CLIMATE CHANGE INFLUENCE ON HYDROTECHNICAL STRUCTURES, EXISTING AND FUTURE

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ABSTRACT
Article approach a very topical issue and little studied: the influence of climate change on existing and future hydro facilities. Climate change may induce changes related to the stresses they are subjected to the resistance of hydraulic structures. This article is a bold attempt to address the issue of climate change impacts on existing infrastructure and design, implementation and operation of infrastructure to be designed in future.

Keywords: global warming, water resources, freeze thaw action, cracking

INTRODUCTION
Global warming, felt especially in the last decade of the twentieth century and early twenty-first century generated an increase of the extreme weather events. According to forecasts studies, it is estimated that over the next 100 years, global warming will lead to the extreme weather phenomenon, with implications to infrastructure engineering. Under these conditions forecasted of climate change, infrastructures rehabilitation engineering a topical issue giving that requires adequate design and impact assessment. Numerical models available coupled with the contemporary computational capabilities make it possible to engineers to forecast complex situations due to extreme events. Unfortunately, worldwide, are very few case studies to approach such issues. That is why this paper represents a bold to attempt the issue of climate change impact on the existing and future hydro technical infrastructure and design.

MATERIALS AND METHODS
1. The influence of climate change on water resources management
Climate changes are already happening. These affect natural water resources and also water users too. As a result, many countries, including Romania already have developed new strategies to adapt to these changes. Studies on influence of climate change, including those who carried out several river basins from Romania, have shown a reduction of the average annual flow, increasing flow in December - January period, maximum flow increases during summer months, reducing the thickness and length of layer snow due to a temperature increase during winter months [1].

The influence of climate change on water user is less studied; fact is the water requirements will certain increase in the near future. Adapting measures aimed to achieving these conditions, lead to a new balance between the existing water resources and user needs. This balance can be achieved by acting both on increasing water resource and water need, within the meaning of their diminution. It is obviously those measures are aimed to adopt a new water management approaches.

It’s known that socio – economic water resource is that part of natural water resources, which by engineering infrastructures, is available for consumer use. These infrastructures are represented by surface water intakes, dams, reservoirs, adductions, etc.
2. **The influence of climate change on existing hydro technical infrastructure**

It is estimated that over the next 50-100 years, global warming will have serious influence on infrastructure engineering construction [2].

The issue is how we specialists can respond to these potential effects of global warming, specific to hydro technical infrastructures? It is said that the main problem that arises is if engineers, can adapt to climate changes effects with responses studied, or will offer randomly responses to ongoing events. Some engineers might say is nothing but classic adaptation of risk management, only that their management is amplified by the uncertainties associated with climate changes.

It is known that one of the most significant impacts of climate change is the modification of hydrological cycle. Extreme events generated by climate change, such as floods or droughts, will become more intense on extensive areas. There will be a change in the probability of overcome the size of the verification flow for dams, dikes and other engineering infrastructures, for which they were designed. As a result, will be needed further more hydrological studies to establish new figures for flows and volumes of flood wave, which correlated with risk analysis, to lead to new solutions for a safe evacuation of these floods. Some dams would require additional arresters of large waters, and also changes in regulations to operating the reservoirs. The same issue arises in the case of flood protection embankments, to whose size should be reviewed.

Uncertainties in measuring the maximum flow process will also require changes in measurement technique. Changing hydrological cycle due to global warming will generate increased levels of seas and oceans, with estimated values from 20 to 50 cm, also more severe hurricanes and storms, with a higher influence on marine hydraulic infrastructures, as well as other infrastructures located on the coastal area such as coastal roads and railways, will be relocated.

Also, it has been estimated a reducing of intake and sediment transport in watercourses, in deepening of their minor riverbeds, with serious consequences on hydro technical works.

Increasing temperatures will lead to appearance and developed of cracks and fissures in the body of dam and dykes. Extreme events such as floods occur in small basins, will become more frequent. In conclusion, is necessary a prudent approach to climate change influence on the infrastructure engineering, so predictions of extreme events should be set in planning, design and rehabilitation of hydro technical structures.

3. **Climate change influence to design, implementation and exploitation of new future hydro technical structures**

Worldwide, it is estimated that climate change will be responsible for approximately 20% water resources reduction. To reduce the effect of global weather changes, but also to satisfy the global water consumer needs, were developed scenarios such as the need to increase water volumes in reservoirs, with 9 to 30% of the current volumes [3].

These scenarios lead Romania to achieve over the next 40 to 50 years, hydro technical reservoirs with volumes between 0.7 to 2.4 km3. Worldwide, held a series of seminars on topics such as “Dams for a Changing World” or “The role dams in adaptation measures”. Unfortunately, these seminars have not tackled the issues of the kind referred to this article.

It is assumed that in the next 50 to 100 years will not be cause spectacular evolutions in the hydro technical structures design [9]. Significant developments could occur mainly to construction and operation of these structures.

