DEGRADATION OF EARTH'S DAMS UNDER THE EFFECT OF CLIMATE CHANGE

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Abstract

The paper presents a summary analysis of the phenomena of the degradation of earth dams by the action of changing climate conditions in the eastern part of Romania. Climate change over the last 30 years has led to hydrological risks in the hydrographic network, represented by rapid, frequent flash floods over short periods of time. The floods are due to the uneven distribution of rainfall over the year. The floods are concentrated in a short time and have a very high intensity. This is a major cause of the degradation of dams. Most damage occurs due to floods associated with structural faults, mechanical faults, or hydraulic faults. This situation is confirmed by the events that have taken place over the last 30 years at a series of earth dams in Suceava county (eg. Crujana, Grănicești, Horodnic etc.). The destructive actions were manifested by structural degradations to the dam body, to the large water drain, to the bottom emptying, to the drainage system, etc. In order to prevent adverse events, the term "safety" of hydrotechnical constructions must be taken into account at all stages of the design, execution and operation work. In order to prevent possible accidents that could occur through a dam failure, tests and models shall be carried out in specialized programs.

Key words: climatic changes, failures, floods, water evacuators

Climate change is one of the greatest threats to the environment, the social and economic environment. Researchers claim that global warming is responsible for increasing these extreme events, but human society's activities also have a significant impact on the climate (IPCC, 2013).

Climate change has caused hydrological risks in the hydrographic network, represented by rapid, frequent floods over short periods of time. These changes have led to damage to some dams causing significant damage (e.g. Breaking the dams Malpasset - 1959 and Banqiao – 1975) (ICOLD, 1995).

These climate change can affect water resources and become hazards that can cause disasters both by excessive (floods, floods) and by lack of water (drought, desertification). An analysis of exposure to various hazards and vulnerability found in the countries of the Southeast European region to be the common threat of floods, with Romania ranked second (Busuioc *et. al*, 2014).

Low-rise earth dams (category C and D) are extremely vulnerable to natural and anthropogenic actions on the site, due to the way they are maintained and the lack of rehabilitation and modernization works. (Luca and Hobjilă, 2002). Accidents are also caused by changes in the type of property and the way they are maintained over time.

MATERIAL AND METHOD

The research material consists of the documentary material in the technical documentation at the water Basin administrations (annual reports or after disaster events). The documentary study also focused on the technical expertise of a series of degraded earth dams on structural and functional components (body, water unloader, protective systems, etc.). The analysis used national and international scientific studies and works applicable to the degradation of earth dams.

The research method included the following work steps:

- selection of study objectives affected by climate change;
- analysis of natural and anthropogenic degradation conditions which have caused structural damage (dam body, large water drains, maneuvering tower with drainage pipe, infiltration water drainage system, etc.);
- analysis of the degradation of ground dams by environmental and maintenance mode factors;

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- the processing of data and their interpretation using programs in the field of design and verification of earth dams at complex on-site actions.

The study required a field analysis with the taking of photo surveys and the preparation of additional studies on dam degradation (topographic, simulations on specialized programs, etc.).

RESULTS AND DISCUSSIONS

Over the years, it has been observed that floods and catastrophic floods have frequently occurred in Romania (Ștefănescu, 2011), *(table 1).* Natural floods created by excessive rainfall are the most dangerous natural phenomenon in terms of dam risk. The formation of a flood in the controlled accumulation basin increases the risk both by increasing the probability of failure and by increasing the consequences downstream, by overlapping the breaking wave with the flood itself.

Table 1

The frequency of floods in Romania

No.	Period (century)	No. of floods
1.	XIV	10
2.	XVII	19
3.	XVIII	26
4.	XIX	28
5.	XX	42

Filler dams are most exposed to climate change accidents, according to ICOLD, about 69%. The risk at dams involves a series of factors, determined according to NP 132-2011 by: the structural elements of the dam, the foundation land, the accumulation lake, extreme natural phenomena and the human factor (Rațiu and Constantinescu, 1989).

Following the analysis of the cases of failure of many dams, it was found that the percentage of risk of destruction is much higher at low dams than at the highest *(figure 1),* and the rate of failures at filler dams and especially at earth dams is higher than at concrete dams.

