ICOLD Incident database
Bulletin 99 update

Statistical analysis of dam failures

Committee on Dam Safety
International Commission on Large Dams (ICOLD)

ICOLD Committee on Dam Safety

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Foreword

In all hazardous industries, incident analysis is an important tool to improve safety. Understanding the causes of incidents makes it possible to change what was identified as a weakness, either in the design, the construction or the operation of any industrial plant. Dams obey to the same rules, and it is the reason why ICOLD has always been involved in dam incidents collection and analysis. ICOLD has on three occasions investigated worldwide surveys to collect the largest amount of information on dam incidents. The 1970's saw the completion of "Lessons from Dams Accidents" (1974), the 1980's produced "Deterioration of Dams and reservoirs" (1984), and in 1995 Bulletin 99 on "Dam failures statistical analysis" was issued.

Why this bulletin?
Since 2005 the Committee on Dam Safety has been collecting additional information on dam incidents and considered that it was time to update this last publication (Bulletin 99) which listed the cases of failures up to 1991. The Committee's position is that it is the responsibility of an international professional organization such as ICOLD to maintain such an inventory and provide the international dam engineering community with important information allowing to draw lessons aimed at improving the safety of dams. Information on dam failures is available in publications and on websites, but this information is often incomplete and biased. In addition, no comprehensive analysis has been carried out in order to draw conclusions that can help in improving safety of dams. It was therefore up to ICOLD, and to its Committee on Dam Safety, to carry out this survey and analysis with the objective of meeting the needs of the dam professionals.

Bulletin 99 presented mainly statistical analysis based on the sizes of dams, their types and temporal aspects such as year of construction, age at failure, etc. For this update other important attributes have been added, such as the context of failures (normal operation, flood, earthquakes, etc.), the failure mode, and the failure causes. Although Bulletin 99 presented an analysis of the failure causes, in the 1990's there was still a lack of complete clarity about the understanding and interpretation of differences between failure modes and failure causes.

Przemyslaw A. Zielinski
Chairman, Committee on Dam Safety

Acknowledgments

The Committee on Dam Safety and the ICOLD Executive gratefully acknowledge the contribution of members of the Committee's Working Group and the support provided by their sponsoring organizations. The final text of the Bulletin is the result of the collective effort of the entire CODS which continued providing general guidance and valuable input during the period of 2013 to 2019.

The task of writing the drafts and preparing the final text was carried out by:

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It needs to be stressed that the effort provided by the members of the Working Group was extensive and its work was instrumental for completion of the task. Working Group members had a substantial knowledge and experience with regard to dam safety issues. This breadth of perspective on regulatory, organizational, managerial and engineering aspects of dam safety management can hopefully provide the readers of this Bulletin with the help in drawing lessons from these failure cases and encouraging to further expand the analyses for specific purposes.

Przemyslaw A. Zielinski
Chairman, Committee on Dam Safety

1. Content of the bulletin

This bulletin includes:

- The sources of the failure cases and comments about the data base used for the analyses;
- Overview on the failure records for each dam including dam characteristics and failure description;
- Statistical analyses:
    - Basic statistics on the failures' repartition over geography and over time, influence of construction year, age at failure, type of dam, height and reservoir volume. Comparisons with existing dams are also presented. This part of the bulletin constitutes an update of Bulletin 99;
    - Statistics concerning the failure contexts, the failure modes and the possible causes. These analyses are new and deserves attention, as they bring valuable information about the failures.
- A table of all the failure cases.

1.1. Failure definition

To characterise a dam incident as a failure the following definition has been retained.

A failure is a catastrophic incident characterised by:

- **an uncontrolled release of impounded water;**
- **and/or by a total loss of integrity of the dam structure, its foundation or abutments.**

By adding "total loss of integrity" to the definition of failure, cases such as the Van Norman dam sliding in the upstream direction during the San Fernando earthquake, although with no resulting uncontrolled release of water, is retained as a failure, which makes sense. "Total loss of integrity" may sometimes lead to subjective interpretation and the working group has collectively done its best effort to sort the incidents according to this definition.

Only failures of "large" dams were retained, according to the definition given in the ICOLD World Register of Dams (WRD) i.e. the dam is $H > 15$ m above its foundation or $H > 5$ m AND $V > 3.10^6$ m^3. However, some smaller dams have been included in the database when useful lessons could be drawn from their failures.

Each failure case is related to a failure event (and not to a dam). It means that several cases may concern the same dam if several failures occurred (provided that the dam has been repaired or rebuilt between the failure cases). These different cases are indicated by "(A), (B)", etc. after the dam name in the table in Appendix 1.

Accidents related to safety appurtenant works (spillways, gates, bottom outlets) and failures of tailing dams (built with mine tailings) have not been included in this bulletin.

1.2. Sources of the data

The analyses presented in this bulletin are based on 1) existing data on incident cases available in ICOLD bulletins 2) existing data in other ICOLD publications and from institutional bodies (National committees, governmental agencies,..), 3) new cases identified and documented by the working group.

1.2.1 Existing ICOLD documentation

The ICOLD publications dedicated to dam incidents and used for this bulletin are:

- **Lessons from Dam Incidents** (1974): 266 cases of "large dam" incidents (before 1-1-1966) are listed, among which about 90 cases are failures; each case is documented, in English and in French, with a short description of the dam characteristics, the condition of the failure, the consequences, and any remedial measures. Some cases are more thoroughly investigated (MALPASSET, SAINT FRANCIS, VAJONT, etc.) than others. At the beginning of the bulletin, a lot of statistical analyses are presented, according to damage, dam types, etc…, of the incidents. Furthermore, several chapters give more detailed information on "famous" failures and other chapters provide recommendations about the design of dams and their foundations.
- **Deterioration of Dams and Reservoir** – **Examples and their Analysis** (December 1983)**:** This publication is an actualization of "Lessons from Dam Incidents" and its content is similar; it describes 1105 deterioration cases, among which 107 are failures. A very important work of statistical analysis is included, dealing separately with concrete and masonry dams, earth and rock fill dams, appurtenant works and reservoirs. All the data gathered after the inquiry is printed, the questionnaire and the codes for dam type, deterioration type, failure causes, etc. are also available. The origins of data are: Lessons from dam incidents (ICOLD and USCOLD) and response of National Committees to the questionnaires.
- **Bulletin 99: Dam Failures - Statistical analysis** (1995)**:** This bulletin is an update in 1995, with data collected before 1993, of the statistical analysis of "Lessons from Dam Incidents", but only for failure cases. A table of 179 failures is presented, with synthetic information on each dam. The committee in charge of this bulletin had prepared several lists of codes for dam type, types of failures, occasion of failures, causes of failures and remedial measures. There is no detailed description of the different failures in the bulletin.

1.2.2 Other existing sources

The purpose of updating Bulletin 99 was to extend the inventory of previously known failures by including known failures that occurred after 1992. For this purpose, other existing publications, either from ICOLD or from National Committees or other official organizations have been used to complement the data listed in 1.2.1. These additional sources are:

- ICOLD bulletins with list or description of failure cases
  - Bulletin 82 (Selection of design flood – 1992);
  - Bulletin 109 (Dams less than 30 m high - Cost savings and safety improvements - 1997)
  - Bulletin 120 (Design features of dams to resist seismic ground motion - 2001)
  - Bulletin 164 (Internal erosion of existing Dams, Levees and Dykes, and their foundations – 2017)
- Other documents issued by National ICOLD committees or institutional bodies, where information about dam failures can be found, have also been used:

- Jansen, Robert B. - Dams and Public Safety. A Water Resources Technical Publication., U.S. Department of the Interior, Water and Power Resources Service, Denver, CO, 1980
- DEFRA - Environment Agency - Evidence report, Lessons from historical dam incidents: Delivering Benefits through evidence - August 2011
- USCOLD Lessons from dam incidents USA I (1975) and USA II (1988);

1.2.3 New failures cases added from international survey

It was not considered useful to launch a survey of all National Committees as it had been done for previous ICOLD publications. The working group has limited itself to an internal survey of the members of the Committee on Dam Safety which already represents more than 30 countries among the most important in number of dams. As a complement, modern technologies of information were used to search for relevant information on additional failures.

1.2.4 Data for existing dams

Some analyses are done with reference to the total number of existing dams. For this purpose, the version of September 2018 of the ICOLD World Register of Dams (WRD) was used to extract the necessary information (dam types and heights, year of construction, …).

1.3. Data selection process and failure cases synthesis

1.3.1 Data selection

The first action was to scan all the available documents and insert numerical values and texts into a database. This task is not trivial because many cases of failures are presented in different documents, and it was necessary to merge data from these different sources. This operation often highlighted discrepancies, sometimes significant, between the data provided in these different documents. In general, the most recent source was considered to be the most reliable. When there were large gaps between the sources, comments were added to a specific database field. Another difficulty was to detect duplicate case descriptions as some dams had different names in the different documents. Furthermore, it was realized during this work that some of the failure cases in the 1974 document, Lessons from dam incidents, were no longer present in the following ones and, on the contrary, sometimes the recent documents contained older failures that were not mentioned in the first published documents.

However, this task is much easier than it was 25 years ago because the development of digital resources greatly facilitates this search and merging work.

One major difference from Bulletin 99 is that the working group has aimed at giving a more detailed characteristics of the failures, with specific information on “Failure context”, “Failure mode” and “Failure cause”. Codes and definitions are given in chapter 1.4.2

1.3.2 Failure cases number synthesis

The Table 1-1 below lists the number of cases analysed in this bulletin, with reference to sources. The table also provides information on the year of failure of new cases compared to the three ICOLD basic publications:

Failure cases year	Before 1993	1993 - 2018	Total
LFDI, DDAR, B99 (*)	202	0	202
Other institutional sources	7	34	41
New cases from survey	58	21	79
Total	267	55	**322**

(*) LFDI: Lessons from Dams Incidents – DDAR: Deterioration of dams and reservoirs - B99: Bulletin 99

Table 1-1 : Failure cases number synthesis

The total number of cases is now 322 compared to the 202 officially reported by ICOLD before 1993. As a result, 120 new cases of failures are now included in the list of dam failures, most of them coming from the survey conducted for this bulletin update. It should be noted that 65 new cases concern failures that occurred before 1993 which were not listed in the documents mentioned in 1.2.1.

It should be borne in mind that these failure cases are certainly not an exhaustive list. Failure reporting is uneven as it is clearly stated by the analysis in chapter 2. It is the reason why these statistical analyses cannot be applied to all regions of the world without careful review of the reliability of the data available for these regions.

Due to practical reasons the failure list has been “closed” during 2018, the last case present in the list being the Solai dam failure in Kenya (May 2018). New failures having occurred since then are not included in these 322 cases.

In many statistical results presented in this bulletin the total number of cases is different from 322. The explanation is very simple: when the data needed for an analysis is missing (no time period available, unknown causes of failure, etc.) the number of cases kept for analysis is lower. The same is true for the number of existing dams.

All these 322 cases are listed in Appendix A.

1.4. Record content of each failure case

The data base developed for the purpose of this update contains about thirty fields for the dam characteristics and the failure description. Many fields are numerical values but some other are “free texts”. All these fields were not used in the statistical analyses but are nonetheless important for understanding and validation purposes.

1.4.1 Dam data

- General dam characteristics: Continent, country, year of construction, river, nearest city, scheme purpose. The year of construction have been categorized as follows:
  - Before 1900
  - Between 1901 and 1925
  - Between 1926 and 1950
  - Between 1951 and 1975

  - Between 1976 and 2000
  - After 2000
- Dam and reservoir characteristics: dam type, height, height range (see chapter 6), length of the crest, foundation type, dam body volume, reservoir volume. Dam types and dam purposes use the same code as the WRD and are recalled in the table below:

Dam Type (*)		Scheme purpose (**)
VA	arch	I – irrigation
MV	multiple arch	C – flood protection, water regime regulation
PG	gravity	R – recreation
CB	buttress dam	H – hydropower production
TE	earth	F – Fish breeding
ER	rock fill dam	N – navigation
BM	barrage	S – water supply
XX	unlisted	X – not listed above

(*) PG (M) or VA (M) for dam made of masonry.

(**) For multipurpose dams several codes are possible (for example: IH)

For earthfill and rockfill dams it has been added information about the type of section when it was available: (Z) for zoned dams, (U) for upstream impervious facing type, (H) for homogeneous type.
Some dams consist of several longitudinal sections of different types. In this case several types are indicated (ER/PG, or TE/ER by example) but only the first dam type has been retained for the analyses. Otherwise, it would not have been easy to interpret the results. It has been verified that this simplification did not affect the final results.

Many dams in the data base are also listed in the ICOLD World Register of Dams (WRD) and, as far as possible, the data of this section are those of the WRD. If important gaps exist between the WRD and the data from other ICOLD publication, this is documented in a specific field of the data base. These gaps are often explained when important repair works have taken place after the incident.
For some dams the country indicated in previous data sources is no more valid, because of geopolitical changes. When no doubt exists, the new country is indicated, but the old one is noted in the data base.

1.4.2 Failure data

The information available is:

- Year of incident (the failure years were categorized in the same way as the construction years)
- Type of incident, with the following codes

Type of Incident	Description
A1	An accident to a dam which has been in use for some time, but which has been prevented from becoming a failure by immediate remedial measures including possible drawdown of the water.
A2	An accident to a dam which has been observed during initial filling of the reservoir and which has been prevented from becoming a failure by immediate remedial measures including possible drawdown of the water.

A3	An accident to a dam during construction, i.e. by settlement of foundations, slumping of wide slope, etc., which have been observed before any water was impounded and where the essential remedial measures have been carried out, and the reservoir safely filled thereafter.
A4/F4	An accident (A4) or a failure (F4) of appurtenant works: spillway, gates, cofferdams, etc.) which did not lead to a dam incident (failure or accident).
F1	A major failure involving the complete abandoning of the dam.
F2	A failure which at the time may have been severe but yet has permitted the extent of damage to be successfully repaired and the dam brought again into use.
F3	Total loss of integrity without water release.

- Incident Time, with the following codes

Incident Time	Description
T1	During construction or major rehabilitation/upgrade works
T2	During first filling
T3	During first five years
T4	After five years
T5	Not available

- Incident context

This field defines the operation condition when the incident occurred. The codes are:

Incident context	Description
NC	Normal condition
UF	Unusual flood condition (*)
UQ	Earthquake condition
UO	Other unusual natural load/hazard
EF	Extreme flood condition (*)
EQ	Extreme earthquake condition
EO	Other extreme “natural” load/hazard (including landslides in the reservoir, upstream dam failure)
HH	Human hostile action
UN	Unknown

The term "unusual flood" represents a large flood but remaining below the design hypothesis. The term extreme flood means a flood higher than the design hypothesis.

- Failure Mode: In order to sort the different interesting cases, the following limited numbers of incident mode were used:

Incident mode	Description	
OT	Overtopping – External erosion	
IE (*) Internal Erosion or inadequate water tightness	IEDB	IE / leakage inside dam body
	IEFO	IE / leakage inside foundation
	IESU	“Surface” erosion / leakage taking place in interfaces inside the dam or its foundation

SF (*) Structural failure	SFBD	Mass movement (sliding, tilting, settlement in dam body)
	SFFO	Loss of support (from foundation, abutment)
UN		Unknown or Unclear
DI		Important disorders (partial loss of integrity)

(*) generic code which are used only if no information is available on a more detailed incident mode.

