DAM SAFETY AND PROTECTION OF HUMAN LIVES

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Abstract
After an introduction, in which both the absolute need of carefully choosing the dam safety measures and the importance of the hydraulic-operational aspects are stressed, a synthesis is done of the dam collapses occurred this century and that have caused loss of human lives. Subsequently, the paper gives examples of the viewpoint of the legislation of some countries on this subject and refers to the effective possibility of saving human lives in case of dam failure. In the next sections, two lists are presented: one of the factors that influence the possibilities of survival and another of the relatively simple measures that can improve the dam safety level.

Keywords: dam safety, dam collapse, risk, civil protection, hydraulic-operational safety

1. Introduction

The dam safety problem is an important issue. The failure of dams may cause and has actually caused loss of human lives and enormous destruction. From this point of view, dams can be considered the most dangerous structures of all the structures of civil engineering.

However, it can be demonstrated that it is possible to protect effectively human lives in the case of dam failure. Dam engineering has concentrated his efforts on the prevention of accidents in dams, namely as regards the structural safety.
Obviously, this is absolutely correct and must continue to be implemented. Nevertheless, it is impossible to ensure a hundred percent safety level in any civil engineering structure and one must be prepared to cope with accidents in dams, including failures.

Another issue that the experience has emphasized is the importance of the hydraulic – operational safety aspects. In fact, if it is true that the structural collapse is the last link of

an unhappy chain, it is also true that the hydrological aspects and all matters related to the design and behavior of the dam hydraulic structures are often part of this chain.
The dam safety problem "is more than a technical problem, it is also an organizational one and, above all, a funding one" (USCOLD, 1982).

Funds are limited. Other civil engineering structures create safety problems. The number of existing dams is large. Small dams have been involved and can be involved in serious accidents (Viseu and Martins, 1998).

Therefore, it is absolutely necessary to choose carefully the dams to be observed with priority and the measures to be carried out. This is obvious and has been mentioned in the literature: "safety dam actions should be concentrated on essential aspects in order to economize time and resources" (ICOLD, 1987) ; it should be identified " those dams, large and small, that truly involve a major risk, improving them quickly without seeking absolute safety, and developing effective, cheap warning systems" (Lempérière, 1995) ; "no country in the world can afford to upgrade all its dams to current safety standards; hence it would appear that the only way forward is to rehabilitate and make safe those dams with the highest hazards first, and concentrate on the remainder later" (Chemaly and Nortjé, 1994).

Two delicate questions are related to this point and, in general, to the safety topic:

- safety and human life are very important matters; so, it is necessary to study thoroughly the subject before the action; but, how much time should be dedicated to this study? in fact, safety and protection of human lives are very urgent matters too;
- human life has no price (that is an objective statement, given the unique character of each human life); but, if all the available means are used to protect some human lives, what will happen to the protection of other human lives?

Finally, it is adequate to point out that an accident in any dam will be a strong argument for those that are against the construction of dams. In fact, if seems very difficult to replace dams in their roles of creating strategic reserves of water, controlling floods and producing clean power.

2. Historical failures

Table 1 contains a list, as comprehensive as possible, of all dams that have failed this century causing loss of human lives. Besides that, only dams from which the type and the height are known are included.

The following cases are not included in the table:

- failures resulting of acts of war;
- failures during construction;
- failures of coastal dikes;
- Vaiont accident (not a dam failure).

As said, the influence of hydraulic – operational factors is frequent (at least in 50 percent of all cases).

From the descriptions of these failures, it is possible to conclude as follows:

- in overall terms there are only three causes of dam failure: overflow, piping, collapse of the foundations;
- seismic phenomena never caused loss of human lives by means of dam accidents;
- the known statement "the failure of embankment dams is a slow failure and the failure of concrete dams is a fast one" is systematically confirmed by the experience.

From the table it is possible to conclude as follows:

- failures of embankment dams : 72% of all failures;
- geographical distribution : Asia 11, Central and South America 2, Europe 12 , North America (USA) 13, Oceania (Australia) 1.

Figures 1 and 2, respectively, show the distribution of failures by dam height and by decades.

Table 2 contains a list similar to the list of Table 1. The only difference is that, in the second list, the available information is very limited (both the type and height are not known for none of the dams).