The failure of a dam is defined by the national Oceanic and Atmospheric Administration (NOAA) as a catastrophic event caused by the sudden, rapid and uncontrolled release of water held by accumulation. The causes can be both natural and anthropogenic (Ruedisser, 2016).

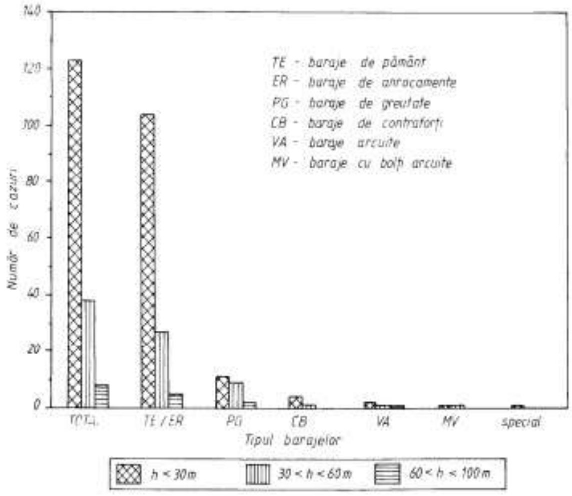


Figure 1 **Number of failures by types and heights of dams (TE/ER – rock soil, PG – dam weight, CB – dam with counter-forces, VA – arched dams, MV – multiple bolt dams) (Ghid AMC –Faza 1)**

The destructive effect of the floods is confirmed by the damage that occurred at a series of dams in Suceava county. The study shows some concrete cases of the degradation of land dams in Suceava county.

1. The Crujana hydrotechnical arrangement, located on the Pătrăuţeanca brook, falls into category C, importance class IV. It has a homogeneous earth dam, two bottom drains and a large water drain *(figure 2)* (ABA Siret, 2010).

Figure 2 **Dam canopy overview - Crujana Dam, Suceava County (ABA Siret, 2010)**

In June 2010, torrential rainfall formed a rapid flood of 133 m^3/s in the dam section. Existing unloaders had an evacuation capacity of only 37.71 m^3/s. Thus, the flood spilled the dam with a blade estimated at 1 m high. There was a loosening of the downstream slope, and finally a 25 m wide gap developed in the body of the dam between the two bottom drains. (CTM, 2010), *(figure 3,4).*

Figure 3 **Crujana Dam, Suceava County, 2010 - breach through the dam, (ABA Siret, 2010)**

Figure 4 **Crujana Dam, Suceava County, 2010 - the maneuvering tower and the lake basin after emptying the lake by breaking the dam (ABA Siret, 2010)**

The event occurred as a result of hydro-meteorological phenomena in June, July 2010, which had a rapid development and a wide evolution.

In 2018, the high-volume rainfall in June caused a new incident at the Crujana dam by transiting the dam retention front and the water evacuators. The passing of the flow has led to the emergence of a large-scale erosion that has led to the major collapse of the dam material. Under the energy dissipator and DAM 2, the existence of an otter burrow was found, which favored the erosion phenomenon.

Following the analysis of the phenomena that took place, it was found that the design parameters of the '70s no longer reflect reality, because the manifestations of climate change are more and more persistent.

2. The Granicesti complex, Located on the Horait River, it is a permanent accumulation placed in the C importance category. It consists of a reservoir, a homogeneous dam, a bottom drain and a large water drain *(figure 5)* (ANIF, 2008). It was affected by floods in 2005, which caused significant damage to the structure. The dam was rehabilitated in 2006. The massive floods of 2008 reactivated the landslides in the Grănicești dam area.

Figure 5 **Grăniceşti Dam, Suceava County, 2008 - general view (ANIF, 2008)**

The significant cumulative rainfall of 247 l/m^2 registered in June 2010 led to the increase of the flow of the Horaiţ brook to 308 m^3/s.

The quantitative precipitations determined the formation of a breach in the dam, in the area of the maneuvering tower *(figure 6).*

Figure 6 **Degradation of the tower at Grăniceşti Dam, Suceava County, during the 2010 floods (CTM, 2010)**

The destruction of the dam was done progressively, the filling material lost its cohesion completely, producing the dislocation and massive entrainment of the material from the dam body downstream. The internal erosion caused the appearance of a rectangular breach which widened to the surface. Shortly the gap became trapezoidal, with depth equal to the height of the dam *(figure 7)*, (CTM, 2010).

