Increasing the Functional Network Stability in the Depression Zone of the Hydroelectric Power Station Reservoir

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Abstract
Sphere of influence of the reservoirs of large HPS involves colossal massifs of rocks. The complex of geophysical fields and processes, mechanical and electrical transformations causes changes in the geophysical situation of the local environment in the depressed zone, which determine the need to make recommendations for the protection of telecommunications. A method for developing measures to protect the telecommunications network from the effects of destructive influences, which includes collecting information on their impact on hardware resources, their analysis and development of appropriate countermeasures. The conditions of functional stability of the telecommunication network are formulated, which are represented by the resistance of the network infrastructure components to the impact of hazards, the ability to reconfigure the operational systems and the transmission network. To verify network protection measures, a matrix of compliance with threats has been developed, the occurrence of which may be due to processes in the depressed zone.

Keywords
Destructive influence; connectivity; infrastructure components; correspondence matrix; reservation; reconfiguration.

1. Introduction

Among all human engineering activities, large hydropower plants with reservoirs have the greatest impact on the natural environment [1]. They draw into the sphere of their influence colossal massifs of rocks. Complex force fields that arise during that process, extend to considerable depths, cause mechanical and filtration deformations of rocks, their physical and chemical transformation [2].

Superficial analysis of the literature (for example, [3, 4]) has showed that a significant number of large reservoirs are intended for integrated use, in particular for the needs of power stations, primarily hydraulic (HPS). Considering this feature, we agree to understand the term reservoir abbreviated name "HPS reservoir."

The study of the effects of reservoirs on the local geological environment has revealed the presence of a depression zone, the size of which is determined by the range of geophysical fields, and the duration of existence corresponds to the cycles of these fields. Geophysical fields will be understood as physical fields of the Earth, as well as fields represented by the values of their geodynamic parameters given in space [5].

Descriptions of the fields of the depression zone of the reservoir are presented in Table 1.

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Table 1.

Geophysical fields of the reservoir depression zone (modified from [6])

Field / Process	Limits of action	Field cycle
Deformation field / Lowering of the earth's surface *	The volume of the funnel of the earth's surface lowering is two orders of magnitude greater than the volume of the reservoir, the deflection extends away from the reservoir for tens of kilometers	The relaxation time, during which the initial stress in the cortex is reduced by *e* times, can be from 2,5 to 30 years.
Groundwater level / Change in pore pressure of groundwater	The width of the zone of hydrogeological influence of the underground prism of filtration waters usually varies within 0.1-6.0 km away from the shores	Groundwater support zones are characterized by two stages of formation - intensive uplift, when 70-90% of the support is formed (duration 2-10 years); slow rise to the limit position (duration 15-20 years and more)
Microseismic Vibration Field / Vibration **	The effective radius of influence depends on the amplitude and frequency of vibrations	It is determined by: - hydrological microseismogenic processes - variations in water level during filling of the reservoir and cycles of replenishment/operation; meteorological and seasonal, tidal, drift, seismic fluctuations of the level; draft, ripples, wind waves; - microseismic processes - oscillations of the rowing body; vibrations from power plant units and powerful pumps; vibrations from falling water
Atmospheric processes/ evaporation from the water surface with the following: formation of the clouds and breezes; precipitation	The width of the action zone of the air masses on land can be up to 10 km, and on large lakes - up to 30-45 km [7, 8].	Determined by atmospheric processes: - microseismogenic - breeze [4, 9, 10], which initiates vibrations of protruding objects [11]; - formation of clouds [10, 12], which are a factor in the formation of atmospheric electricity [13]; - precipitation [12], which is a factor in the formation of infiltration nutrition [14, 15]

* Lowering the earth's surface can result in landslides, landslides or debris.

** In addition, in the last century, the effect of earthquake excitation during the filling of reservoirs was discovered, which will be taken into account in the future [16].

The study of geophysical processes shows that the action and development of some phenomena always creates the preconditions for the emergence and development of others. In the late 1930s, A. Ivanov reported the discovery of a seismic effect of the 2nd kind, the essence of which is that the geological environment under the action of a seismic field generates an electromagnetic field [17]. Analysis of variations in the electromagnetic radiation of the geological environment has showed that they are determined by the mechanisms of energy conversion of these processes into the energy of the electromagnetic field (see Table 2).

Table 2.

Mechanisms of electromagnetic field generation due to geophysical processes [18]

Mechanical and electrical converters	Geophysical processes	
	Changing the pore pressure of the groundwater	Deformations due to subsidence of the earth's surface and vibrations
Electrokinetic effect	+	+
Electromagnetic induction	+	+
Piezo effect	-	+

The complex of geophysical fields and processes, mechanical and electrical transformations causes changes in the geophysical situation of the local environment of the reservoir in the depressed zone.