- Fatalities: Number of human victims (sometimes the precise number is not known and only a range “mini-maxi” is available).
- Description of the failure: a description of the failure scenario,
- Failure causes: Bulletin 99 presents an analysis of failure causes, but all these causes were “technical” causes, whereas nowadays it is recognized that organizational or human behaviour issues are the root cause of many failures. Finally, finding the right causes need careful analysis which has been rigorously carried out for only some of the more important failures. For this update the working group has identified two categories of causes:
  - Causes linked to organizational issues or human behaviour:

BD	Design insufficiencies
BC	Construction insufficiencies
BM	Maintenance or surveillance
BO	Inadequate operation (including spillway gates)
NN	None or Unclear

  - Causes linked to internal causes (technical issues, ineffective barriers of defence).

GC	Geotechnical issues
ST	Structural issues
MA	Material ageing
IF	Overtopping (OT) due to Inadequate Freeboard
IA	Overtopping (OT) due to Inadequate Available capacity (including gates malfunction)
II	Overtopping (OT) due to Inadequate Installed capacity
HF	Hydro mechanical equipment malfunction or failure (including loss of power supply)
UN	Unknown

- Other information: detection mode, remedial measures, etc.

1.5. The ICOLD Data Base on Dam Incidents

All the data collected from the references cited above and the answers of Dam Safety Committee members were introduced in a data base. The purpose of this data base is to give to the dam community a tool providing a list, as exhaustive as possible, of dam incidents. The objective is not to have very detailed information for each incident record; rather the data base gives some references, many of them being now available on the Internet.

The main objective is to provide dam professionals with a reliable (as much as possible) source of dam incidents making it possible to sort by type of dams, countries, period, etc, in order to study in more details the cases related to some particular question. Obviously, these detailed studies cannot be undertaken only with the data available in this data base but must rely on the references provided and on specific research of reports, articles, etc.

The second objective of the data base is to allow periodical statistical analysis as it is done in this update of bulletin 99.

2. Failed dams <-> Geographical repartition

To assess the representativeness of the failures' data, the repartition of failed dams by continent has been analysed by comparison with existing large dams as reported in the WRD. The following table gives the main values:

	Existing dams	Failed dams	ratio
ASIA	35176	67	0,19%
NORTH AMERICA	11118	130	1,17%
EUROPE	7713	61	0,79%
AFRICA	2330	30	1,29%
SOUTH AMERICA	1887	22	1,17%
AUSTRAL-ASIA	824	12	1,46%
CENTRAL AMERICA	23	0	0,00%
TOTAL	59071	322	0,55%

Table 2-1: Ratio of failed versus existing dams by continent

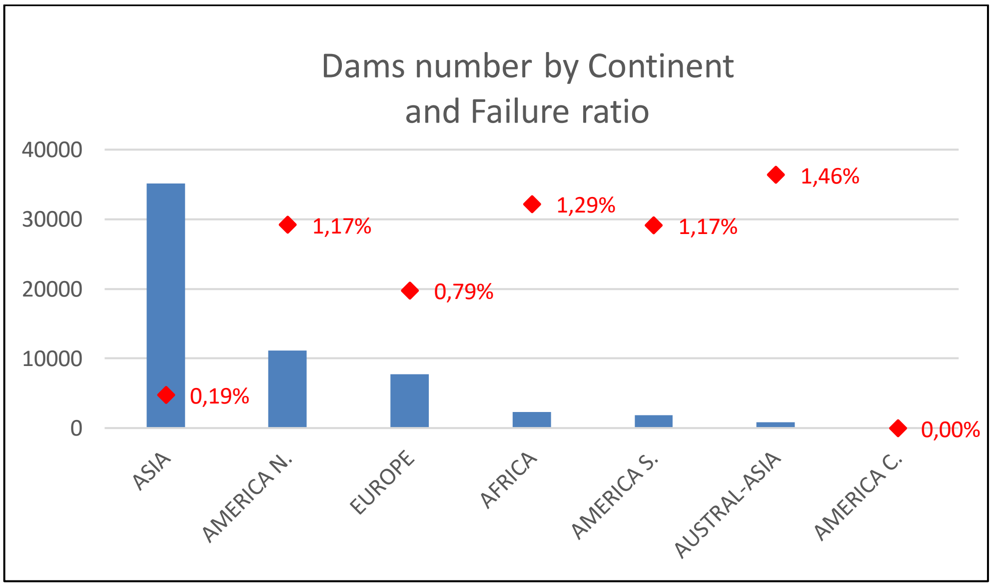

Figure 2-1: Number of large dams by continent and failure ratio

It clearly appears, that the average value of the ratio failed dams / existing dams is in a range of 0,8 % (Europe) to 1.3 % (other continents). With a ratio of 0.19% Asia is obviously different from the other regions. In order to ensure the soundness of the statistical analysis performed in this bulletin, some data from Asia have been excluded in the following analysis, both for existing and failed dams. The total number of existing and failed dams considered in the bulletin is therefore 35230 and 311 respectively, and not 59071 and 322 as listed in Table 2-1 above.

The Table 2-1 is then modified as follow:

	Existing dams	Failed dams	Ratio
ASIA	11335	56	0,49%
NORTH AMERICA	11118	130	1,17%
EUROPE	7713	61	0,79%
AFRICA	2330	30	1,29%
SOUTH AMERICA	1887	22	1,17%
AUSTRAL-ASIA	824	12	1,46%
CENTRAL AMERICA	23	0	0,00%
TOTAL	35230	311	0,88%

Table 2-2: Modified ratio of failures versus existing dams by continent

Sometimes enough information to fill all the fields of these existing and failed dams have not been available. Therefore, for many analyses results the total number of cases is different (lower) than 311 or 35230.

For existing dams in the WRD, it can be pointed out that only 57093 dams are large dams with the ICOLD definition (for 52738 dams $H \geq 15$ m and for 4355 dams $H < 15$ m and $V \geq 3$ hm^3). That means that 1978 dams (3.3% of the total) in the register are not “ICOLD large dams”.

For failed dams the working group has considered that some failures deserved to be included even if the “ICOLD large dams” criteria were not strictly fulfilled. On the 322 failures’ cases the number of these cases is 14, representing 4.3% of the failed dams.

3. Failures <-> Time

Registered dam failures during 25-year time periods are shown below. The tendency is clearly a decrease in failure ratio with time. The table and the figure below summarize these data, compared to the cumulative number of existing dams to obtain the evolution of failure rate:

Time period	≤1900	1901-1925	1926-1950	1951-1975	1976-2000	>2000
Cumulative number of existing dams	1588	3808	7375	19724	30829	33470
Failed dams	35	54	41	77	63	40
ratio	2.20%	1.42%	0.56%	0.39%	0.20%	0.12%

Table 3-1 : Dam failures by time periods and ratio with existing dams

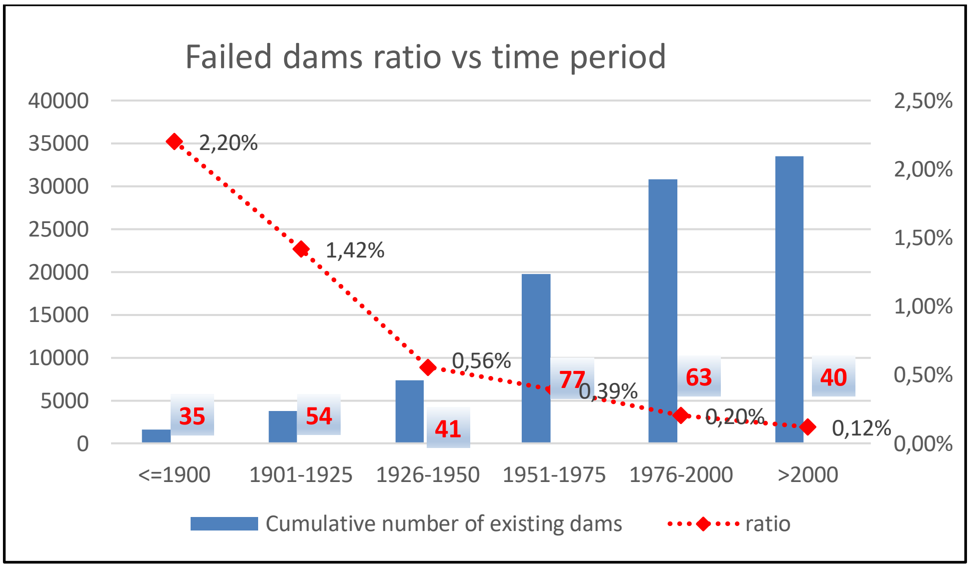

Figure 3-1 : Dam failures by time periods and ratio with existing dams

The number of failures was at a maximum in 1950-1975 with 77 failures recorded. Since then the number has decreased but is still rather significant with 40 failures from 2000 to 2018. However, due to the growing number of dams the failure ratio shows a continuous and promising decrease. It is worth noting that 87 % of the failures concern dams built before 1975. Only 13 % concerns dams built after 1975 (see next chapter).

The number of failures registered after 2000 is still significant, but the overall trend seems to be a decrease in the number of failures since the period 1950-1975.

4. Failures <-> Year of construction.

One of the most interesting lessons learnt from failure of dams is to check that continuous progresses are made along time: lessons from failures have been considered in dam design and operation of existing dams. The table below summarizes these data, comparing the number of dams built during a period of time to the number of these dams that have failed to date.

Year of construction	≤1900	1901-1925	1926-1950	1951-1975	1976-2000	>2000
number of dams built	1588	2220	3567	12349	11105	2641
Failed dams	67	73	41	73	32	10
ratio	4.22%	3.29%	1.15%	0.59%	0.29%	0.38%

Table 4-1 : Failures of dams versus their year of construction

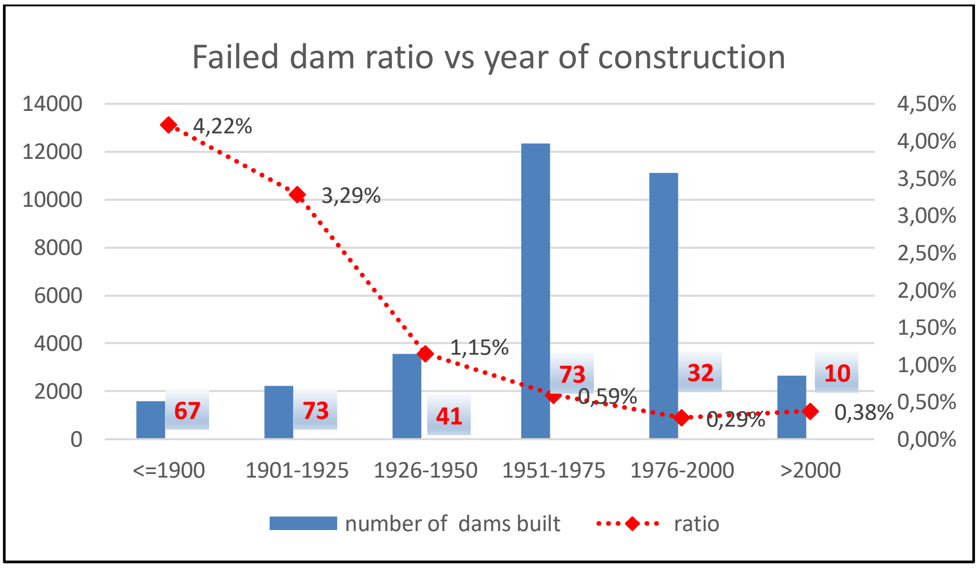

Figure 4-1: Failures of dams versus their year of construction

The ratio for dams built after 2000 is higher than during the previous 25 years period. This would tend to show a slight increase in the rate of failure in the last 20 years.

Another explanation could obviously be a better detection of dam failures since 2000 thanks to the Information Technology progress (Internet, ..).

5. Failures <-> Dam age

The time span between the year of construction and the failure year (i.e. the dam age at failure) is an important factor. An analysis has been made comparing the dams which have failed before 5 years of operation (i.e. during construction, first impounding or during the first 5 years of operation) to the total number of failed dams during the same time period. This is reported in the following table:

Year of construction	<=1900	1901-1925	1926-1950	1951-1975	1976-2000	>2000
Ratio of failures during first 5 years of operation vs total	30%	51%	46%	59%	59%	100%

Table 5-1 : Ratio of failures occurring during the first 5 years versus total number of failures

It can be seen that except for the dams built before 1900, this ratio is around 50 %, which confirms the usual statement that 50% of the failures occur during the first five years. To date all dams built after 2000 have failed during their first five years.

The next Figure 5-1 refines this analysis by selecting the age of failed dams by period of ten years versus their period of construction.

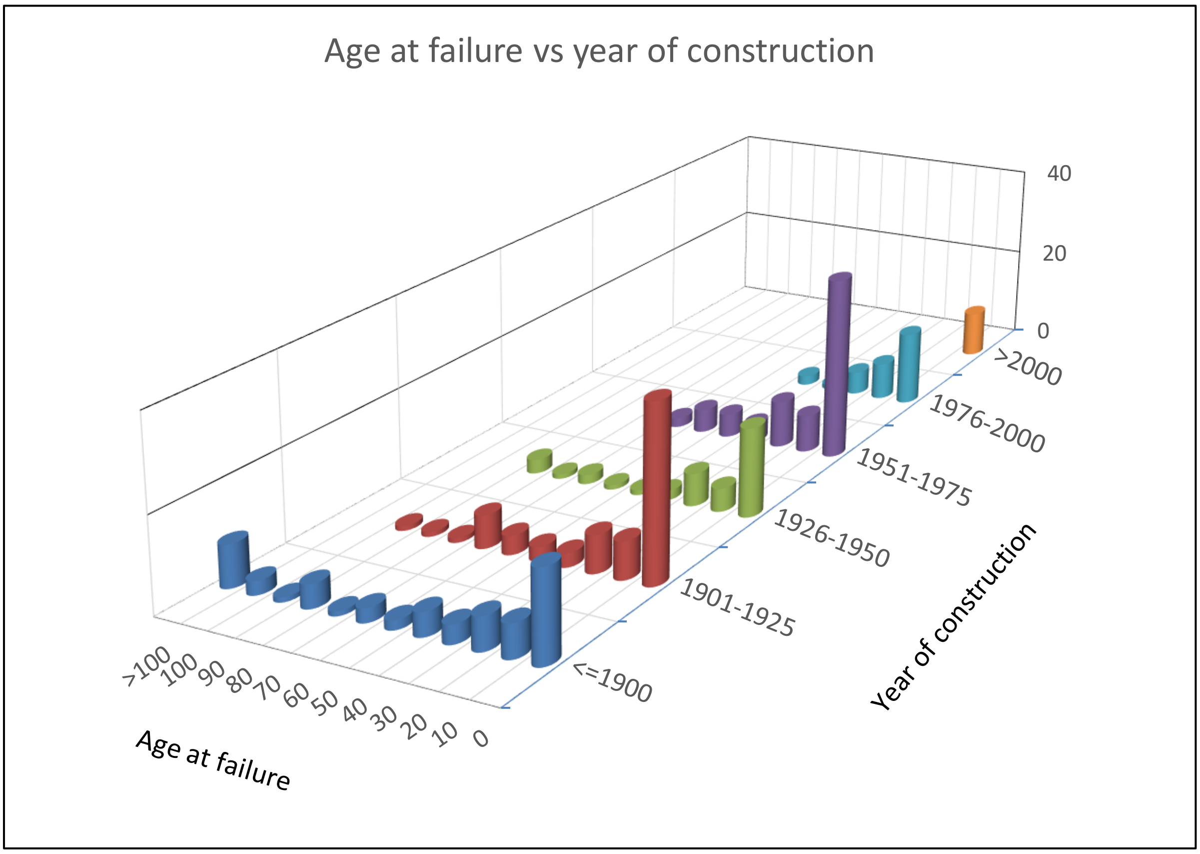

Figure 5-1 : Age at failure versus year of construction

The first ten years are clearly the period where many failures occur. But it seems that a significant number of failures continued to happen during the 30 first years for dams built between 1900 and 2000. There are also failures on older dams: as dams get older, they will naturally be more prone to failure if they are not maintained and upgraded. For dams built after 2000 it is too early to draw conclusions.

