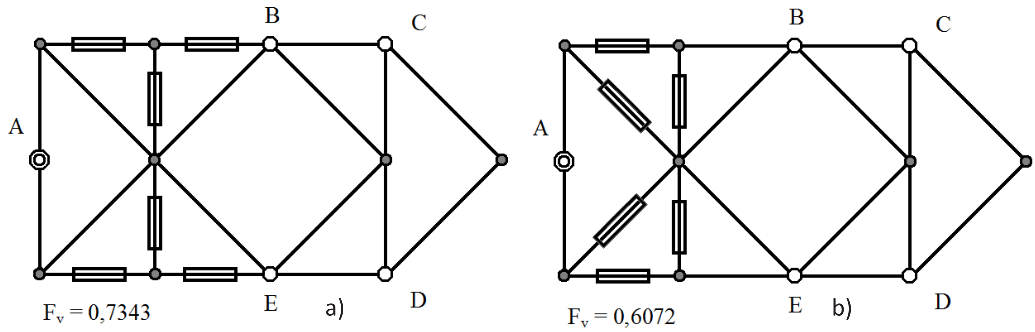
The effect of protection of linear elements on development of progressive damage was studied using the simulation modeling method [8, 9]. In the implementation of the computer experiment, a sequential transition to the state of inoperability of unprotected linear elements of the network structure was performed in a random order with an assessment of the possibility of delivering the target



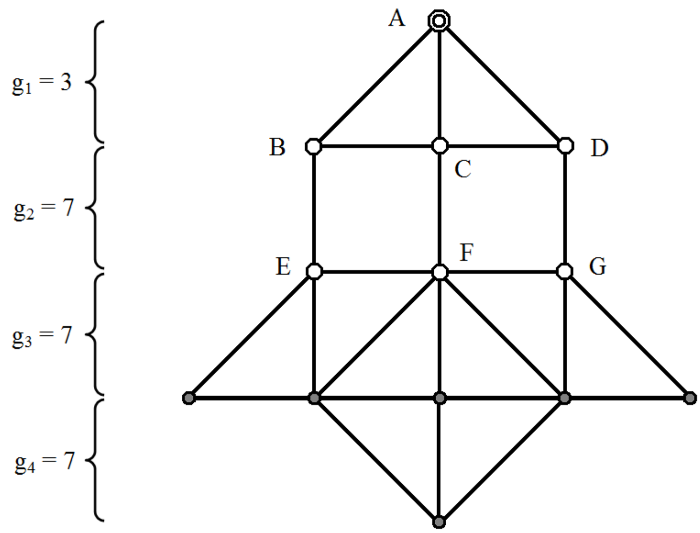
Pic. 1. Structural diagram of the pipeline system, which includes four consumers, 20 linear elements and 12 nodes.



Pic. 2. Growth of the values of stability indicator as the elements of the simplex gradually shift towards the source of the product.



Pic. 3. Decrease in the values of stability indicator as consumers of the target product C, D (a) and B, E (b) leave the composition of a simplex of dimension 6.



Pic. 4. Structural diagram of the pipeline transport system, as well as the characteristic of the quantitative composition of the elements of the subsets G1–G4.

product at each stage of the damage to unprotected consumers.

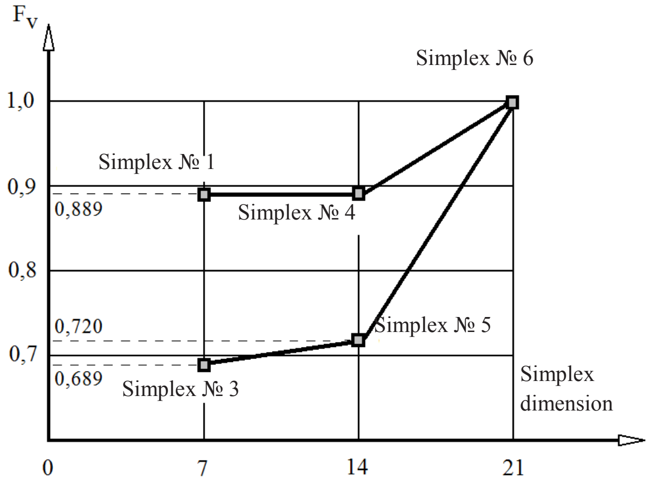
In order to understand how the position of the simplex in the structure of the network structure affects the efficiency of protecting the pipeline system, let's consider the object shown in Pic. 1.

Let's suppose that a simplex with dimension 6 will be used to protect the network structure with 20 linear elements. In this case, any element can be within the structure of this simplex, except for those belonging to the subset G5, and its position in the network can be arbitrary. Under these conditions, objects formed on the basis of the original structure and containing a simplex with the specified characteristics will be comparable. The change in the topology and position of the simplex in the network makes it possible to evaluate their effect on resistance of the analyzed network object

