Innovative methods of concrete dams’ inspection

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Abstract: A methodology for the operation of remote controlled uninhabited vehicles during the inspection of concrete dams is proposed. The main elements of concrete dams and the damages arising in them are indicated.

1. Introduction
The federal law of Russia «About the safety of hydraulic structures» posed a number of problems for the Russian energy sector in order to ensure reliable and safe operation of hydraulic structures (HS) and power plants. One of the most important tasks in this case is the development of the «Declaration of safety of hydraulic structures» for large hydropower plants (complex and unique facilities), the destruction of which can lead to very large material, social and environmental damage [1,2]. In the paper of Skvortsova O.S. [3] a methodology for determination of the probabilities implementation of emergency scenarios at hydroelectric stations using the method of expert assessments was developed. All possible scenarios of emergencies at the hydroelectric power plants were considered as a separate set (system). Signs of such processes were assigned that are independent and common to all processes of the analyzed set: the cause of the accident, the location of the accident and the nature of the accident [4], to represent the entire set as separate groups. In this paper, authors considered a special case of concrete dams.

The main stage of the examination is associated with data collection, research and expert evaluation, analysis of the available material, i.e. results of monitoring the object of examination. The authors believe that in order to present the initial information to the experts in the most convenient form, data on the state of the object can be represented by the space of two signs: the place and type of defect. The following main types of concrete dams were identified - deaf massive gravitational, deaf buttress gravity and spillway massive gravity - to create this kind of space [5].

2. Material and methods
Below is an expanded classification of concrete dams’ parts that are subject to mandatory monitoring developed by the authors and a classification of types of defects.
Table 1 Concrete dams’ parts – subjects for monitoring

| The first sign (place) \( x_1^m \) (\( m=1…24 \)) |
|--------------------------------------------------|
| top brink                                        |
| bottom brink                                     |
| dam body drainage                                |
| dam crest                                        |
| dam base drainage                                |
| gallery                                          |
| impervious curtain                               |
| strengthening cementation                        |
| viewing gallery                                  |
| floor slabs                                      |
| floor beams                                      |
| concrete insulating wall                         |
| shutters                                         |
| deep spillway                                    |
| separation walls and butresses                   |
| bank protection                                  |
| ice protection                                   |
| structures                                       |
| downstream apron                                 |
| toe basin                                        |
| termination                                      |
| intake chamber                                   |

Table 2 Concrete dams - classification of types of defects

| The second sign (type of defect) \( x_2^n \) (\( n=1…36 \)) |
|--------------------------------------------------------------|
| concrete masonry                                             |
| mechanical damage                                            |
| normal and inclined cracks in the stretched zone              |
| loss of concrete protective properties in relation to         |
| rebar exposure                                                |
| Mechanical damage to rebar                                    |
| damage caused by corrosion                                    |
| loss of concrete protective properties in relation to         |
| temperature and force cracks along the axis of the structure  |
| temperature and force cracks across the axis of the structure |
| deformation of the shape of the structure                     |
| excessive porosity                                            |
| temperature and force cracks along the axis of the structure  |
| suture opening                                                |
| shrinkage cracks                                              |
| damage due to specific operating conditions                   |
| peeling of the protective layer of concrete                   |
| damage to concrete due to contact with aggressive water or    |
| corrosion damage to floor beams                               |
| corrosion of concrete surface parts due to temperature        |
| softening of butt structures                                   |
| changes in the structure of concrete                          |
| destruction of concrete culverts                              |
| colmatage                                                     |
| suffusion                                                     |
| offset                                                        |
| breakthrough                                                  |
| seam damage                                                   |
| seam groove damage                                            |
| corrosion damage to floor beams                               |
| mechanical damage to metal                                    |
| shutter offset                                                |
| exit from the grooves                                         |
| corrosion of the metal components of the shutter              |
| damage to the groove misfeed                                  |
| damage to the groove seal                                     |
| other mechanical damage                                       |

A significant problem is the inaccessibility of many dense elements under water. In accordance with [4], the underwater surfaces of structures and the relief of adjacent areas should be studied by sonar and visual methods.