Growth of air temperature and extreme flows are factors which should be considered when are designing hydro technical structures. For example, the arch dams will need in – depth studies regarding temperature variation effects, temperature distribution, both from the air and reservoir.
The delimiting areas where arch dams can be placed should be characterized by average temperatures from 5 to 10° C upstream, and amplitude oscillations in the air between 12 to 15° C. Similar issues are also available to dams built from concrete piles and slabs.

Probably in future, the number of the inflatable dams and small earthen dams, placed locally on certain valleys or lowlands, for temporary accumulation of water from the rainfalls purpose, will extend. As a result, water supply systems will require new additional reservoirs for water storage, in order to compensate the increasing consumer needs, and water supply systems will be necessary new interconnections.

4. Other extreme events generated by climate change influence on hydro-technical construction

4.1 Aridity

Aridity may reduce the amount of water stored in reservoirs, degradation of water quality in reservoirs, temporary out of service of dams, fairway failure, less water for irrigation systems, soil erosion which led to an increasing amount of silt and clogging in reservoirs.

Dam cracking is just a symptom and not an actual degradation process, usually accentuated because of "stress" induced by thermal gradients[8]. Cracking may be given by the reactions of alkali or concrete contractions, but, in most of cases is also linked to design errors and initially contraction of concrete or special feature of the soil. It may also be a result of hydrostatic loading and thermal cycles. Real-time tracking of dam behavior revealed the emergence of cracks on the vertical buttresses, some of them having a complex (fig. 1).

![Fig. 1. The emergence of cracks on the vertical buttresses](image)

Generally, cracks are due to the contraction of the concrete and heat exchange, but also, local conditions or an inappropriate use of technology can increase intensity of the cracks. Seasonal temperature variation and levels of water retention can cause also slow process of deterioration generated by cracking (fig. 2).

![Fig. 2. Process of deterioration generated by cracking](image)
However, these cracks may not affect the response of external loads applied to monolithic dam, but the cracks filling and restoration of concrete buttresses degraded can improve the stability of the structure [4]. In operation, the dam structure degraded by cracking, induce more sensitivity to prolonged or repeated efforts. Actually, cracking process does not affect directly the dam structure, unless there are difficulties in transmitting shear efforts. Laboratory experiments made on an excerpt from a haunch cracked, extracted by logging, to tracking the water pressure effects in the downstream direction, showed that upstream-downstream cracks propagation to such kind of external efforts, is rarely enough. Specialist's trend is to overestimate the cracking effect. Usually, the shear efforts can have bad influences on the structure safety.

4.2 Rainfalls

Extreme amounts of rainfall may have the following effects on hydro technical structures: additional volumes of water entering the reservoirs, major damages to tipper waters and bottom drains, dam slopes and dyke damages, increase infiltration flow, sliding slopes or banks of lakes as a result of raising groundwater, damage or destruction of hydraulic groundwater capture, increase infiltration flows, increased risk of dykes and dam discharge, generating and amplifying phenomena of sliding slopes or banks of lakes, as a result of raising groundwater, damage or destruction of hydraulic groundwater capture, out of use of meteoric water discharge networks, damage of water collecting works and transportation, deterioration and damage of river beds regularization works, land degradation by erosion, landslides or water stagnation phenomena [10].

4.2.1. Influence of water discharge

Exceeding the limit of safety thresholds in terms of precipitation may result in discharge water over the dam canopy. The stability problems are given by the increasing permeability and destructive action of currents and waves.

Fig. 3. Types of dam damages

4.2.2. Influence of water growth infiltrations

Dam built-up by local materials, strong infiltration downstream slope may be due to a high piezometric level. These can lead to deep slide (fig. 4).
To increase the hydro technical constructions safety, are required:
- vertical drain to routing the infiltrations to filter based on slope;
- filter on the old contour downstream embankment;
- thickening downstream slope with gravel, to increase stability and filter protection (fig. 5).

4.2.3. Influence of hydro geological conditions changes

When using clays, hydro technical construction safety can be affected by changing hydro geological and geotechnical conditions. Such situation may occur to the central and downstream area of the dam. Foundation layer consists of marl, superimposed on a layer of clay altered (fig. 6).
Dam consolidation can be done by putting back into operation the drainage network to the dam foot, from upstream and downstream, also putting into work the material and compacting with a roller tire, and execution of scarifications, with purpose to remove the structure defects (fig. 7).

![Fig. 7. Strengthening the dam](image)

1 - sand drain; 2 - tight clay layer; 3 - filling of sand and gravel; 4 - drain filter; 5 - clay; 6 - molded wall

In this case, it is necessary to use a measuring and control devices network, to tracking the dam areas of weakness. Profile of the dam can be modified with purpose to increase the stability coefficient.

### 4.2.4. Frost phenomena

Frost phenomena usually generate ice-thaw, additional efforts on hydro technical structures, degradation to protection structures and improvement of a river channel, degradation of concrete structures (cracking) under freeze-thaw cycles.

### 4.2.5. Deterioration due to freeze-thaw action

In cold climates, dissolution of concrete constituents can combine effects occurred with those generated by freeze thaw action, with extremely rapid destruction of poor quality concrete [7]. Under the action of freeze – thaw cycles, concrete is deteriorating while the water content of structural defects (voids, crazing), exceeds the correspondent threshold of saturation, and ambient temperature is below 0 degrees C. This type of damage is manifested especially to hydro technical works located at high altitude to the old cold climate countries.