A focus on these first 10 years is plotted below: the two first years stand for 50 % of these failures.

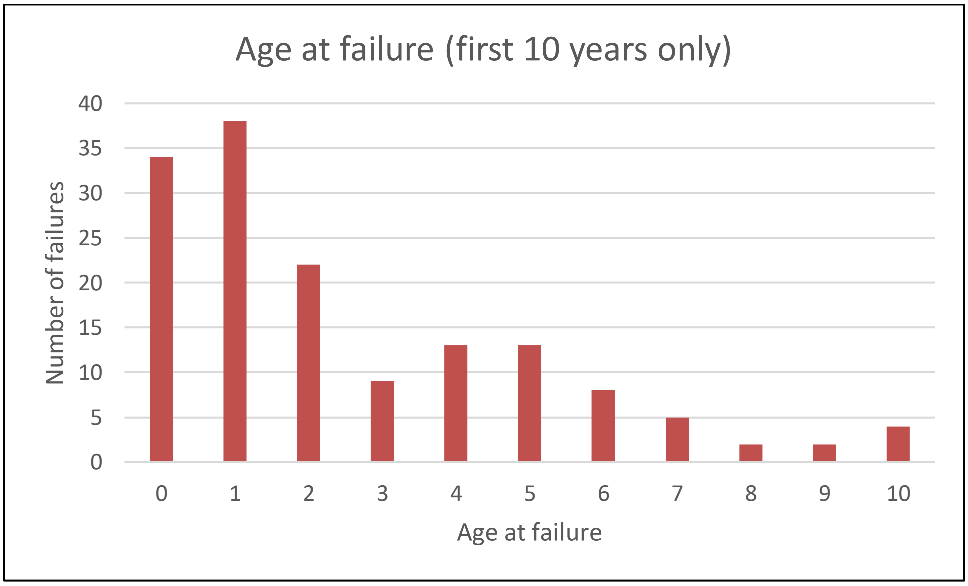

Figure 5-2 : Age at failure – zoom on the first 10 years

6. Failures <-> Dam height

This analysis is easier when considering height range instead of absolute height values. The table below gives the height range definition and the number of existing and failed dams:

Height range	Existing dams	Failed dams	Ratio
< 15 m	6984	45	0.64%
15 - 30 m	18831	188	1.00%
30 - 50 m	5570	52	0.93%
50 -75 m	2218	22	0.99%
75 - 100 m	866	3	0.35%
> 100 m	761	1(*)	0.13%
Total	35230	311	0.88%

* *Vajont* Table 6-1 : Failures versus dams' height

The figure below gives the number of existing and failed dams versus their height category. It seems that for the range 15 – 75 m this ratio is quite constant at around 1%. The value for dams lower than 15 m is significantly lower. One explanation could be that failures of these smaller dams are perhaps not as well reported as for the higher dams. The more interesting lessons from this figure concern dams higher than 75 m: with a ratio of 0.35% (only 3 failures reported; Hwachon, Fort Peck and Teton dam) it seems to indicate that high dams are less prone to failure, likely because they have been well designed and built and well operated. For dams higher than 100 m only one dam is included in the statistics. But this case is the Vajont dam which did not fail or lose its structural integrity. The Vajont dam was hit by a tsunami caused by a massive landslide into the reservoir in 1963, causing more than 2000 fatalities. The dam structure is still standing, with minor damages to the dam crest, but it has not been in operation since the accident as the reservoir is filled with landslide material.

In conclusion it could be stated that the failure ratio of large dams is quite independent of the dam height for heights ranging from 15 to 75 m (same conclusion as Bulletin 99). For higher dams this ratio is rapidly decreasing, and is ~ 0 for dams higher than 100 m.

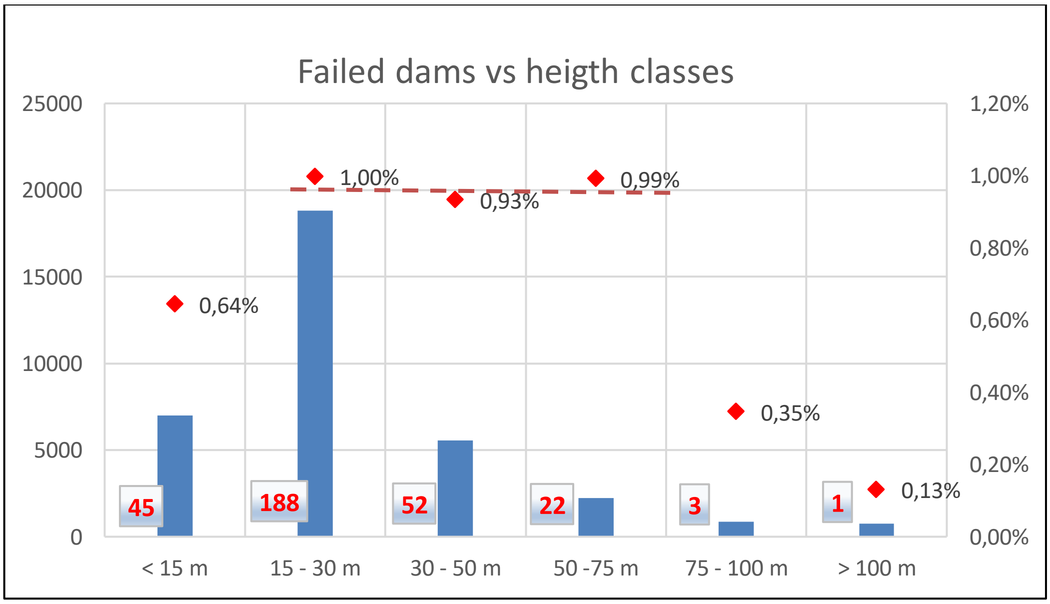

Figure 6-1 : Failures versus dam height

7. Failures <-> Dam type

Analysing the influence of the dam type on the failure ratio is simple if only one dam type is specified. For composite dams the choice has been to keep only the first type indicated in the WRD and in the dam failure database; it means for example that a PG/TE (Gravity/Earthfill) dam will be considered as a gravity dam.

Dam type	Existing dams	failed	ratio
VA - Arch	890	6	0.67%
CB - Buttress	340	8	2.35%
MV - Multi Arch	105	4	3.81%
PG - Gravity	5571	46	0.83%
ER - Rockfill	2378	33	1.39%
TE - Earthfill	21977	209	0.95%
BM - Barrage	224	0	0.00%
XX - Unknown	715	5	0.70%

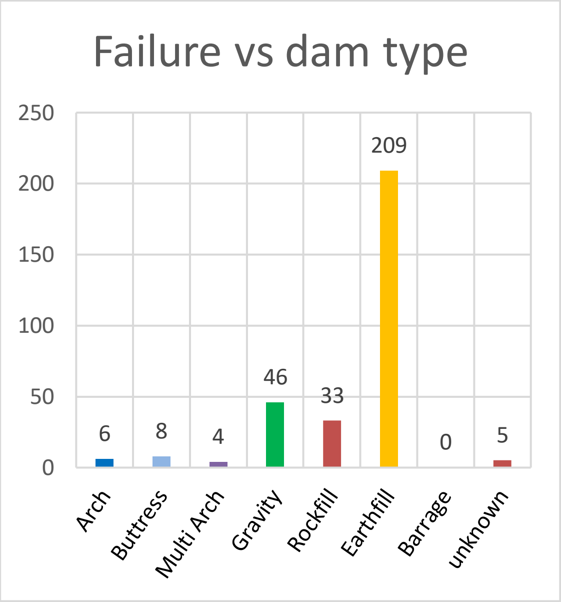

Table 7-1 : Failure versus dam type

The ratio seems very similar (failure rate between 0.8% and 1.4%) except for buttress and multi arch dams which are much higher (2.35% and 3.81%). But these values are relative to a small number of failures and are perhaps not statistically significant. The rockfill dam's failure ratio at 1.43% is therefore the higher ratio. For the gravity dams, masonry gravity dams stand for 2/3 of the reported failures.

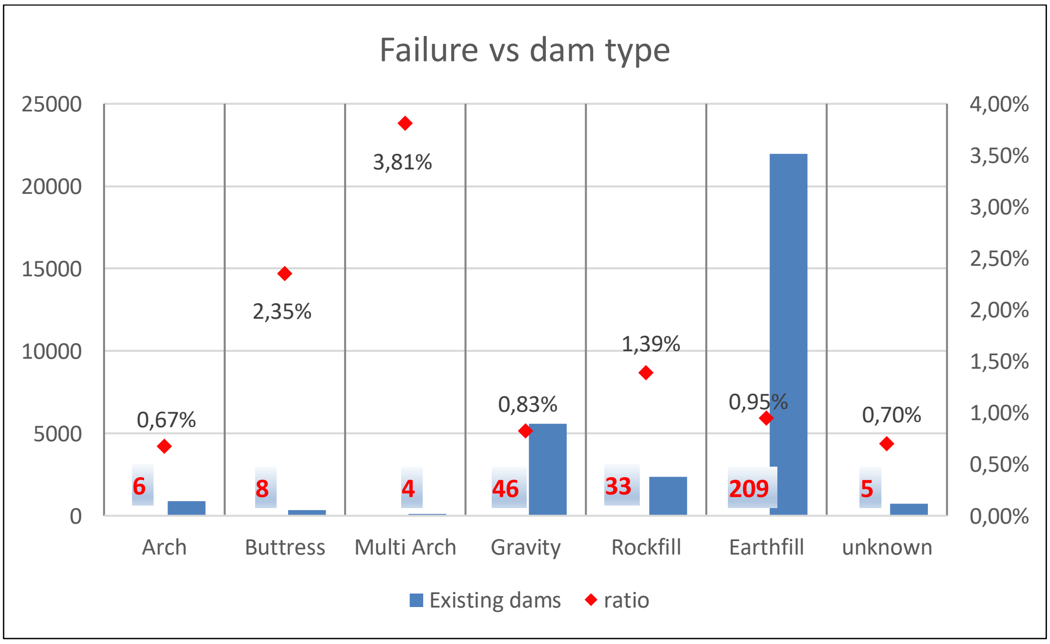

Figure 7-1 : Failure versus dam type

The repartition of the failures according to the dam type and the year of failure is shown in the Figure 7-2.

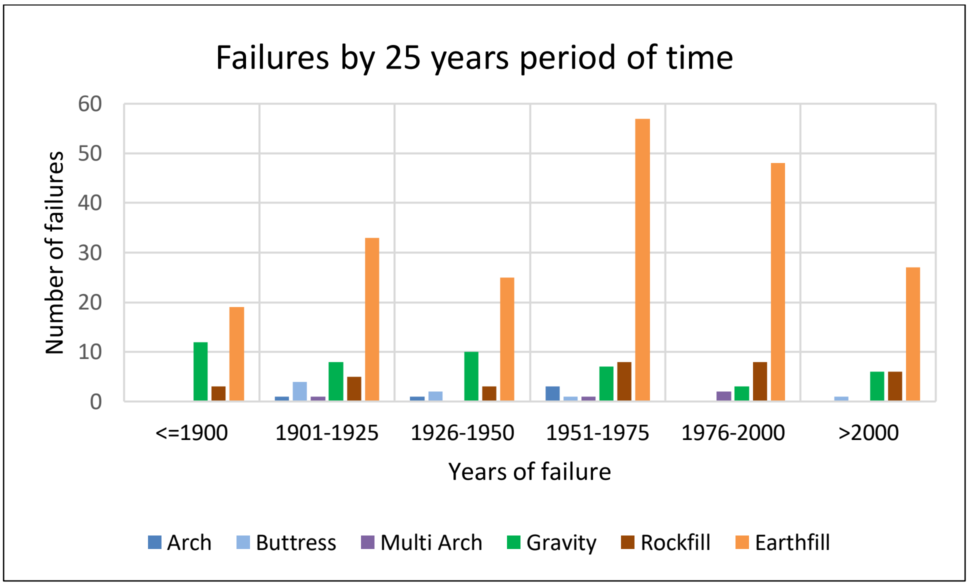

Figure 7-2: Failures sorted by failure period and dam type

The age of the dams at failure can also be compared to the dam types, as illustrated in the figure below:

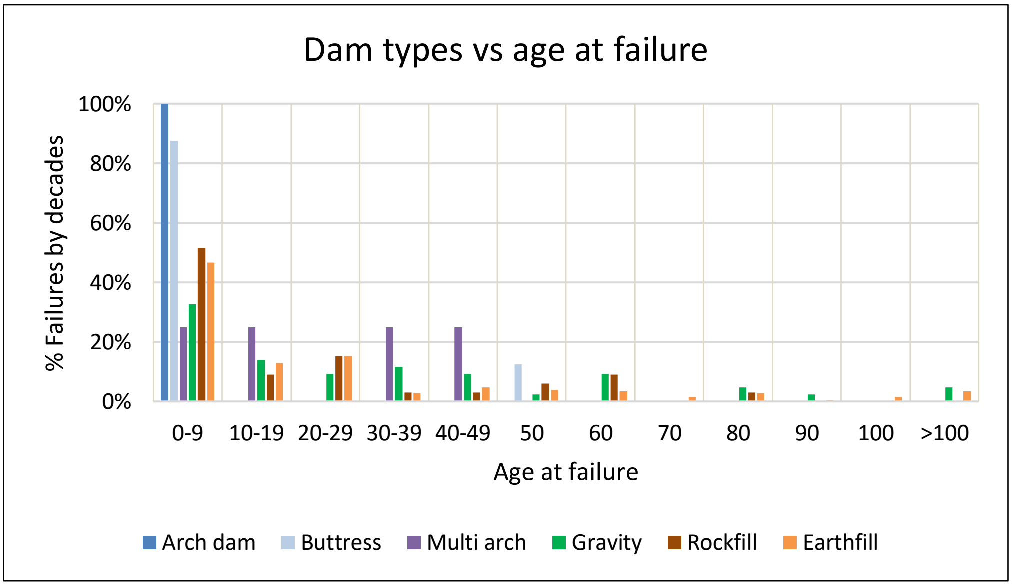

Figure 7-3: Dam type versus age at failure

As already noted, the larger number of failures happen during the first decade for all types of dams. However, the failures of all arch dams and all buttress dams have occurred during the first decade. For multi arch dams the failure seems indifferent to the age of the dam. For gravity dams, masonry gravity dams stand for 2/3 of the reported failures. The detailed repartition of these failures of gravity dams versus their year of construction and their material (masonry or concrete) is presented in the Figure 7-4

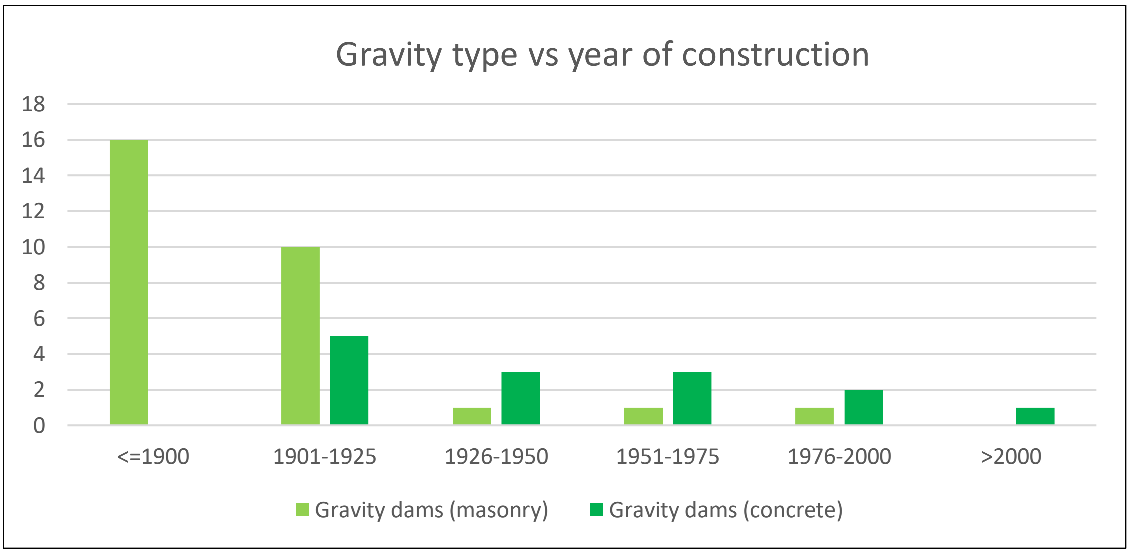

Figure 7-4: Failures of gravity dams according to their material (masonry or concrete)

The conclusion about the influence of the type of dams on their failure’s ratios is the same as in the bulletin 99: there is no significant effect of dam type on the failure ratio, except perhaps for rockfill dams with a somewhat larger failure ratio. There are too few failures of multiple arch dams and buttress dams to be statistically significant.