Figure 7 **Grăniceşti Dam, Suceava County, Year 2010 - breach in the body of the dam (CTM, 2010)**

The filling washing took place quickly, that the gap was fully developed after 2 hours. The bottom drain was totally discovered by the floods, the material being driven downstream *(figure 8).*

Figure 8 **Grăniceşti Dam, Suceava County, 2010 - bottom emptying degradation (CTM, 2010)**

The analysis of the event found that the breaking of the dam in the earth was the result of anthropogenic causes in design, execution and monitoring:

1. The design did not take into account the creation of a robust connection and a high degree of impermeability between the two materials, thus leading to the destruction of the dam;

2. The selection, sorting and analysis of the filling material in the laboratory was neglected during the execution. The technological standards for filling and the technological standards for compaction, which are frequently encountered in small dams, have not been observed.

3. In monitoring, the fact that small dams are not equipped with measuring and control devices made it difficult to give the responsible bodies instant warning.

3. Horodnic Dams 1, 2, 3

The regularization of the Horodnic and Toplița streams in a barred regime belongs to the Siret river basin. Dams 1 and 2 are located on the Horodnic brook, and dam 3 is located on the Toplița brook uncoded tributary of the Horodnic brook. The accumulations are located upstream of Horodnic de Sus locality, Horodnic commune, Suceava county (CTM, 2010).

Figure 9 **Non-permanent accumulation Horodnic 1, Suceava County, (CTM, 2010)**

The accumulations were executed in 1979 and have the class of importance III, category C. The dams were built in order to mitigate the floods on the Horodnic and Toplița streams to protect the downstream areas against floods. The accumulations were designed for a flood attenuation in the downstream section of the Horodnic-Topliţa confluence from 144 m^3/s to 99 m^3/s, for the probability of 0.5% and from the value of 83.4 m^3/s to 36 m^3/s at the probability of 2% (CTM, 2010).

t the end of June 2006, a flood occurred on the Horodnic brook, with a maximum flow of 210 m^3/s, with a maximum volume of 3.4 million m^3, and which severely affected dams 1 and 2, discharging them. Large water discharge, the connection area with the energy dissipator, has been practically removed from operation.

Following the measurements for the reconstitution of the flow during the flood period, it was found that dam no. 1 has a settlement of approx. 1.0 m. During the flood, the dam was discharged over a width of approx. 300 m and the water blade had in the central area approx. 0.80 m. Dam no. 2 was discharged on approx. 100 m and the water blade had a height in the central area of approx. 0.50 m. The flow that discharged dam no. 1 was 82 m^3/s, and at dam no. 2 the discharged flow was 30 m^3/s. In 2006, an expertise was carried out which recommended works to raise the dams by 0.50 m, but these works were not executed.

The large, short-term rainfall of 73,2 L/m^2 and 81,71 L/m^2, recorded in the period 24 to 27.07.2008, has increased the flows to a maximum of 260 m^3/s and a maximum flash-volume of 6,95 m^3 (CTM, 2010). These phenomena caused damage to the Horodnic 1 and 2 dams. The body of the non-permanent Horodnic 1 dam broke, forming a 10 m wide gap *(figure 10).*

Figure 10 **Horodnic Dam 1, Suceava County, 2008 - dam body degradation (CTM, 2010)**

The breach produced in the body of Horodnic dam 1 was accentuated and determined the flooding of Horodnic dam 2.

In a short time, a gap was formed in the central area, near the bottom drain, with a length of 30 m. *(figure 11, 12).*

Figure 11 **Horodnic Dam 2, Suceava County, 2008 - dam body degradation (CTM, 2010)**

Figure 12 **Horodnic Dam 2, Suceava County, 2008 - bottom emptying degradation (CTM, 2010)**

The cause of the accident was the large amount of precipitation. These focused on high flow rates that exceeded sizing assurances. The damage to the Horodnic 2 dam was also caused by the breaking of the Horodnic 1 dam.

At the Horodnic 3 dam, the water discharged the canopy on the right side on the length of 100 m, the dam being intact after the water discharge.