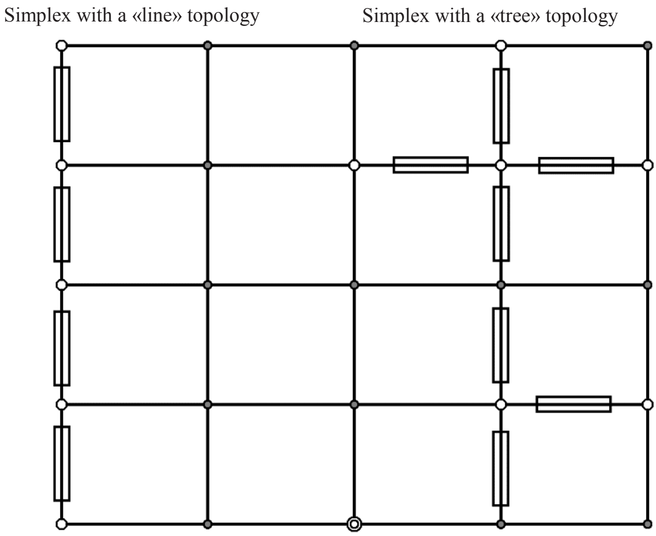
Table 2

The characteristics of simplexes used to protect a network object

Symplex characteristics			
Designation	Dimension	Quantitative composition	Structural features
No. 1	7	$g_2 = 7$	It has the minimum dimension and is at the minimum «distance» from the source
No. 2	7	$g_3 = 7$	It has the minimum dimension and is at some «distance» from the source
No. 3	7	$g_4 = 7$	It has the minimum dimension and is most «removed» from the source
No. 4	14	$g_2 = g_3 = 7$	–
No. 5	14	$g_3 = g_4 = 7$	–
No. 6	21	$g_2 = g_3 = g_4 = 7$	All possible linear elements of the simplex are under protection



Pic. 5. The values of stability index, established with the use of different options for protecting the network object.



Pic. 6. A network object protection scheme using two simplexes with dimensions of 4 and 7.

to development of the process of progressive damage.

Schemes of gradual displacement of the simplex elements towards the source of the product and the results of calculating F_v values for each of the protection options are shown in Pic. 2 and 3.

It can be seen that as the simplex moves to the source of the product, the values of F_v continuously increase (Pic. 2a–e), and the splitting of the original simplex into two with the same total dimension does not lead to a decrease in the values of the stability index (Pic. 2e).

The decrease in F_v values is observed only at the final stages of the simplex shift, as the consumers of the target product are removed from its structure (Pic. 3).

Thus, it is advisable to protect the network objects using a set of interconnected protected linear elements taking into account the following recommendations:

1. A simplex of a given dimension is placed between the source and the consumers of the target product.

2. Consumers of the target product should, if possible, be included in the structure of the simplex.

3. The effectiveness of protection is not reduced in case when several simplexes are used instead of one simplex, with the same total dimension.

Evaluation of the results of protection of linear elements of various network structures suggests that the greatest positive effect is achieved when protecting elements of a subset of G2 located at a minimal «distance» from the source of the product.

When protecting elements of a subset of G3 located at a greater «distance» from the source of the target product, the effectiveness of such activities is reduced. The least positive effect occurs when the protected elements of the subset G4 are most «removed» from the source.

To clarify the views on the impact of these factors on the effectiveness of protective measures, let's consider the structural diagram of the pipeline system, shown in Pic. 4.

As part of such a system, there are seven elements of subsets G2, G3 and G4. In addition, the elements of the subset G2 are located at the minimum «distance» from the source of the target product, the elements of the subset G3 are at a greater «distance», and the subsets of G4 are the farthest from the source. If we protect the object under consideration using a simplex of dimension 7, we should expect that the inclusion of elements of the subset G2 in its composition will give the greatest positive effect.

Less effective is the option of including seven elements of the subset G3 in the simplex, and the minimal protective effect should be expected when elements of the subset G4 are included.

Characteristics of such simplexes with the conventional designations No. 1, No. 2 and No. 3 are given in Table 2.

At the same time, in assessing the effectiveness of various protection options for the analyzed structure, the possibility of using simplices No. 4, No. 5, and No. 6 with dimensions 14 and 21 was also considered (Table 2). The corresponding calculated values of durability indicators are shown in Pic. 5. It can be seen that the earlier assumption about the existence of rational schemes for protecting network structures is justified.

Thus, the use of simplex No. 1 to protect the network object is most effective, although it contains only seven protected elements. The increase in simplex dimension due to the inclusion of new elements belonging to the subset G3 in its composition does not lead to an increase in the value of F_v (Pic. 5). The indicator of stability is the greatest only in the case of using simplex No. 6 with dimension 21.

It is precisely such a scheme for increasing the dimension of a simplex that should be considered as rational and allowing the most effective use of the available resource potential.

In addition, the analysis of data presented in Pic. 5 allows us to conclude that the worst-case variant of protection takes place when using the simplex No. 3, built on the elements of the subset G4. In this case, further growth in simplex dimension – due to additional inclusion of elements of the subset G3, and then G4 – is accompanied by a continuous increase in the values of F_v. Obviously, in this case, the available resource associated with the ability to protect the network object by including additional linear elements in the simplex is not used effectively.

It turns out that along with rational schemes for formation of simplexes as a tool for protecting network objects, there are irrational solutions that are characterized by low efficiency.

From a practical point of view, it is of particular interest to analyze the situation in which the required level of protection of the network structure can be achieved using a simplex of the minimal dimension. Then a single simplex should be a «line» or a more complex object of a «tree» type [10].

Pic. 6 shows an example of formation of two simplexes with the topology «line» and «tree», in which all consumers of the target product are present.

Here, however, it must be borne in mind that the solution thus obtained is often ambiguous, and the final choice and choice of the protection scheme should be carried out by evaluating and comparing the additional characteristics of alternative design solutions [11].

Conclusions.

1. It is established that the use of simplexes in the network structure of pipeline transport systems is an effective tool to ensure their resistance to progressive damage.

2. The greatest protective effect is observed when the simplex is located near the source, and all unprotected consumers of the target product are included in its composition.

3. When protecting against progressive damage, the use of simplexes with the topology «line» and «tree» is most preferable. In this case, the required positive effect is achieved in conditions of minimizing the number of protected linear elements.

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