The main causes are given by multiplication of cycles freeze - thaw to concrete wetted, characteristic to cold climates. The frost effect is fast acting where the structures are more fragile. Crest of wave is also a subjected to freeze-thaw action, but that does not compromise the security of structure. To dams where used appropriate concrete and additives, resistance to this type of aggression has been increased considerably. Generally, frost action does not result in significant degradation of structure.

Motivation:
- Submerged upstream of the dam is not subject to frost action;
- Dams subjected to severe winter weather conditions may have a seasonal operation, so that the effect of number of freeze-thaw cycles on the building is significantly reducing;
- If the retention varies less, attacks on structures are localized to marginal areas.

Freezing action of meteoric waters to downstream facing lead to a concrete exfoliation, without significant effects to dam structure, still this action facilitates the appearance of vegetation and also degradation on the concrete surface. An inefficient drainage can cause dripping on the downstream facing, with significant negative effects. It can also cause damages to leaking valves or lower water area. In time, damages caused by freezing can increase, if accompanied by dissolution of concrete or alkali reactions. The most exposed hydro technical construction to freeze-thaw cycles are the arch dams build from concrete elements, with relatively small thickness compared to gravity
dams [9]. Thermal regime extremely negative may lead to cracking of arches based (fig. 8 and Figure 9).

**Fig. 8. Plan and elevation of a multiple arch**

**Fig. 9. Different types of cracks: 1 – parallel cracks; 2 - top-down oriented cracks; 3 - oblique cracks; 4 - concrete-rock contact damages**

Development of cracks can lead to an increased infiltration flow of drainage system of arcs.

### 4.2.4.1. Damage of dam protection masks and upstream

Protection of upstream dams from local materials is achieved in most of cases, with masks of concrete, bitumen concrete or membranes. Fragile elements of these sealing systems are joints between tiles and mask-spur connection. In time, or because changes in operational tasks, these may be affected by subsidence caused by:
- loads from ice-thaw pressure exerted;
- inadequate compaction of breast body;
- deformability of dam foundations;
- earthquakes.

Strengthening the damaged masks can be done by:
- restoration of dam joints with mastic asphalt or bitumen;
- restoration of dam mask surface with mastic asphalt or bitumen;
- building a new dam mask;
- Execution of synthetic membranes.
Upstream embankment filling causes mask damage and deterioration, but these incidents do not directly affect dam foundation. We conclude that:

a) Absence of the upstream protection to dams built from rock fill can produce superficial erosions padding and fragmentation. Surface erosion is not dangerous, is easy to fix, but disorganization of filling and its protection due to the formation of ice lenses in the middle or near the level filling retention, can induce under certain conditions of diffusion, the effect of granulometry.

b) Protections upstream of the dams, which is acting as sealing, can be executed from rock fill or pitching. Rock fills can be weathered by waves, in terms of physics - chemical or geometrical of the riprap blanket. The pitching is more susceptible to such attacks, because the moderate down-grade breast can increase water stagnation and vegetation occurrence. Ice pressure may also generate harmful effects. The uplift pressure, in case of large waves, as well as damaged pitching, can foster bleeding in rock fill, being a harmful factor regarding its stability [5].

c) Facing defacement may affect stability of the breast during the time. These have a similar action as thin concrete dam. First undermining figure out to joints or to the improperly compacting concrete, due to implementation difficulties in work, of high hydraulic gradients and to concentrate efforts where excessive mound movement. Rock fill dam with moraine core are often built in the Nordic countries. Defects caused by the wave action on the upstream slope are presented to Figure 10.

Fig. 10. Rock fill arch dam upstream face gliding due waves action

The rehabilitation resource to restore dam tightness consist in execution of grout curtain on the crest of wave [6]. The stability of the dam can be increased by thickening downstream mound. Repairs and reinforcements needed are presented to Figure 11.
CONCLUSIONS

Hydro technical construction safety is an important issue which should increase the designers and specialists attention. Any potential crash of these structures could have serious effects, similar as those caused by large natural disasters. Therefore, the risk assessment should be done with utmost responsibility and revised according to the new present - day weather climate.

Safety and risk concepts concerning hydro technical construction management are inseparable elements of the engineering design and operation processes. In conditions of climate change, the ratio between these two elements changes with the effect of decrease risk safety and increase operational. Therefore, is necessary to monitoring the climate change, induced by extreme events, such as:

- Changing geological conditions of the site;
- Response of hydro technical structures to operating efforts;
- Increase of infiltration flow through hydraulic structures;
- Changing takeover flow conditions downstream of hydraulic structures (exceeding the carrying capacity of the riverbed, the erosion of riverbeds, lower water deterioration of ecosystems);
- Degradation structures to cracking efforts;
- Need to update data for design and operation assumptions;
- Need to restore the operating regulations and regulations for the management of emergency situations;
- Need to review the warning systems and emergency situations alarm;
- Decrease the safety and increase operating risk of hydro technical constructions.

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