8. Failures <-> Reservoir volume

The number of failed dams according to their reservoir volume ranges is shown in the Figure 8-1 below.

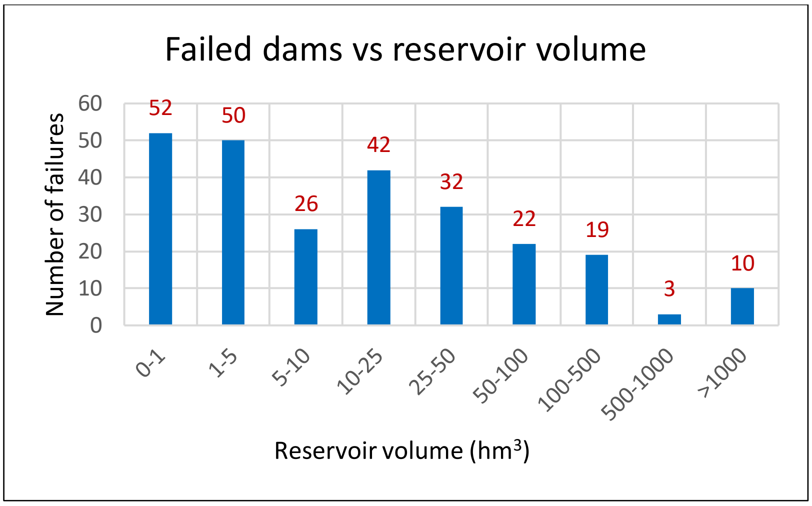

Figure 8-1 : Failures versus reservoir volume

The Table 8-1 and the Figure 8-2 give the number of failures by reservoir volume range and the failure ratio versus the number of existing reservoirs of the same volume range :

Reservoir volume range (hm^3)	Existing dams	Failures	Ratio
0-1	9474	52	0,55%
1-5	9980	50	0,50%
5-10	3527	26	0,74%
10-25	3340	42	1,26%
25-50	1836	32	1,74%
50-100	1518	22	1,45%
100-500	2291	19	0,83%
500-1000	551	3	0,54%
>1000	1143	10	0,87%

Table 8-1 : Failures versus reservoir volume

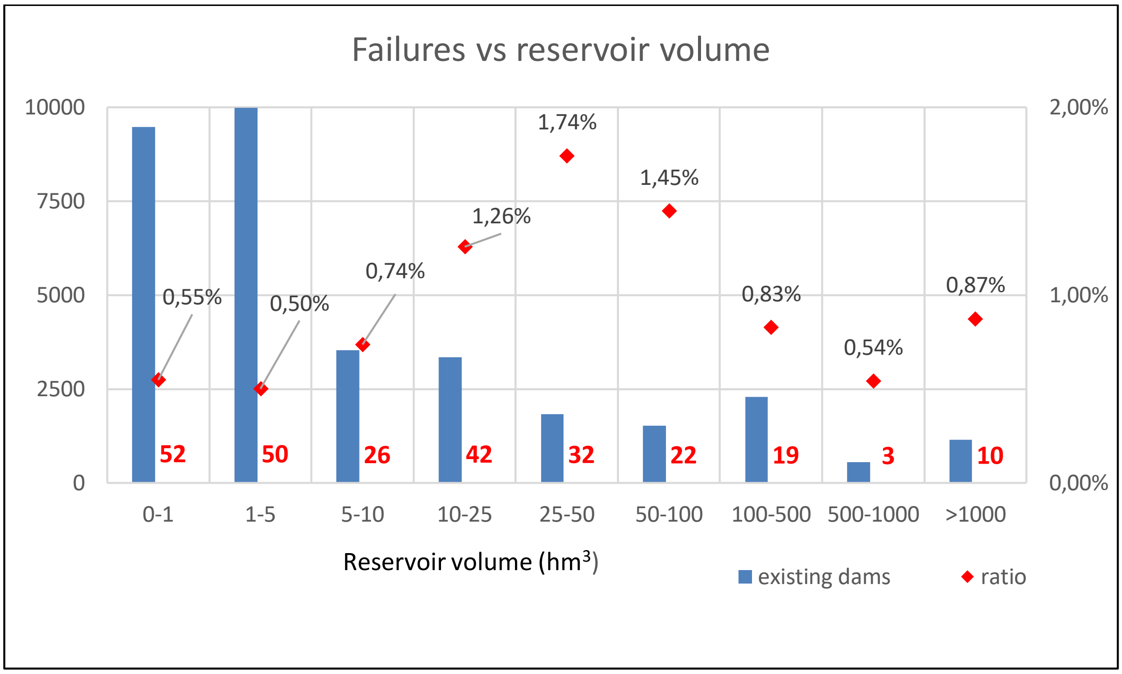

Figure 8-2 : Failure number versus reservoir volume and ratio with existing dams

These statistics indicate that the dams with a reservoir volume between 10 and 100 hm^3 have a higher failure ratio than the smaller or larger ones. But this may likely indicate lack of reporting on failures for dams with smaller reservoirs.

9. Failure context

Several contexts of failure have been considered in the data base: normal condition, flood (unusual or extreme), earthquake (unusual or extreme), other natural hazards (unusual or extreme) and hostile human actions. The table below gives the number of contexts of these different categories.

Normal operation condition	Flood (*)	Unusual Flood	Extreme Flood	Unusual Earth-quake	Extreme Earth-quake	Other unusual natural event	Other extreme natural event	Hostile Human action	Un-known
110	40	59	33	4	3	2	2	6	52

** Flood magnitude not specified*

Table 9-1 : Failure contexts repartition

It is obvious that the two most important contexts are the normal operation (110 failure cases) and the flood condition (132 failure cases), the figures of which are similar, and represent more than 90% of the total of the known failure contexts. However, flood context is the more important. It is interesting to note that the number of failures during “unusual” flood (i.e. below the design flood) is more important than during “extreme” flood (i.e. above the design flood). This last ascertainment is not surprising as unusual floods occur far more often than extreme floods. And also; the design flood from the original year of construction may in many cases be underestimated, so the dams and spillways are in reality below present standard. In addition, some dams have experienced malfunctioning of spillways which also causes damages and possible failures during “moderate floods”.

In Figure 9-1 and Figure 9-3 a more detailed analysis can be done by examining the influences of three parameters on the number of failures: the construction year, the age at failure and the types of dam.

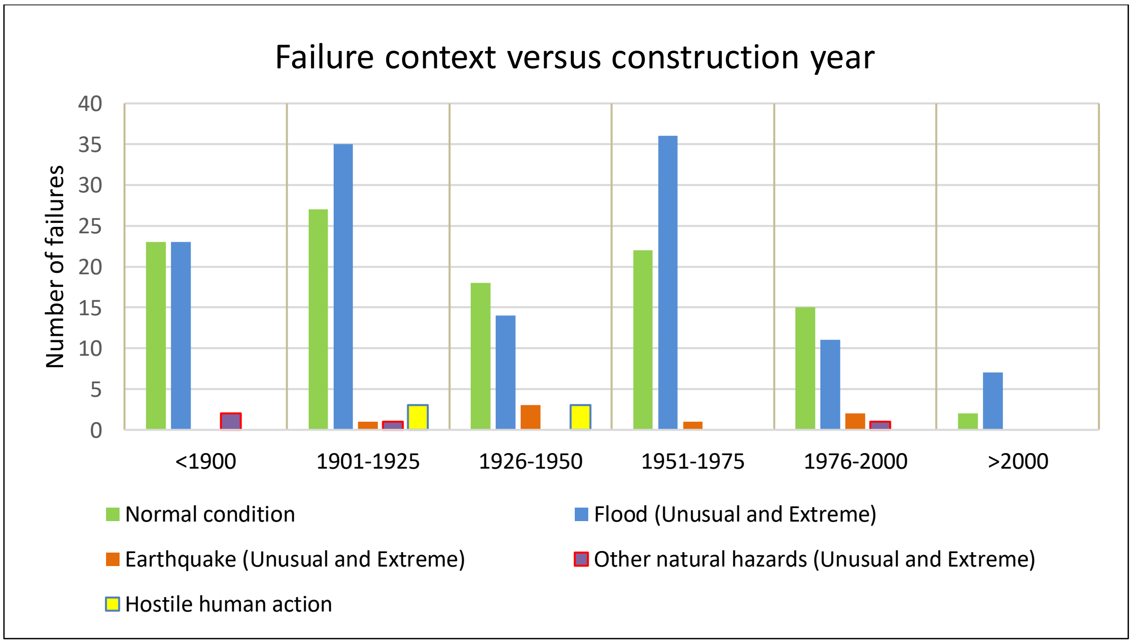

Figure 9-1 : Failures context versus construction year

As given in Figure 9-1 the construction year has not a significant influence on the repartition between normal operation and flood failure contexts: these two main failure contexts are the more important for each construction year periods.

Figure 9-2 below gives a focus on the failures during flood: the ratio between unusual and extreme floods is always lower than 1 except during the construction period 1925-1950. On the contrary this ratio is the lowest for the dams built after 2000. It can be noted than until the 1950ies the ratio of embankment dams among all other dam types was slightly below 50%. This situation changed very quickly after 1950 when more large dams were made as embankment dams because of the development of construction equipment/technology. So, the population of dams constructed before 1950 were, on average, more robust against overtopping.

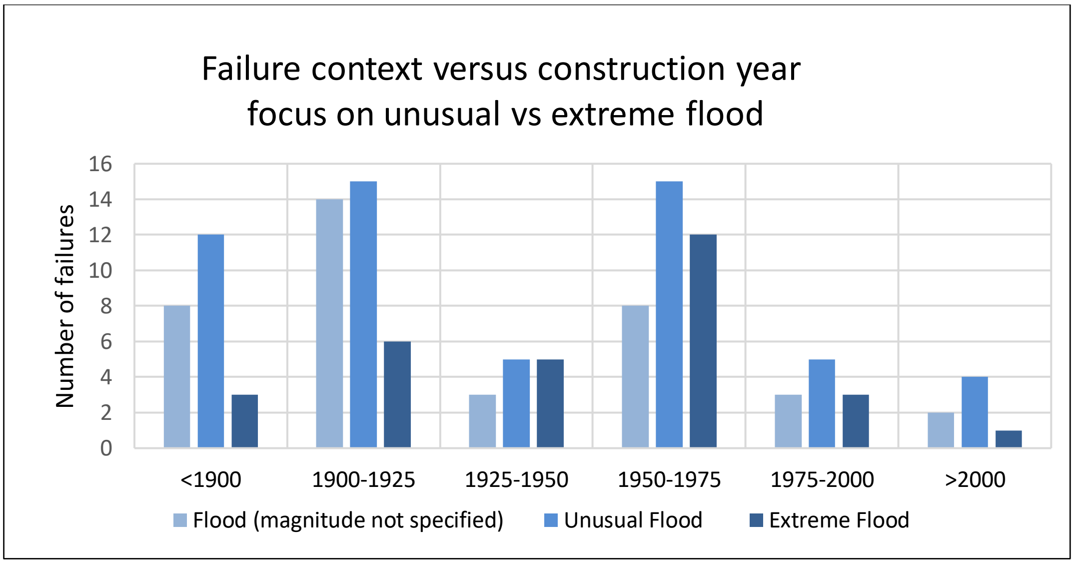

Figure 9-2 : Flood failure context versus construction year

Looking at the distribution of the failure contexts versus the age of the dams at the time of the failure, as given in Figure 9-3, it is interesting to note that the "flood" context becomes the main context as soon as the age of the dam is 20 years or older. The “negative” ages stand for failure during construction.

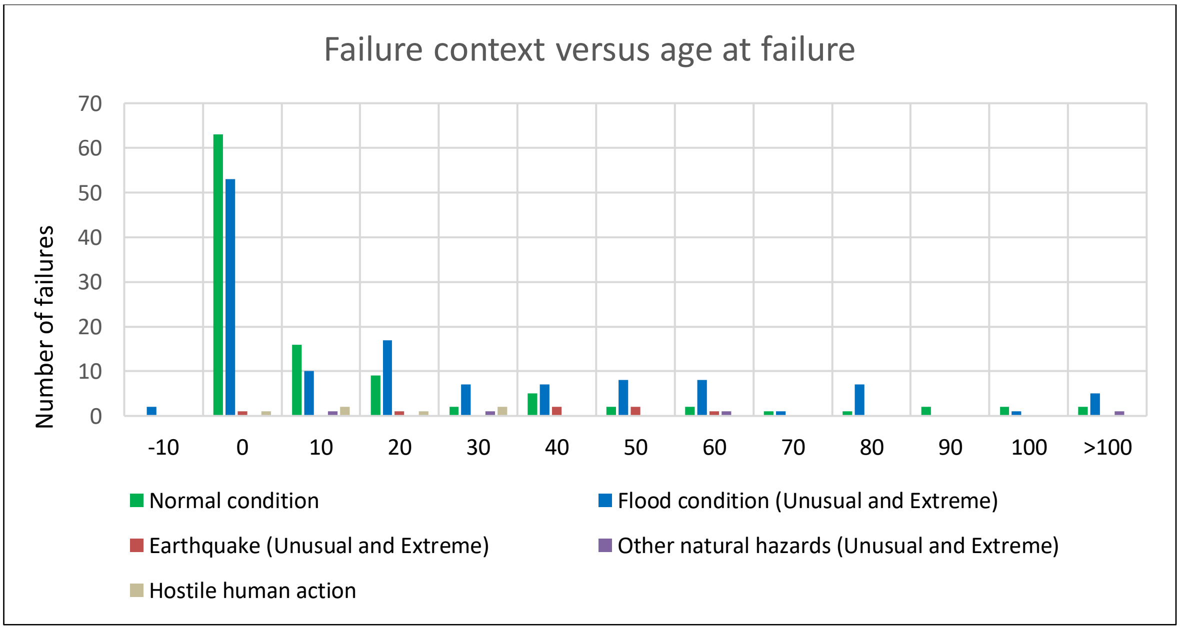

Figure 9-3 : Failure context versus age at failure

Looking at the influence of the dam type, the flood contexts are the more important for earthfill, rockfill and gravity dams while the normal operation condition is the major context identified for buttress and arch dams. Figure 9-4 illustrates once more the significant number of failures of embankments dams. Masonry gravity dams stand for quite 70% of the gravity type either for normal condition or flood events contexts.