Following the analysis of the phenomena that took place, it was found that the work was affected due to the undersizing of the unloaders of the accumulation. the dam drains must be resized in accordance with the conditions for the formation of the maximum runoff from the river basin, which is severely affected by deforestation.

In order to prevent these negative events, the term of safety of the hydrotechnical constructions is required, which must be taken into account in all stages of the work: design, execution and operation.

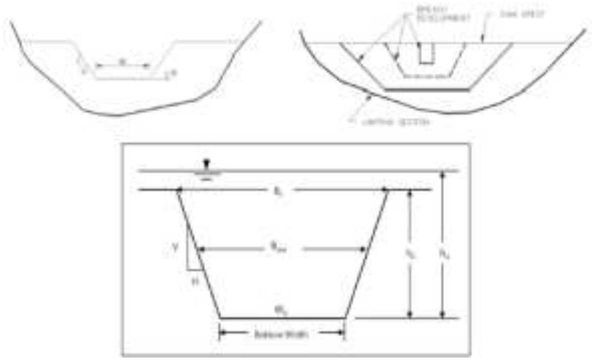
The evolution of technology, as well as the superior materials used today, have a significant contribution in the process of supervising the operation of hydrotechnical works. (Cercel, 2011).

In order to prevent negative events that may affect dams, the calculation of rupture hypotheses is performed using simulation methods and models.

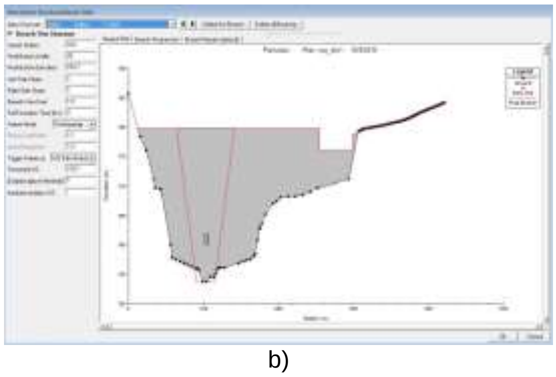
In order to perform the calculation of the propagation of the breaking waves, the following programs can be used: HEC-RAS, Surface-Water Modeling System (SMS), Hydro_As-2D, etc.

The Hec - RAS software allows the modeling of the flow in the riverbed, with the reproduction of flood waves in natural regime and in arranged regime.

The program allows highlighting the hydrological and hydraulic characteristics of the riverbed and the effects of flood transit on the studied hydrotechnical works (HEC-RAS 5.0 – Users Manual) (*figure 13*).



a)



b)

Figure 13 **Schematization of the gap formation by discharging the canopy, using the HEC-RAS program: a - gap parameters; b - how the gap is formed (ABA Prut Bârlad, 2010).**

Exceeding the exploitation quotas at the earth dams at the transit of floods determines an intensification of the filtration process through the earth massif. The phenomenon is studied in technical expertise through the use of specialized software or software made in various programming environments (Luca and Pop, 2016, Bartha et al., 2014). The checks should be carried out on dam operating scenarios according to natural and anthropogenic actions in the site. For final data processing, specialized methods and programs such as Robot, Matlab, stability determination methods and programs shall be used (Fellenius, Bishop), Galena, GeoStudio SEEP/W, etc.

The studies carried out on the earth dams have highlighted the defective way of their maintenance and rehabilitation, as well as the need to resize the dams in accordance with the regulations in force, imposed by the changing climatic conditions.

CONCLUSIONS

1. The current climate changes on the territory of Romania favor the production of fast floods, which cause a series of accidents at the earth dams.

2. Dams made of local materials involve a relatively high risk of flood damage. To reduce the risk of failure, it is necessary to understand all possible failure mechanisms for each component structure.

3. The safe operation of earth dams is a topical issue, given the lifespan of existing dams, their aging and changes in the hydrological regime.

4. Monitoring the behavior of dams during construction, first loading and throughout operation is a guarantee of their safety and the prevention of accidents that can become catastrophic.

5. In order to reduce the disasters caused by climate change, it is necessary to re-evaluate, simulate the flow phenomenon and adopt rehabilitation programs and modernize the dams.

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