The variability of the geophysical environment of the local environment of hydroelectric reservoirs and its changes in comparison with the "local environment without reservoir" determine the need to make recommendations for the protection of one of the main industries in electricity generation and transmission - telecommunications (e.g. [19–21]).

The aim of the article is to study the functional stability of telecommunication network equipment in the geophysical situation of the depression zone of the HPS reservoir.

To achieve this goal it is necessary to solve the following tasks:

- Analyze network threats and their consequences
- Develop a scheme for the application of protection measures
- Verify protection measures

2. Research Method

According to the provisions of the project method, a method for developing measures to protect the telecommunications network from the effects of destructive effects (DE) has been developed, which includes the phased collection of information about the DE effect on the infrastructure components of the telecommunications network, their analysis and development of appropriate countermeasures [22].

At the initial stage, a list of the threats is determined, the occurrence of which may be due to the processes caused by the changes in the geophysical situation of the local environment of the reservoir in the depressed zone. This list has been determined during the analysis of changes in the situation.

At the second stage, the analysis of destructive influences of functioning of a telecommunication network is carried out.

At the final stage, a synthesis of possible measures to reduce the damage caused by the certain threats is performed. The generalized scheme of application of measures of protection against dangerous events is shown in Fig. 1.

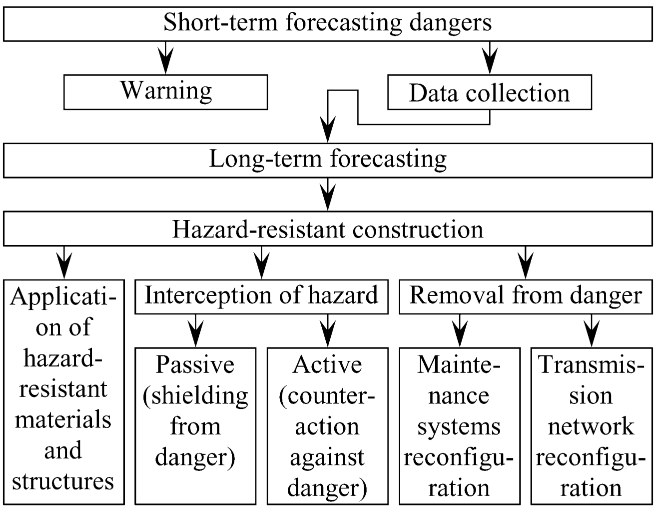

Figure 1: Scheme of the protection measures application of the telecommunications means from dangers [23]

The proposed scheme is designed to develop an action plan to prevent hazards [24–27]. Short-term hazard forecasting is based on current geophysical field measurements and development simulations, and is performed to alert the public to hazards and collect data. Data are used in long-term forecasting. It is used to assess risks and their acceptable levels for declaring the safety of telecommunications, deciding on their location and operation, developing measures to prevent and prepare for accidents. The list of protection measures includes:

- The use of resistant to certain hazards materials and structures
- Interception of danger, which involves shielding the object or its most vulnerable and responsible elements, from danger, or shielding danger from the object, as well as counteracting the danger
- Reconfiguration of the systems for ensuring efficiency (power supply, ventilation and air conditioning, fire alarm, fire extinguishing, warning, etc.)
- Reconfiguration of the transmission network

To verify network protection measures, a matrix of compliance of protection measures with threats, the occurrence of which may be due to processes in the depressed zone, has been developed (Table 3).

Table 3.
Matrix of compliance of the protection measures of the information transmission network to threats, the occurrence of which may be due to processes caused by changes in the geophysical situation of the local environment of the reservoir in the depressed zone

Protection measure	Threats *						
	1	2	3	4	5	6	7
1. Short-term forecasting	a_{11}	a_{12}	a_{13}	a_{14}	a_{15}	a_{16}	a_{17}
2. Notification; data collection for long-term forecasts	a_{21}	a_{22}	a_{23}	a_{24}	a_{25}	a_{26}	a_{27}
3. Application of stable materials and structures	a_{31}	a_{32}	a_{33}	a_{34}	a_{35}	a_{36}	a_{37}
4. Passive interception of a danger	a_{41}	a_{42}	a_{43}	a_{44}	a_{45}	a_{46}	a_{47}
5. Active interception of a danger	a_{51}	a_{52}	a_{53}	a_{54}	a_{55}	a_{56}	a_{57}
6. Reconfiguration of operational systems	a_{61}	a_{62}	a_{63}	a_{64}	a_{65}	a_{66}	a_{67}
7. Reconfiguration of the transmission network	a_{71}	a_{72}	a_{73}	a_{74}	a_{75}	a_{76}	a_{77}

* 1 - subsidence of the earth's surface, landslides, landslides or debris; 2 - increase in groundwater level (flooding), change in pore pressure; 3 - vibrations, earthquakes; 4 - breeze; 5 - precipitation; 6 - variations in water level, floods; 7 - electromagnetic radiation of the medium.