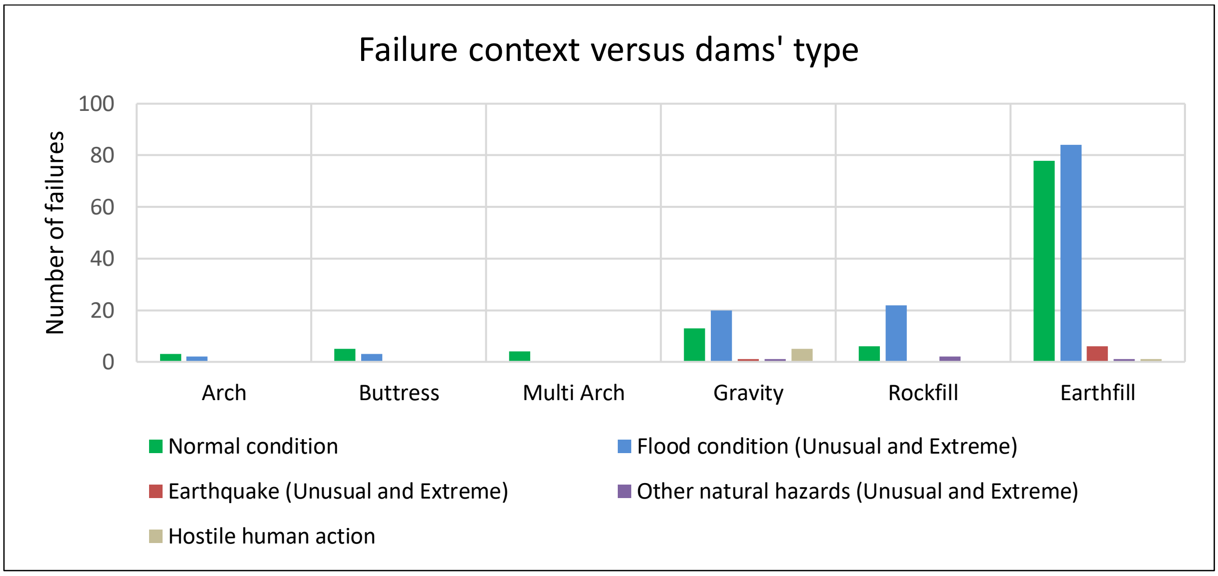

Figure 9-4 : Failure context versus type of dams

10. Failure modes

The failure modes according to the types of dams are presented in the Figure 10-1 with a focus on gravity dams in Figure 10-12. A more detailed analysis of the failure modes is done in sections 10.1 and 10.2, for embankment dams and rigid dams.

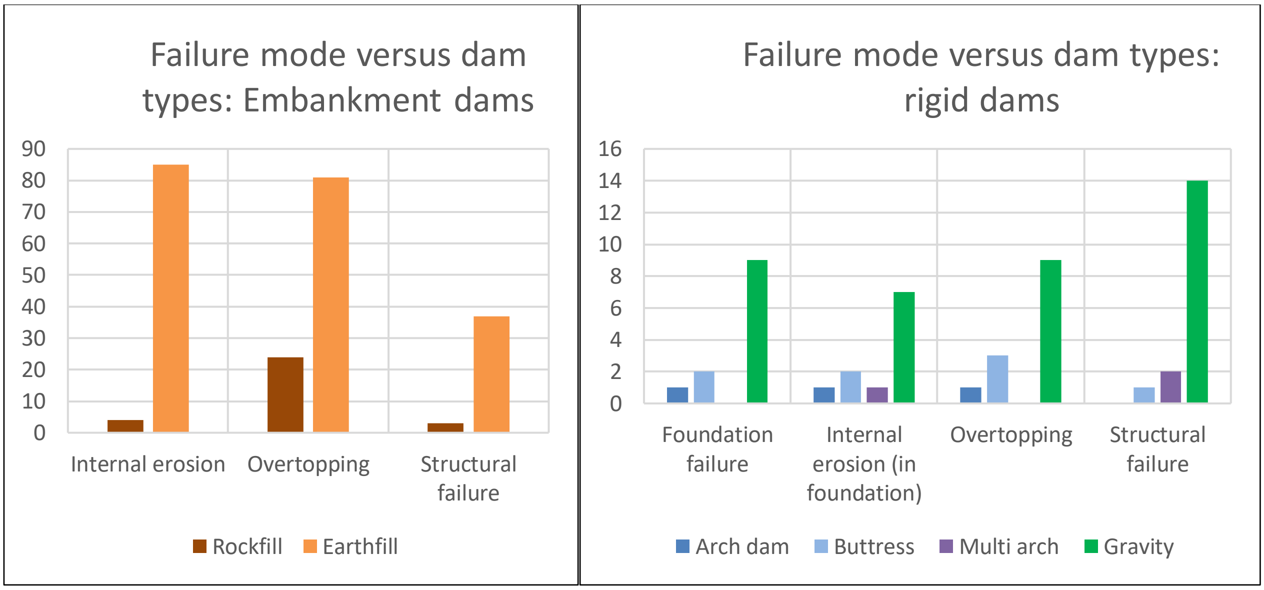

Figure 10-1: Number of failures according to the dam type and the failure mode

10.1. Embankment dam failures

In this section the rockfill and earth fill (ER and TE) dam failures are analysed. The failure mode analyses are done separately for the effect of a) year of construction, b) age at failure and c) context.

10.1.1 Failure mode <-> Construction year

Total number of failures for embankment dams is 232.

The results related to construction year category and failure mode are shown in the Table 10-1 and Figure 10-2 below.

Failure mode (embankment dams)	Year of construction						
	<=1900	1901-1925	1926-1950	1951-1975	1976-2000	>2000	Total
Internal Erosion	18	20	11	16	12	3	80
Overtopping -Ext Erosion	22	22	11	30	11	5	101
Structural Failure	8	9	12	12	5		46
Unknown	2			2		1	5
Total	50	51	34	60	28	9	232

Table 10-1 : Embankment dam failures per year category and failure mode

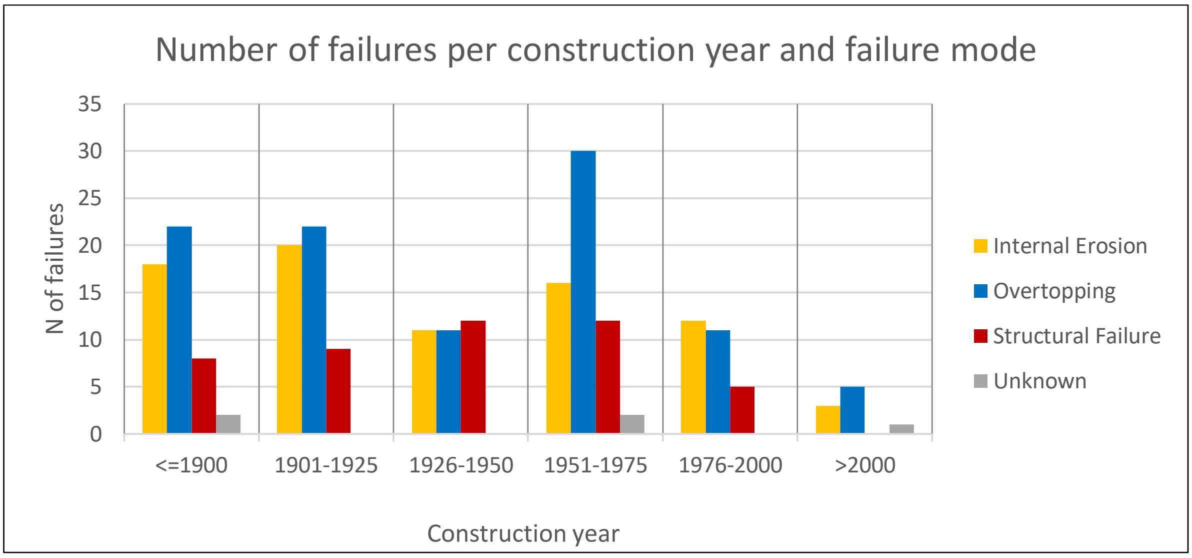

Figure 10-2 : Embankment dam failures per year category and failure mode

Figure 10-3 shows the ratio of the failures versus the total number of embankment existing dams (from the World register of dams) per construction year category as given below:

Year of construction	<=1900	1901-1925	1926-1950	1951-1975	1976-2000	>2000
WRD number of existing embankment dams	1177	990	1774	8538	9034	1747

Table 10-2: Number of existing embankment dams

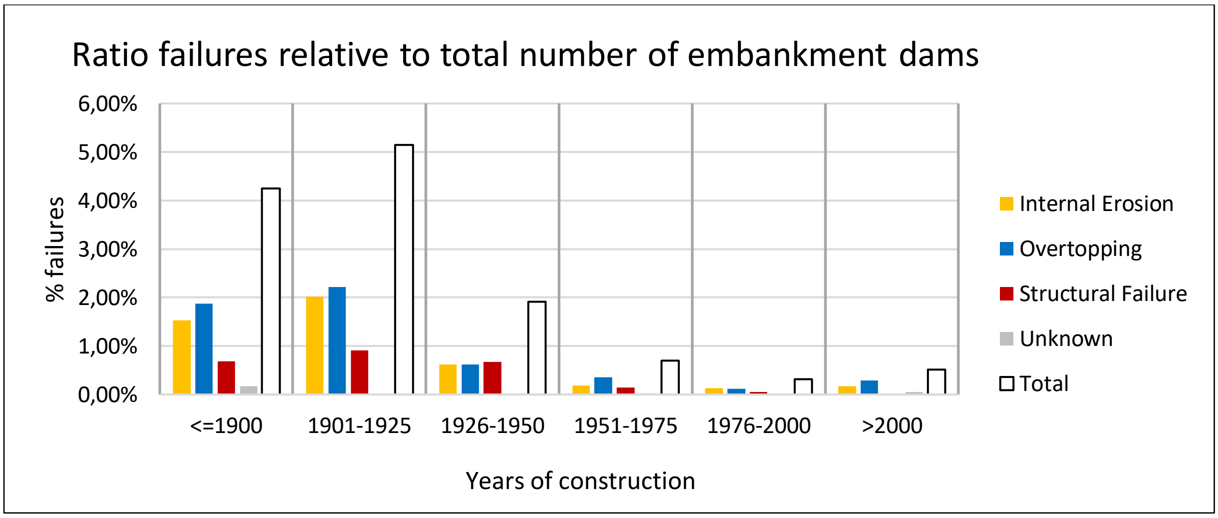

Figure 10-3 : Embankment dam failures in % of total fill dams in the world categorized by failure mode and year of construction of the dam

This leads to the following conclusions:

- In absolute numbers overtopping and internal erosion are the most frequent failure modes
- In the periods later than 1950 the relative number of failures drops to less than 0.2% but increases again in the period beyond 2000.

Detailed analysis shows that Internal erosion can be divided in several subcategories as indicated in Figure 10-4

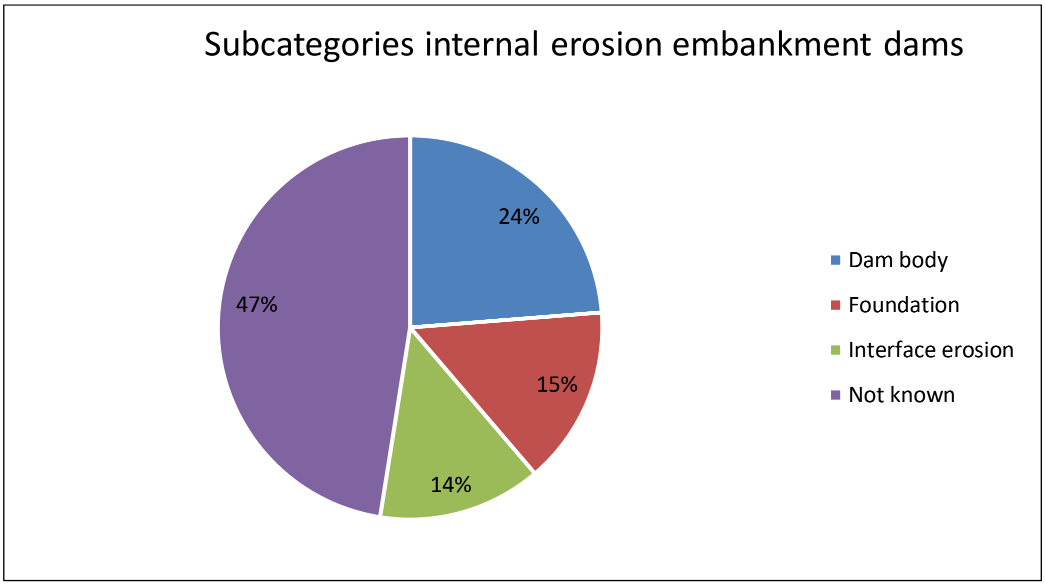

Figure 10-4: Embankment dams failures subcategories Internal erosion

Structural failure can also be divided in several subcategories as shown in Figure 10-5 showing that structural failure of the dam body is the most important one.

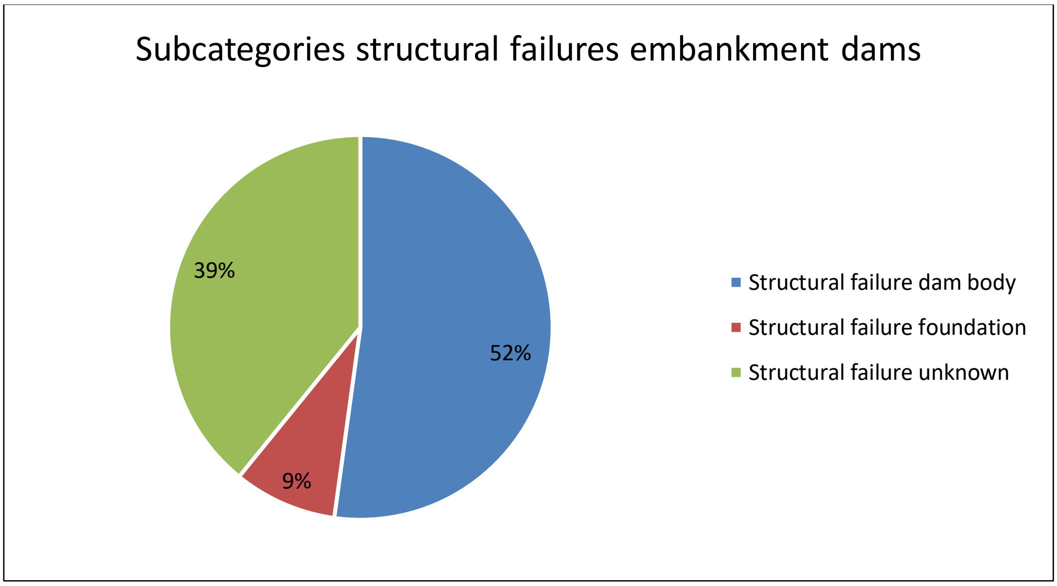

Figure 10-5: Embankment dam failures subcategories structural failure

10.1.2 *Failure mode <-> Age at failure*

- To analyse the failure mode and age of the dams, the same data is used as described in 10.1.1. However, two dams failed during construction and they were omitted from the data. The total number of failures is then 200.
  The results are shown in Table 10-3 below.