Name	Country	Year	Height (m)	Type	Hydraulic-operational factors involved?
Austin	USA	1911	15	G	-
Lower Otay	USA	1916	40	R	Yes
Bilá Desná	Czechoslovakia	1916	17	E	Yes
Tigra	India	1917	26	G (M)	Yes
Gleno	Italy	1923	44	B	-
Eigiau	UK	1925	11	G	-
Coedty	UK	1925	11	E	-
St. Francis	USA	1928	62	A/G	-
Cascade	Australia	1929	19	R	Yes
Castlewood	USA	1933	21	R	Yes
Zerbino	Italy	1935	12	G	Yes
Vega de Tera	Spain	1959	34	B	-
Malpasset	France	1959	61	A	-
Panshet	India	1961	50	E	Yes
Poona	India	1961	40	G (M)	Yes
Baldwin Hills	USA	1963	71	E	-
Zgorigrad	Bulgaria	1966	12	E	-
Nanaksagar	India	1967	16	E	-
East Lee	USA	1968	8	E	-
Frías	Argentina	1970	15	R	Yes
Buffalo Creek	USA	1972	13	E	Yes
Canyon Lake	USA	1972	6	E	Yes
Hubacov	Czechoslovakia	1974	6	E	-
Bear Wallow	USA	1976	15	E	Yes
Bolan	Pakistan	1976	19	E	Yes
Teton	USA	1976	93/123	E	-
La Paz	Mexico	1976	10	E	-
Laurel Run	USA	1977	13	E	-
Kelly Barnes	USA	1977	13	R/E	Yes
Machhu II	India	1979	26	E	Yes
Gotvan	Iran	1980	22	E	Yes
Karnataka	India	1981	2	E	Yes
Lawn Lake	USA	1982	7	E	-
Tous	Spain	1982	50	E/G	Yes
Kantalai	Sri Lanka	1986	27	G (M)	-
Belci	Romenia	1991	18	E	Yes
Gouhou	China	1993	70	CC	-
Artik	Armenia	1994	18	E	-
Tirlyan	Russia	1994	13	E	Yes

A – arch, B – buttresses, CC – compacted gravel, E – earth, G – gravity, G (M) – gravity (masonry), R – rockfill

Table 1: Historical failures

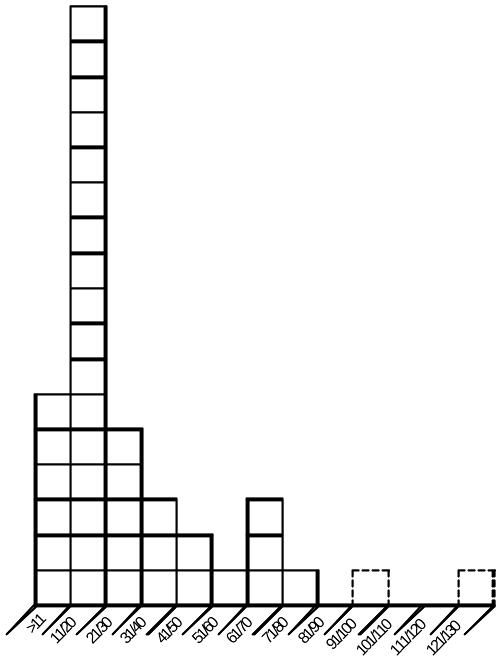

Fig. 1: Distribution of failures by dam height (m)

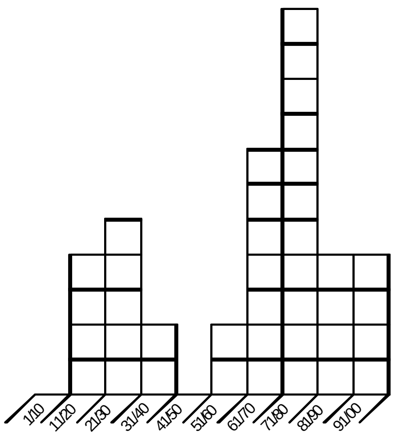

Fig. 2: Distribution of failures by decades

NAME	COUNTRY	YEAR
Skelmorlie	UK	1925
Granadillar	Spain	1934
Babii Yar	Ex-USSR	1961
Hyokiri	Korea	1961
Kuala Lumpur	Malaysia	1961
El Cobre	Chile	1965
Aberfan	UK	1966
Koyna	India	1967
Virginie	USA	1972
Hirakud	India	1980
Teseno	Italy	1982
Stava	Italy	1985
Sargozan	Ex-USSR	1987
Jinduicheng	China	1988
Chongtu	China	1990
Kiselevsk	Russia	1993
Harmony	South Africa	1994
Xuriguera	Spain	1994
Placer	Philippine Islands	1995
Kénogami	Canada	1996

Table 2: Historical failures (incomplete data)

3. Legislation and protection of human lives

The legislation of the different countries on dam safety stresses, as could be expected, the protection of human lives.

However, certain nuances can be observed, in particular, as regards the typical distinction between dams with an associated high risk and dams with an associated significant risk.

The Committee on Safety Criteria for Dams, of the USA, has recommended in 1985 that a probable loss of life of one person would be enough for attributing the classification high risk.