3. Ways to Protect the Telecommunications Network from Hazards

3.1. Conditions of Functional Stability

Let's define functional stability of a telecommunication network, as resistance of the network infrastructure components to influence of dangers, ability to reconfiguration of systems of maintenance of serviceability and a transmission network.

The resilience of network infrastructure components to the impact of hazards is ensured through the use of stable materials and structures, passive and active interception of hazards and is estimated by the formula [28]:

$$\forall i_I \in I\,,\ I_{i_I} < S_{i_S}\,,\ i_S \in S\,,\ i_I = \overline{1, n_I}\,,\ i_S = \overline{1, n_S}\,, \qquad (1)$$

where $\forall$ is quantifier of generality; i_I, i_S are identifiers of destructive effects on equipment and indicators of equipment stability, respectively; I, n_I are the set and quantity of the destructive effects on equipment; S, n_S are the set and quantity of the indicators of resistance of the equipment to these influences; I_{i_I}, S_{i_S} are the magnitude of the effects on the equipment and the resistance of the equipment to them, respectively.

Reconfiguration of the performance systems is provided by their redundancy, and is estimated by the formula [29]:

$$P_\Sigma = 1 - \prod_{i=1}^{n} \left(1 - P_i\right),\ i = \overline{1, n} \qquad (2)$$

where P_Σ is the probability of connectivity of the path formed by parallel connected chains-systems, P_i is the probability of the operability of each of the systems.

Reconfiguration of the transmission network is provided by redundancy of nodes and communication lines, and is estimated by the formula [30]:

$$\chi\left(G\right) \geq 2\,,\ \lambda\left(G\right) \geq 2\,,\ P_{ij}\left(t\right) \geq P_{ij}^{normalized}\,,\ i \neq j\,,\ i, j = \overline{1, n}\,, \qquad (3)$$

where $\chi(G)$ is number of vertex connectivity (the smallest number of vertices (nodes), the extraction of which together with the incident edges (communication lines) leads to a disconnected or single-vertex graph); $\lambda(G)$ is number of edge connectivity (the smallest number of the edges that remove a disconnected graph); $P_{ij}(t)$ is the probability of the connectivity (the probability that the message from node i to node j will be transmitted in a time not exceeding t).

3.2. Analysis of Destructive Influences

Analysis of the destructive effects on the functioning of the telecommunications network is performed in order to identify its most vulnerable elements (see Tables 4 and 5).

Table 4.

Typical consequences of the DE action [31]

Destructive influences	Consequences of the DE action
Landslides	Destruction of underground gas pipelines keeping cables under excess pressure; damage to line and cable structures.
Earthquake	Destruction of external telecommunications facilities; ruptures of gas pipelines holding cables under excess pressure and ruptures of cables.
Strong wind (taking into account that the speed of the breeze is 1–5 m / s, we will estimate its influence as insignificant)	Collapse of overhead lines, radio towers; gust, damage to overhead lines.
Floods	Flooding of cable sewerage; potential damage to cables; cable locking.

Table 5.

Matrix of destructive impacts of the depression zone and their impact on the components of the telecommunications network infrastructure [32]

Infrastructure components	Destructive influences			
	Landslides	Strong wind	Rain	Floods
Overheaf line support	M	S	I	S
Antenna	M	S	S	M
Electronics	I	I	M	I
Premises for installation of the devices of the telecommunication network	I	I	S	S
Fiber optic cable	S *	I	I *	I
Symmetrical and coaxial cables	S **	S	M	S
Power supply system	M	I	M	S
Backup power supply	S **	I	M	S
Satellite earth communication stations	M	S	S / M	M
Heating, ventilation and air conditioning systems	I	I	I	I [2]

I: insignificant; M: moderate; S: significant

* When laying an underground fiber-optic cable, the risk of landslides is taken into account, the most common causes of which are the weakening of the strength of the rocks when they are wet by precipitation.

** The degree of influence of the factor is largely determined by the location of the resource.

3.3. Verification of the Protection Measures

To protect line and cable structures from threats, it is proposed to lay them underground. Fig. 2 presents the examples of enhanced precautions for the protection of underground cable structures.