Visual methods include those that could be performed using remote-controlled optional underwater vehicles and divers equipped with photo-video equipment for underwater shooting. The work of divers involves considerable time, so it is preferable to use RCUV (remote-controlled uninhabited underwater vehicles) [6-9].

Figure 1 shows the corresponding combination of signs (green), red circles - impossible, and yellow circles - not visible.
The space of attributes (see Fig. 1) was considered directly from the point of view of choosing RCUV as a monitoring tool. The underwater parts of dams could be examined exclusively with this method. Before the direct development of survey algorithms, a list of assumptions necessary for their creation is given:

- Inspection of parts of dam elements located in zones of variable water level is carried out only by their flooded area;
- Inspection of parts of dams located in areas with a fast flow of water is carried out during flow passes, at which the technical characteristics of the hydraulic pump allow to overcome the flow velocity. If the skipping of such expenses is impossible in any period of time - monitoring of such parts by the selected method is not performed;
- Dam parts are monitored only if these parts are presented in the structure;
- If it is impossible to detect damage directly - detection can be made by indirect signs;
- Each dam is unique and if it is impossible to monitor any part of it as part of the algorithm, it is subjected to additional examination separately;
- If the dimensions of the proposed equipment do not allow inspection of a specific part, its monitoring by the selected methods is not performed;
- Despite the fact that some elements of the dams were not considered in detail, this does not cancel their mandatory visual inspection;
- The main task of examining concrete dams with the help of RCUV is to identify the existing damages, while the chosen methods cannot always establish the cause of their occurrence.

3. Results and discussions
Separate algorithms were developed for monitoring of each type of dam (Figures 2, 3, 4, and 5) based on these assumptions. US means the upstream of the dam, DS - the downstream, and SPEC are special elements of the dams. The sequence of inspection of damage sites in these algorithms is defined as follows:
- Bilateral arrows linking the places of damage indicate the cross-location of damage at the same time in several parts of the dam;
- One-sided arrows indicate the sequence of examination from one place of damage to another;
- The OR operator indicates that only one of several damage sites inherent in the dam of this type is examined, depending on particular design features.

Figure 2 Algorithms for monitoring the status of deaf massive gravity dams
* - damage to the item was not understood in detail

Figure 3 Algorithms for monitoring the status of spillway massive gravity dams
Figure 4 Algorithms for monitoring the state of deaf buttress gravity dams
Monitoring of the status of dams, including one as part of pressure head hydroelectric facilities, is a rather urgent problem for our time due to their large number in Russia and the whole world as a whole, as well as their potential danger. In order to optimize the monitoring process, a modern approach was proposed in the form of innovative equipment usage in the face of robotic solutions.

According to the requirements of Russian regulative documents, hydraulic structures during operation are subjects of the centralized examination by commissions of technical specialists, experts from federal executive authorities, design and scientific organizations, and company representatives once every five years. The authors of this work considers such a frequency of inspection insufficient.

**Figure 5** Algorithms for monitoring the status of spillway massive gravity dams

4. Conclusion

Monitoring of the status of dams, including one as part of pressure head hydroelectric facilities, is a rather urgent problem for our time due to their large number in Russia and the whole world as a whole, as well as their potential danger. In order to optimize the monitoring process, a modern approach was proposed in the form of innovative equipment usage in the face of robotic solutions.

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It is proposed to carry out additional monitoring of the status of dams using the means described in this paper at least once a year, given that many facilities have practically exhausted their resources.

This work, without claiming to be a complete solution to the problem of assessing the state of concrete and reinforced concrete structures of hydraulic structures based on their survey data, provides recommendations about the improvement of the overall level of safety of their operation. The variations of survey algorithms using RCUV, which allow optimizing the monitoring process, were developed.

This work suggests the use of new and currently not widely used tools in the survey of hydraulic structures, and also raises the question of the need for their development and integration into monitoring processes.

Consideration should be given to replacing part of the diving operations currently underway during surveys of the underwater parts of structures with underwater operations using RCUV.

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