Failure mode	Age at failure (years) embankment dams											
	0	10	20	30	40	50	60	70	80	90	100	>100
Internal Erosion	46	14	7		4	2	3		1		2	1
Overt. -Ext Erosion	41	10	16	4	4	5	6	3	4		1	5
Structural Failure	21	4	7	3	3	3	1		2	1		1
Unknown	4		1									
Total	112	28	31	7	11	10	10	3	7	1	3	7

Table 10-3: number of failures versus age at failure and failure modes

Figure 10-6 shows the number of failures per age decade and the failure mode.

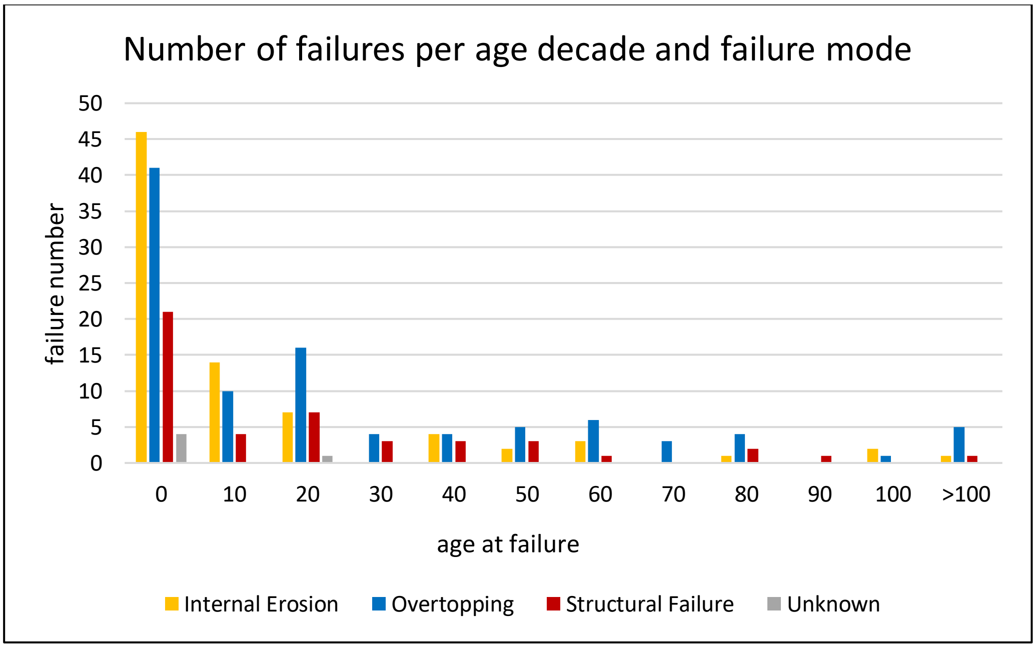

Figure 10-6 : Number of embankment failures categorized by failure mode and age at failure

This leads to the following conclusions:

- In the first years after construction (0-10 years) most failures occur. The largest contributions come from internal erosion and overtopping.
- A clear decrease is visible after 30 years
- The number of failures strongly decreases when dams get older, but overtopping remains a risk.

10.1.3 *Embankment dams' failure mode <-> Incident context*

In Table 10-4 below and Figure 10-7 the results are shown:

	Incident Context					
Failure Mode (embankment dams)	Normal condition	Flood Condition	Earthquake condition	Other Extreme Load	Unknown	Total
Internal Erosion	57	12	0	1	16	86
Overt. -Ext Erosion	3	88	0	0	18	109
Structural Failure	24	7	8	2	7	48
Unknown	1	1	0	0	3	5
Total	85	108	8	3	44	248

Table 10-4: Failure modes versus incident context

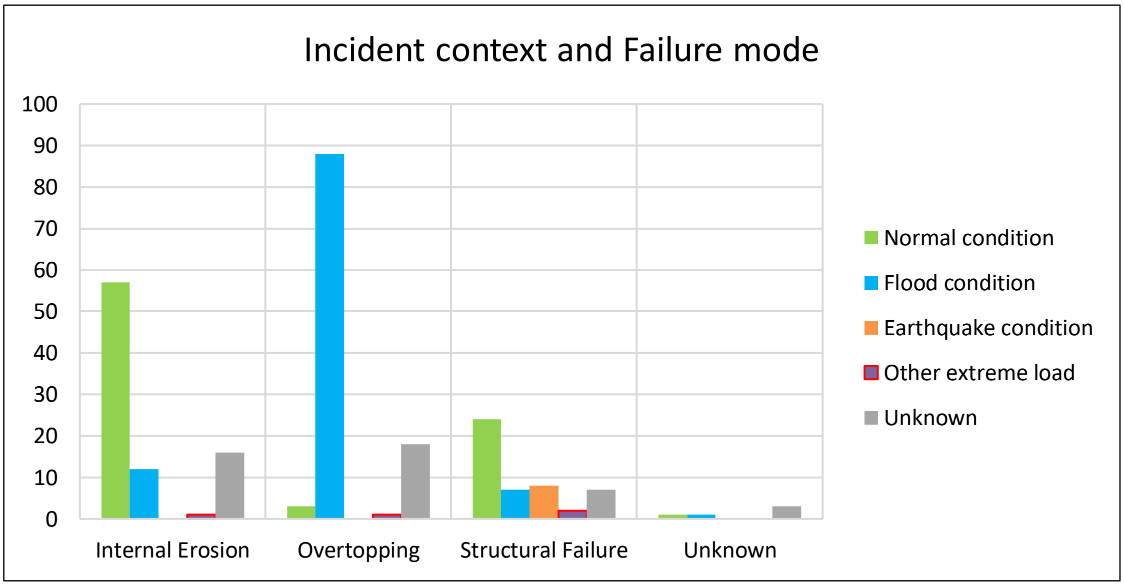

Figure 10-7 : Number of embankment dam failures categorized by failure mode and incident context

Conclusions:

- Most failures occurred due to Overtopping during Flood condition
- Internal erosion occurred most in combination with Normal condition
- Structural failure occurred most in Normal condition but also with all other conditions

10.1.4 Failure mode analysis conclusions

- In general Overtopping and Internal Erosion are the most common Failure modes
- Related to year of construction
  - Decrease of failure ratio after 1950
  - Small increase of failure ratio after 2000
- Related to age
  - Most failures occur in the first years
  - For dams older than 30 years a low number of failures have occurred, apart from overtopping which remains at a stable level
- Failure mode related to Incident context
  - Overtopping mostly in combination with flood conditions
  - Internal erosion mostly in combination with normal conditions
  - Structural failure occurs in all loading conditions

10.2. Concrete and Masonry dams

In this part the concrete and masonry dam failures are analysed. Dams built of concrete, stone, or other masonry are called “rigid dams”, including gravity, (multiple)arch and buttress dams. For the failure mode a separate analysis is done for the effect of a) year of construction, b) age at failure and c) context.

It should be noted that for rigid dams the “Internal Erosion” failure mode is always related to a foundation deficiency, while “Foundation Failure” addresses the structural failures inside the foundation.

10.2.1 Failure mode <-> Construction year

Total number of failures for rigid dams is 59.

The results related to construction year category and failure mode are shown in the Table 10-5 and Figure 10-8 below.

Failure mode	Construction year							
	<=1900	1901-1925	1926-1950	1951-1975	1976-2000	>2000	Total #	%
Foundation failure	5	1	1	1	1	1	10	17%
Internal erosion (in foundation)	3	5	4	2	1	0	15	25%
Overtopping	2	8	0	4	0	0	14	24%
Structural failure	5	6	1	3	1	0	16	27%
Unknown	2	2	0	0	0	0	4	7%
Total #	17	22	6	10	3	1	59	100%

Table 10-5 : Number of failures vs the failure mode and the construction period

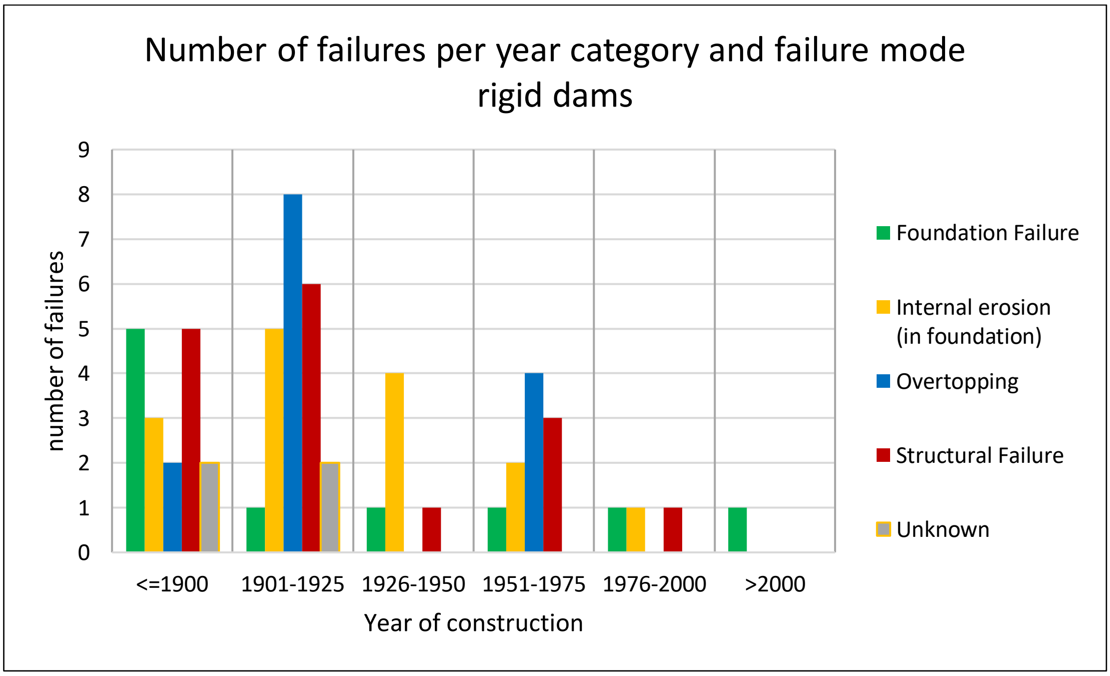

Figure 10-8 : Concrete and masonry dam failures per year of construction and failure mode

Table 10-6 gives the total number of existing rigid dams per year category from World Register of Dams and Figure 10-9 shows the ratio of the failures:

Construction year	<=1900	1901-1925	1926-1950	1951-1975	1976-2000	>2000
Number of existing rigid dams from WRD	168	661	1215	2675	1501	657

Table 10-6: Total number of existing “rigid” dams

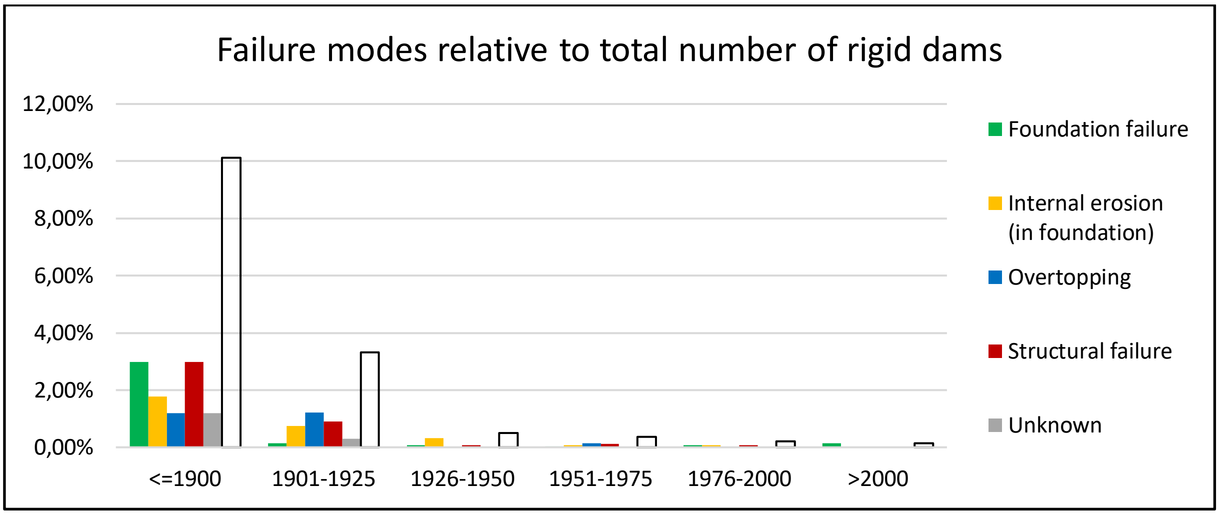

Figure 10-9 : Failure modes of rigid dams in % of total number of existing dams categorized per year of construction of the dam

From the data and figures the following conclusions can be drawn:

- In absolute numbers the period before 1900 and from 1901 till 1925 has the most failures, but relative to the number of rigid dams completed in these periods the period before 1900 clearly has most failures.

10.2.2 *Failure mode <-> Age at failure*

To analyse the failure mode and age of the dams, the same failure modes are used as earlier described in 10.1.2. The results are shown in the Table 10-7 below and Figure 10-10. The total number of failures is 59 and a clear decrease is visible after the first decade.