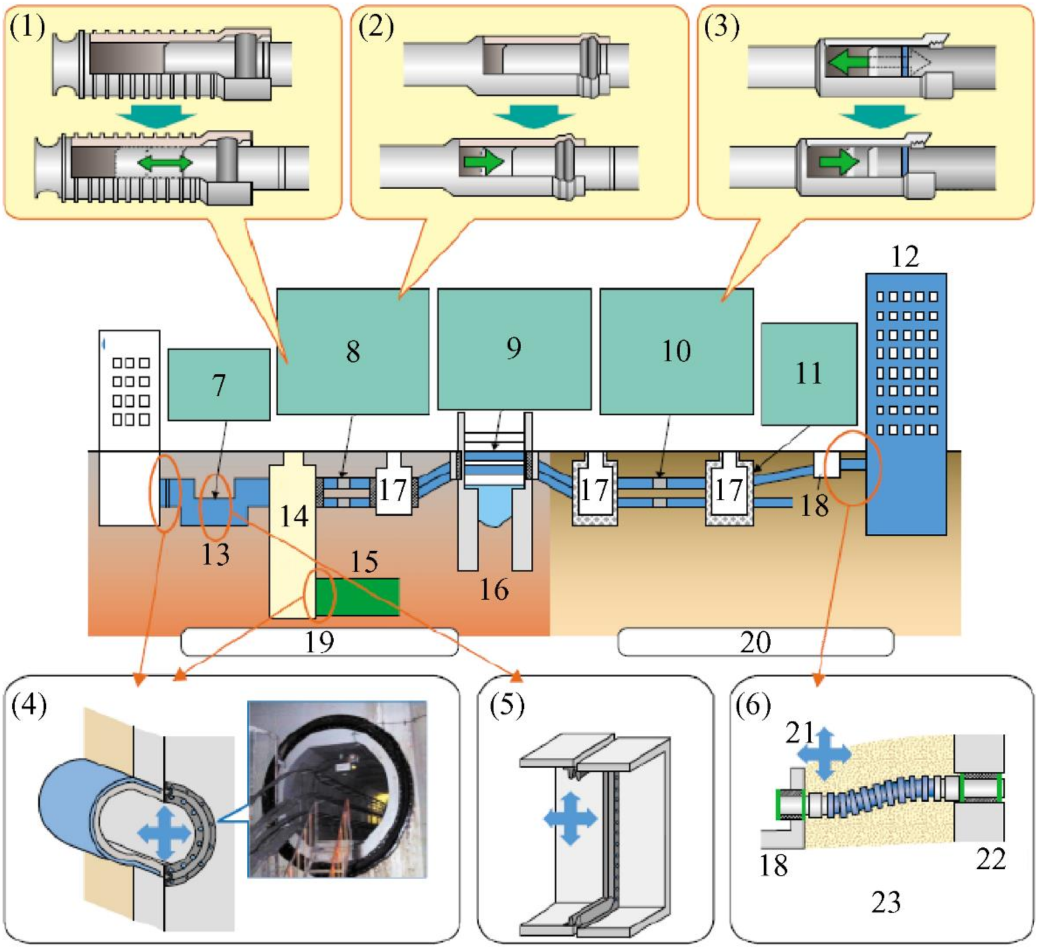

Figure 2: Examples of precautionary measures for the protection of the underground line and cable structures from the experience of Japanese telecommunications specialists [30]: (1) - sliding connection for inspection wells (connecting pipeline coupling); (2) - sliding connection for gas pipelines; (3) - sliding connection with stopper; (4) - flexible connection for penetrating the wall of the cable shaft; (5); - flexible connection of cable channels; (6) - flexible connection of sections of the gas pipeline for penetration into the building; 7 - flexible connection; 8 - sliding connection + coupling; 9 - sliding connection with stopper + concrete cable tray; 10 - sliding connection with stopper + coupling; 11 - reinforced concrete manhole cover; 12 - building of the user of services; 13 - cable channel; 14 - cable mine; 15 - cable sewerage; 16 - penetration of the bridge crossing; 17 - inspection well; 18 - inspection well; 19 - normal soil; 20 - water-saturated soil; 21 - directions of displacements; 22 - the wall of the building; 23 - flexible corrugated gas pipeline

4. Discussion of the Research Results and Conclusions

The result of the study of the functional stability of the components of the telecommunications network infrastructure in the depression zone of the HPS reservoir is the realization that the local environment needs physical and geographical zoning of the territory. This is due to the need to determine the climatic conditions of operation of the network, which, in turn, determine the measures to maintain its efficiency.

Threats to the network are geophysical fields of the depression zone of the HPS reservoir (deformations and microseismic oscillations, pore pressure of groundwater, atmospheric processes), supplemented by an electromagnetic field of geophysical origin. These threats are presented in the form of a scheme of changes in the geophysical situation of the local environment of the reservoir due to geophysical fields and processes, mechanical and electrical transformations in the depression zone.

To develop an action plan to prevent hazards, a proven scheme of application of measures to protect telecommunications has been used. The conditions of functional stability of the telecommunication network are formulated.

The effectiveness of the protection measures scheme is confirmed by the verification of protection measures against threats, which, in fact, are recommendations for improving the functional stability of the telecommunications network in the depression zone of the HPS reservoir.

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