Other dam safety laws are not so strict. Typical examples are:

- current legislation of South Africa and United Kingdom: the classification high risk implies a minimum number of 10 persons in danger;
- current legislation of Spain : it is necessary more than a small number of houses for attributing the classification high risk;
- current legislation of Portugal : for the same effect, it is necessary more than a few human lives.

On the one hand, the American proposal could be considered equivalent to the classification of all dams as high risk dams (it is always possible to have a person walking on the dangerous zone of any dam). However, on the other hand, the words ten, small, a few seem inappropriate when classifying a risk for the human life.

Therefore, it seems more logical to consider the existence of high risk in any case of permanent population in the danger zone downstream the dam, whatever the size of the urban area. In certain cases (concrete dams, short distance dam – urban area) the best solution may be the transference of the population.

4. The effective possibility of protecting human lives in case of dam failure

This possibility depends essentially on three factors:

- dam type (embankment or concrete);
- distance to the dam;

- existence of warning systems.

It should be noted that, for any type of dam, failures have occurred in a context of bad weather and very high levels in the reservoir, i.e., in a context that, in itself, imposes an attitude of surveillance. Furthermore, in several cases, other previous signs of danger were observed.

Other favorable factors to the rescue of people are:

- typical maximum of average celerity of the inundation wave: 25 km/h[1] (Vogel 1998);
- typical maximum width of dam – break flow :1 km[2] (Goubet,1993).

The failure of Teton dam (USA, June, 5,1976) raises an important question.

A very brief description of the event (according to Jansen, 1983) is:

- 8 30 muddy flow appears downstream (approximately 1m^3/s)
- 10/11 repair attempts;
- 11 50 the breach attains the crest of the dam (the lethal flow begins).

Hundreds of people in the downstream valley were saved by the protection teams (the number of casualties was 11 or 14).

However, taking into account the available time for evacuation, it seems reasonable to ask: why the loss of human lives?

5. Risk factors

A more developed list of the factors that influence the possibilities of survival, based on a paper by Funnemark et al, 1998, is presented in this section.

It is possible to divide these factors into three groups.

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[1] It may be higher near the dam and in case of bed with high slope.
[2] I.e., 10 minutes walking.

a) <u>characteristics of the dam-break flow</u>

- depth (h)
- velocity (v)
- material carried by the flow
- water temperature
- erosions and landslides

Obviously h is the decisive parameter. In case of not very high h, the parameter hxv becomes important.

b) <u>warning time</u> (i.e., the available time that the population has for evacuation)

- decision of starting evacuation either prior to the dam-break or not
- celerity of the dam-break wave (c)
- distance to the dam (d)
- reliability of the warning system
- automatic or manual warning
- warning from the dam or from an operation center

Obviously the warning moment and the parameter d/c are the decisive parameters.

c) <u>evacuation efficiency</u>

- population knowledge on how to act in case of a dam-break
- quality of the civil protection teams
- availability of escape possibilities
- fraction of elderly persons, disabled persons, children
- weather, night or day, previous flow conditions

Obviously the first factor is very important and depends on the existence of evacuation plans, general information and emergency preparedness exercises.

6. Simple measures can improve the safety level

In certain cases only very expensive measures are effective in improving safety (for instance, the construction of a second spillway). But, in several other cases, simple[3] and relatively low cost measures are useful and should be used.

A group of these measures are related to personnel:

- existence of a dam safety group near the Authority;
- existence of a hydro-mechanical equipment inspection and maintenance team;
- each dam should have a safety officer;
- regular training of the operators (including substitute operators);
- existence of rules that ensure the permanence of personnel in the dam in all critical situations.

Other group is related specifically with emergency situations:

- existence of a clear decision chain, sustained by safe communications, to act in these situations;
- installing warning systems and keeping the downstream population informed;
- keeping in good conditions the circulation zones inside the hydraulic scheme perimeter;
- lighting of all zones of the hydraulic scheme that are related with safety.

Other measures concern documents:

- existence of reservoir operation records;
- existence of written operation rules for gates and valves.

Lastly, other simple measures:

- carrying out visual inspections;
- maintenance and use of the monitoring system and transmission of the data;
- removal of vegetation or any material from zones in which flow obstruction or hiding of anomalies are possible.

[3] The optimization of the reservoir operation, keeping, without waste of water, a high level of safety, is the best (and non-structural) measure in some cases. But, anyway, it is not a simple measure.

7. Conclusions

a) The task of improving dam safety should take into account an absolute need of selection of dams and measures and should be performed with economy and without bureaucracy.

b) Hydraulic-operational aspects are highly related with safety.

c) Dams relatively low are the most dangerous dams.

d) Embankment dams fail more than concrete dams. However, they are less dangerous. In certain cases of concrete dams, the transference of population can constitute the most logical procedure.

e) The possibility of protecting human lives in case of dam failure is real. There are many cases in which this possibility is, besides real, relatively simple and not very expensive.

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