Failure Mode	Age at failure (decades)											Total/ Mode	%
	0	10	20	30	40	50	60	70	80	90	>100		
Foundation failure	8	0	0	1	0	0	0	0	0	0	1	10	18%
Internal erosion (in foundation)	8	2	1	0	1	0	0	0	1	0	1	14	25%
Overtopping	5	1	1	1	1	1	2	0	1	0	0	13	23%
Structural failure	4	3	2	3	2	0	1	0	0	1	0	16	29%
Unknown	1	0	0	0	0	1	1	0	0	0	0	3	5%
Total/Decade	26	6	4	5	4	2	4	0	2	1	2	59	100%

Table 10-7: Rigid dams failure modes versus age at failure

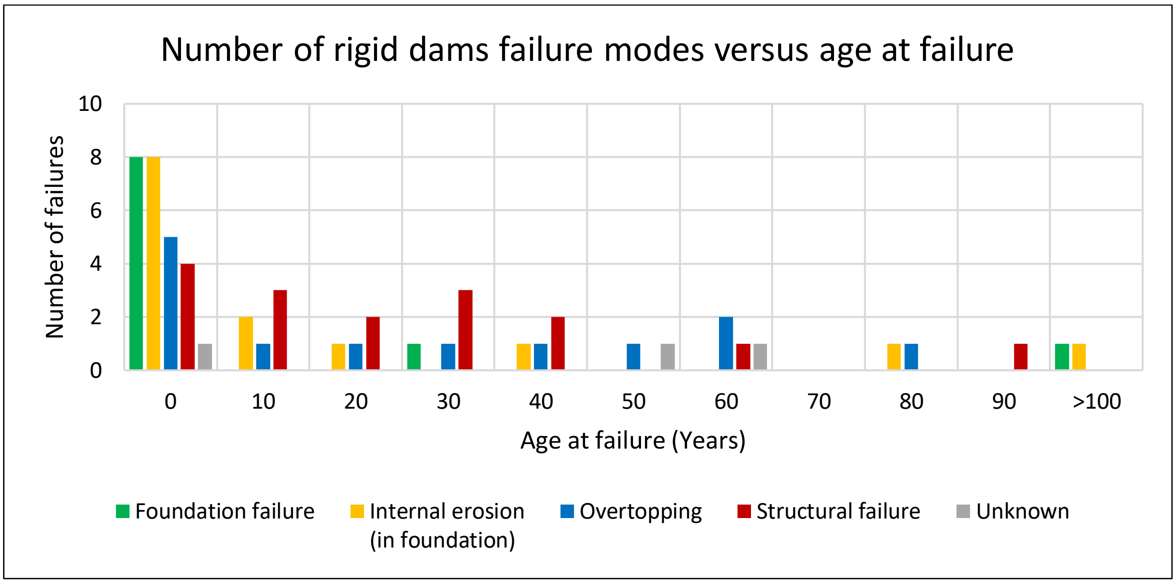

Figure 10-10: Number of rigid dams' failures categorized by failure mode and age at failure

From the graphs the following conclusions can be drawn:

- Overall most failures are linked to the foundation (43%, foundation failure and internal erosion in foundation), followed by structural (29%) and overtopping (23%).
- Most failures occur in the first decade (46%).

Further analysis of the first decade failures shows that most failures occurred at gravity dams and are linked to foundation deficiencies (see Figure 10-11), caused by Loss of support (foundation or abutment) or internal erosion (in foundation).

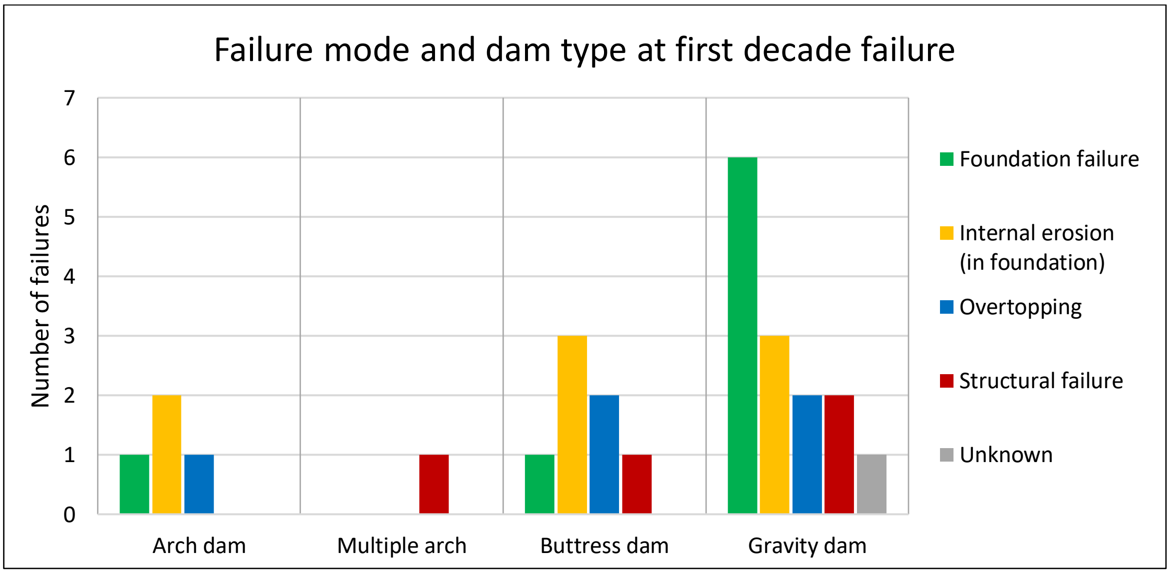

Figure 10-11 : Rigid dams failures in the first 10 years after construction by failure mode and dam type

- Concerning the gravity dams type (concrete or masonry) and their failure modes the Figure 10-12 shows that there are no differences between these two types of gravity dams for all failure modes except for structural failures which concerns much more the masonry dams (86% of this failure mode).

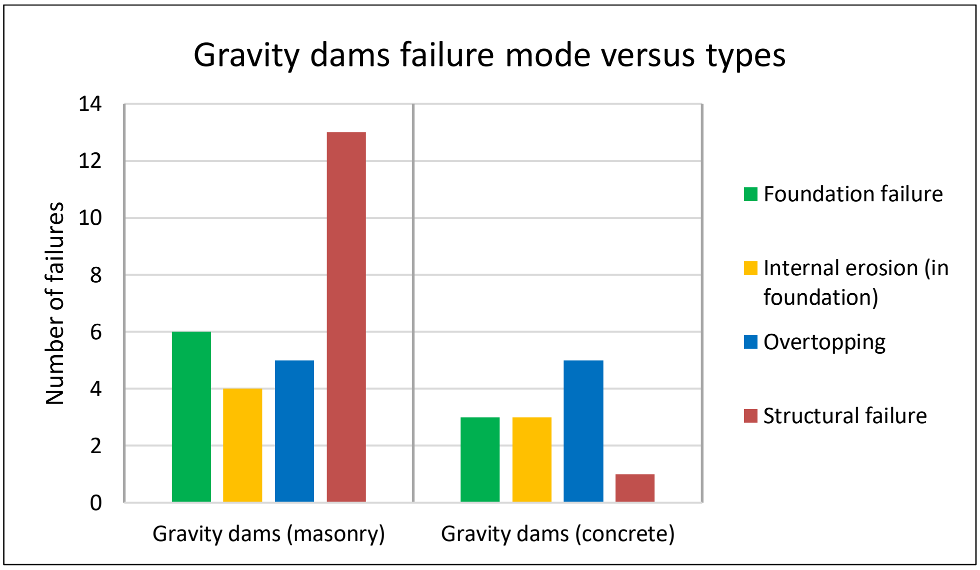

Figure 10-12: Number of failures according to the gravity dams type and the failure modes

10.2.3 Failure mode <-> Incident context

In Table 10-8 below and Figure 10-13 the results are shown:

Failure mode	Normal condition	Flood condition	Earthq. condition	Other extreme load	Hostile human action	Unknown	total	%
Foundation failure	5	2	1	1	0	1	10	17%
Internal erosion (in foundation)	11	2	0	0	0	2	15	25%
Overtopping	0	14	0	0	0	0	14	24%
Structural failure	6	6	0	0	4	0	16	27%
Unknown	0	1	0	0	0	3	4	7%
Total	22	25	1	1	4	6	59	100%

Table 10-8: Number of failures by failure modes versus incident context

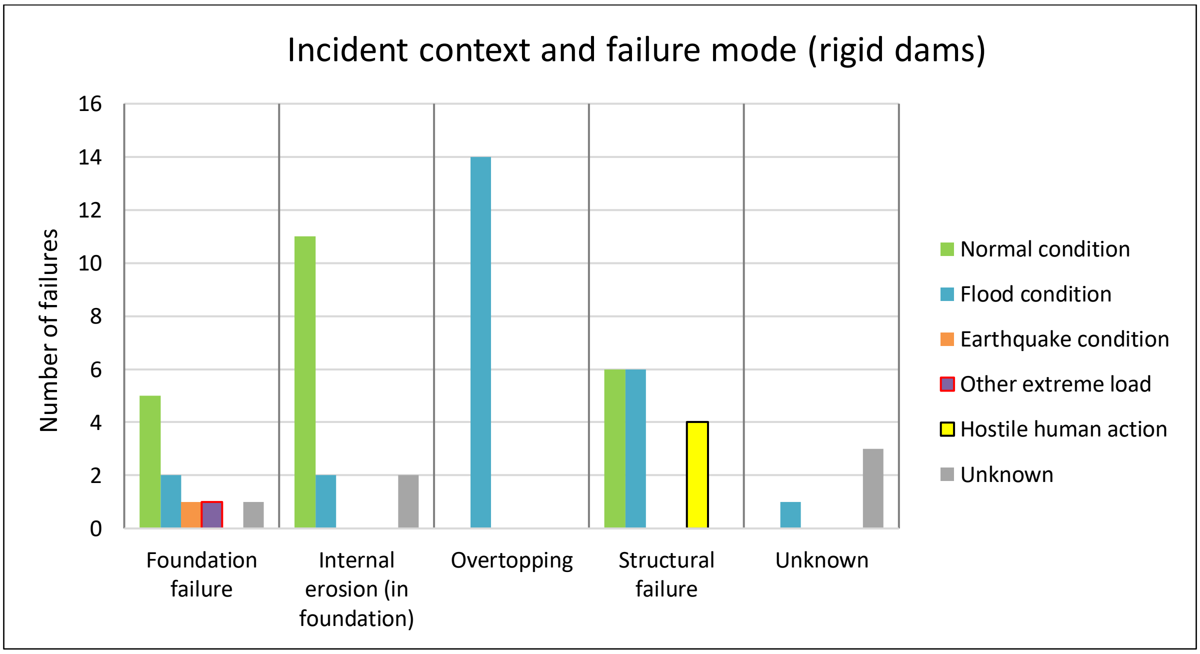

Figure 10-13 : Incident context and Failure mode for rigid dams

From the Figure 10-13 the following conclusions can be drawn:

- Foundation failure occurred 10 times and mainly in normal condition.
- Internal erosion (in foundation) failure occurred frequently (overall 15x, 25%) and mostly in normal condition (11x) and only twice during flood condition. In two cases the condition was unknown.
- Overtopping/external erosion failure occurred frequently (14x, 24%), but only during flood condition, which is logical.
- Structural failure occurs 16 times (27%) and is distributed over different conditions (context).

10.2.4 Failure mode analysis conclusions

- Both in absolute and relative numbers most failures occurred in the foundation, either by internal erosion or by structural deficiencies.
- Related to year of construction:
  - Decrease of failures at dams built after 1925,
  - Structural failure mainly occurs at gravity dams made of masonry.
- Related to Age at failure:
  - Most failures in the first decade after construction (0-10 years),
  - After the first decade the number of failures strongly decreases.
- Related to Incident context:
  - Overtopping only in combination with flood conditions,
  - Internal erosion mainly in combination with normal conditions,
  - Structural failure mainly in normal and flood conditions.

11. Failure causes

Two categories of causes are available in the data base: organizational causes and technical causes.

11.1. Organizational causes

Organizational causes have been grouped in several main categories:

- Design: 162 cases
- Construction: 18 cases
- Operation: 27
- Maintenance: 10
- Not indicated: 105

About design and construction insufficiency it should be noted that the design and construction methods can be acceptable at the time of construction, which later proves to be insufficient due to new knowledge from research and experiences. Construction insufficiencies can be a “hidden cause” which may be very difficult to reveal after a failure. Thus, construction insufficiencies may be the cause even though it has not been reported.

In Figure 11-1 below these causes have been detailed by dam types:

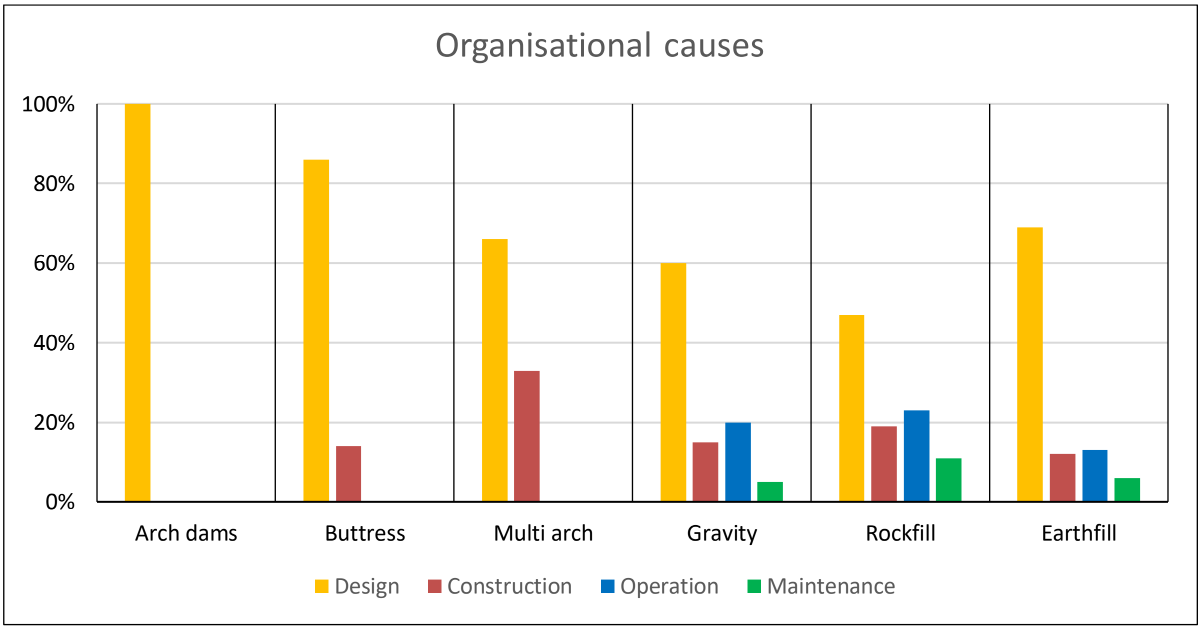

Figure 11-1 : Organizational causes versus dam types

Figure 11-1 indicates a different pattern between two dam types: for arch, buttress and multi arch dams the main cause is design (100% for arch dams), less frequently construction. The main organisational cause for gravity, rockfill and earthfill dams is always design insufficiencies but operation and maintenance stand for 19% to 34% according to the types.

The organizational causes versus the age of the dams at failure is shown in the Figure 11-2:

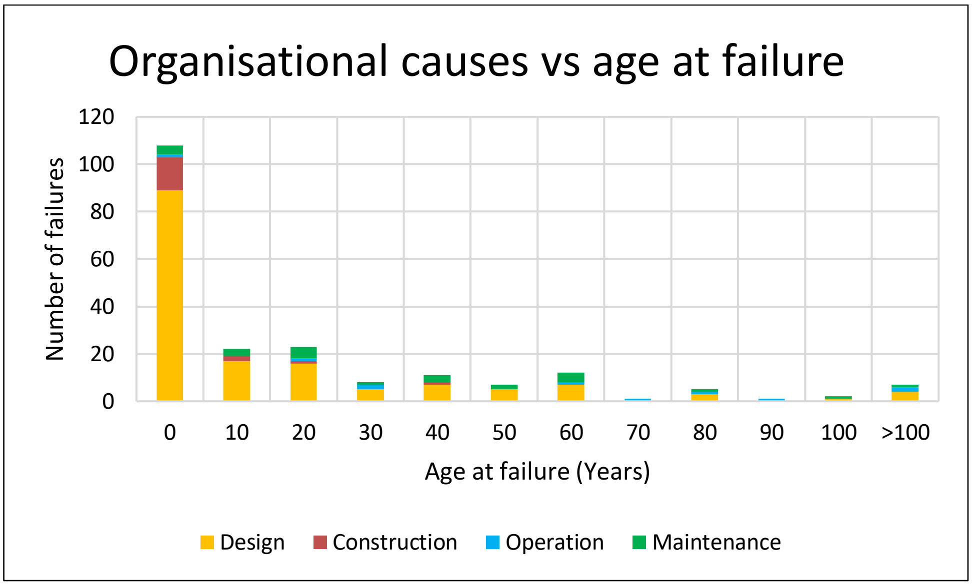

Figure 11-2 : Organisational causes versus age at failure

Design insufficiencies are the main causes of failures, even after 100 years. On the contrary construction insufficiencies have an immediate effect during the first 10 years but is no more a failure cause after 40 years.

11.2. Technical causes

Technical causes have been grouped as follows (when several causes were indicated only the first one has been kept):

Geotechnical concerns	: 146 cases
Hydromechanical failure	: 10 cases
Insufficient spillway capacity (*)	: 71 cases
Material ageing	: 3 cases
Structural deficiency	: 23 cases

(*) These cases are all related to dam overtopping with three identified causes: insufficient installed capacity (40 cases), insufficient available capacity (13 cases), insufficient freeboard (5 cases) and 13 cases without precision.

Figure 11-3 below presents these technical causes versus the dam types, the first figures with the numbers of dam failures, the second one with the percentage of each technical causes per dam type (making it easier to distinguish the causes). For arch dams the only cause is the geotechnical one referring obviously to the foundation deficiencies (for example Malpasset). Gravity dams are prone to geotechnical and structural failure causes approximately at the same rate. Insufficient spillway capacity or availability also play a role. For Rockfill dams the spillway insufficiency is the more important cause of failure. And finally, for earth-fill dams the geotechnical deficiencies are logically the more important failure cause, spillway insufficiencies being the second one.

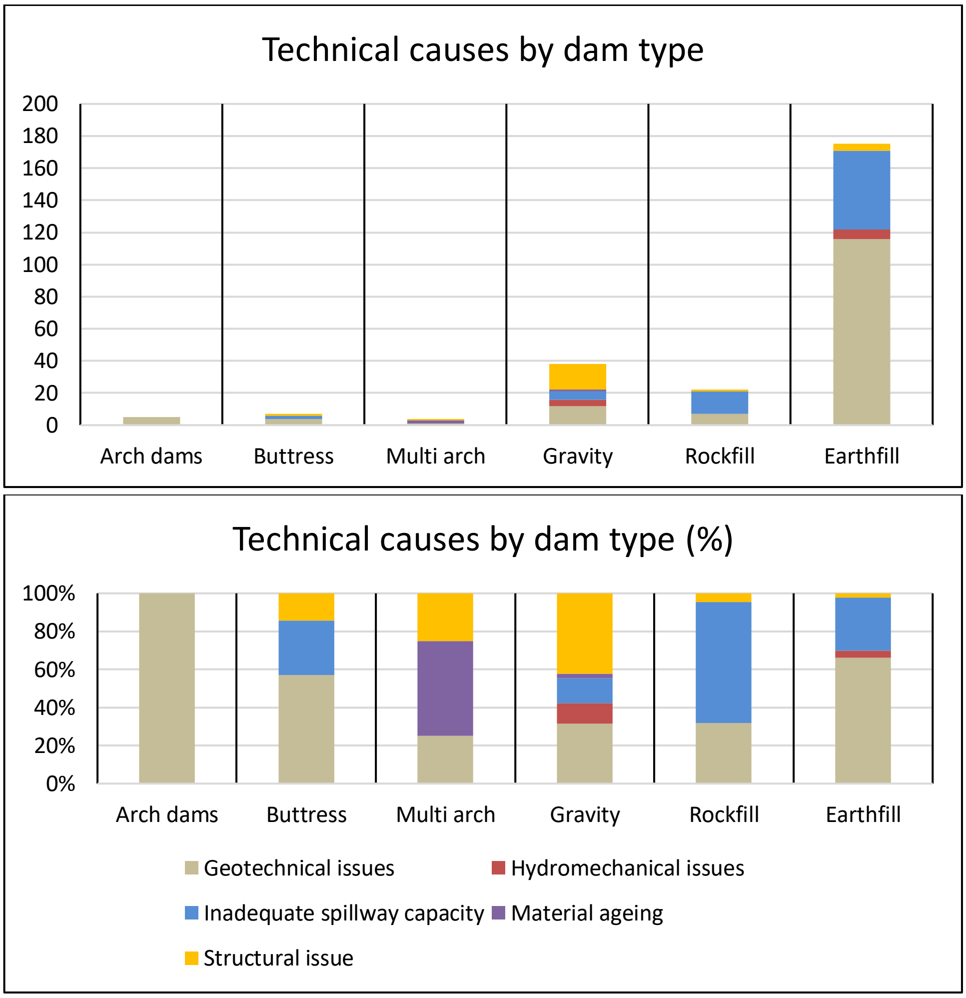

Figure 11-3 : Technical causes of failure versus dams' type in number and ratio

Figure 11-4 presents the repartition of these causes versus the year of construction.

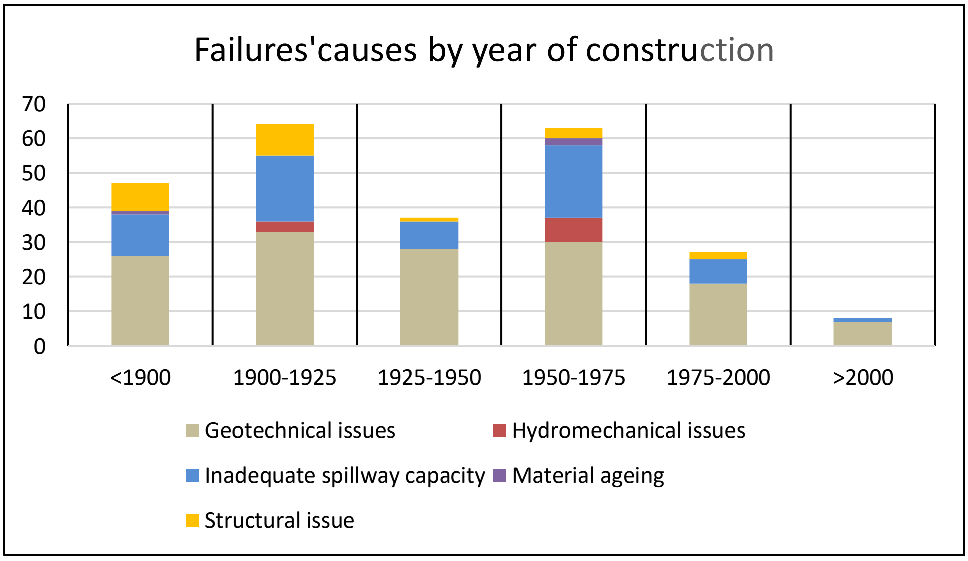

Figure 11-4 : Failures' cause by year of construction

It can be deduced from this figure that dams built before 2000 exhibit roughly the same kind of technical failure causes, with some variations between the periods but with geotechnical issues always being a main cause. For the dams built after 2000 it can be said that the main cause clearly refers to geotechnical deficiencies.

11.3. Conclusions

Looking at the failure causes versus the period of failures (Figure 11-5), three comments can be made:

- For the last period (since 2000) no structural cause was identified as a failure cause
- Inadequate spillway capacity has been an important failure cause, and its rate has been growing since the period 1975-2000 up to almost 50% of the failures' cause since 2000.
- This can be explained since many dams were originally designed for a design flood lower than required, because flood data was scarce and flood calculation methods were of "lower standard" than today (so the design floods were underestimated). In addition, in many parts of the world there is a trend that floods are increasing. On the other hand, the structural cause is nowadays less important. An explanation could be that the dams affected by serious structural problems have already failed, and that the dams built after 1975 are better designed.

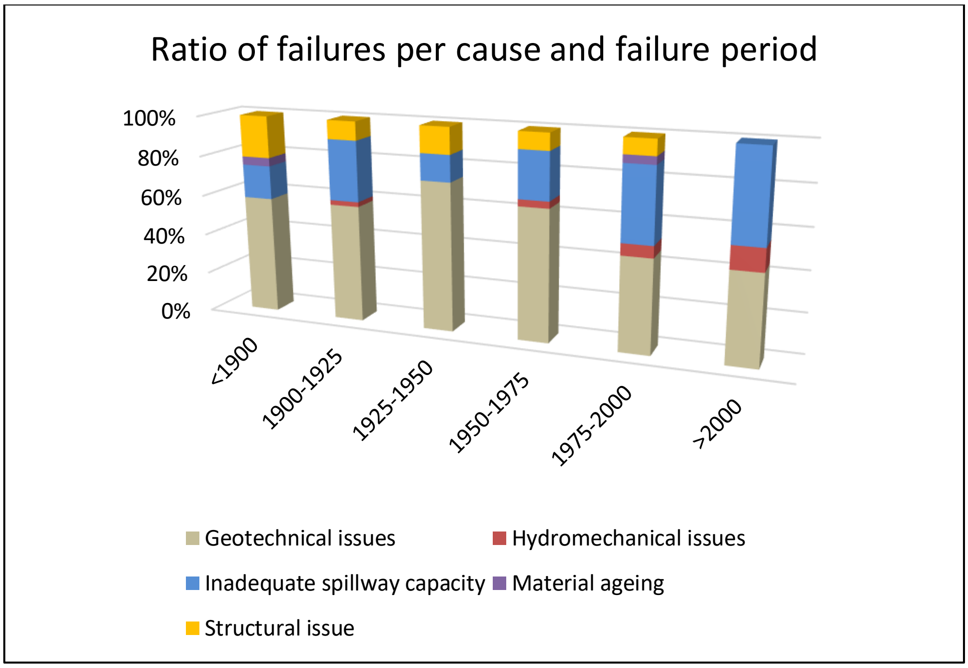

Figure 11-5 : Ratio of failures per cause and failures' period

The relation between organizational causes and technical causes is shown in the Figure 11-6. For the design organisational cause, the geotechnical issues stand for about 2/3 of the failures. For the construction organisational cause, the geotechnical issues and inadequate spillway capacity represent about half of the failures each. For operation and maintenance organisational causes the inadequate spillway capacity is present in about 50% of the failures.

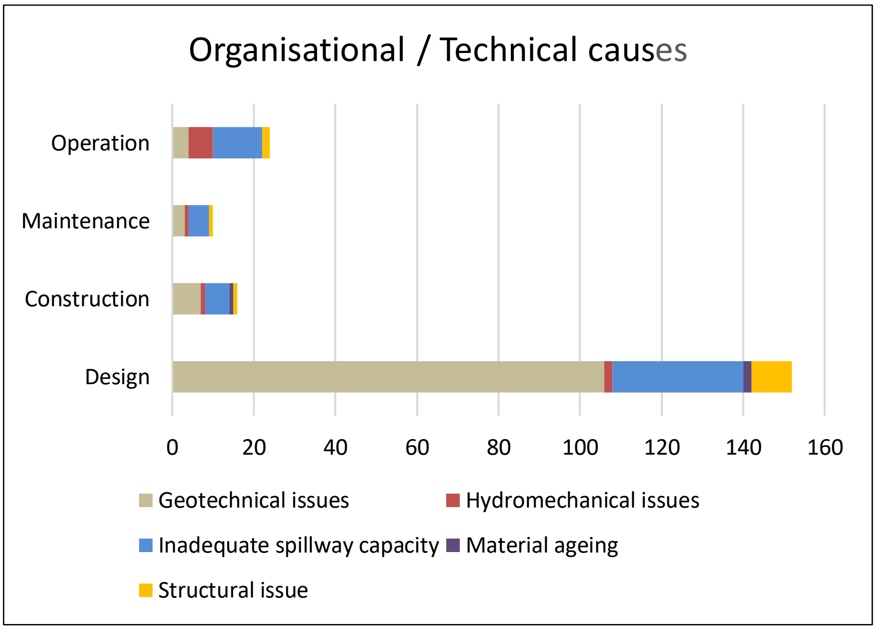

Figure 11-6 : Organizational versus technical causes

12. Conclusion

As a conclusion of this update of bulletin 99 “Dam failures - Statistical analysis” it can be stated that:

- Three ICOLD bulletins have been specifically developed for the description and statistical analysis of dam’s incidents. The last bulletin was the bulletin 99 issued in 1995. At this date 202 dams’ failures were identified by ICOLD “official” documents.
- The present update adds 120 additional failures’ cases: 65 occurred before 1993 and 55 in the period 1993-2018.
- There are important differences in the accuracy and reliability of failures’ reporting among ICOLD countries, which makes it necessary to discard some data in order not to distort statistical analysis results.
- The ratio of the number of failures divided by the total number of existing large dams decreases continuously from 1.42% during the years 1900-1925 to 0.12% since 2000. However, the ratio of failed dams built during a certain period brings a less positive view. This ratio was 0.29% for the years 1975-1999 and is 0.38% since 2000.
- As it was stated in Bulletin 99, the ten first years of a dam life is still the period where 50% of the failures occur. For arch dams and buttress dams this ratio is 100%.
- For dams’ height ranges between 15 and 75 m the ratio of the failures compared to the existing dams of the same height ranges is quite constant. For higher dams it decreases significantly. To date no dam higher than 100 m has failed.
- There is no significant influence of the dam type and of the reservoir size on the failure’s ratio. There are too few failures of multiple arch dams and buttress dams to be statistically significant.
- Dams failures occur either during normal operation or during flood events, these two failures’ contexts standing for 90% of the failures with flood context being slightly more important. Since 2000, 70% of failures have occurred during flood events.
- The three failure’s modes for embankment dams are overtopping (40%), internal erosion (39%) and structural failure (21%).
- For rigid dams, foundation failure and internal erosion in foundation are the dominant modes. Structural failure mainly occurs at gravity dams made of masonry.
- About organisational causes it can be stated that inadequate design or construction are by far the main causes identified for concrete dams of arch, buttress and multi arch types. For the other dams’ types (gravity, embankment) inadequate operation during floods appears to have a role in about 20% of failures.
- Technical causes are different according to the dam types: Foundation deficiencies are the dominant cause for arch and buttress dams. For gravity dams made of masonry structural deficiencies of the dam body is an important technical cause. For the other gravity dams structural deficiencies are as important as foundation deficiencies while inadequate spillway capacity is also one of the causes. For earthfill dams the two dominant causes are geotechnical issues (66% of the causes) and spillway inadequate capacity (28%). For rockfill dams these two same dominant causes are distributed differently, geotechnical deficiencies standing for only 32% and inadequate spillway capacity for 64%.

13. References

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Appendix 1

List of all dam failures (up to May 2018)

Acronyms used for dams' types, Incident contexts, Incident modes, organisational causes, technical causes are defined in 1.4.

Country	Continent	Dam name	Construction Year	Dam type	Height (m)	Height range	Year Incident	Reservoir range (hm^3)	Incident context	Incident mode	Organi-sational cause	Technical cause
Algeria	AFRICA	CHEURFAS	1884	PG (M)	42	H3	1885	10-25	NC	FF	BD	GC
Algeria	AFRICA	EL HABRA (B)	1871	PG (M)	35	H3	1881	25-50	UF	SFBD	BD	MA ST
Algeria	AFRICA	EL HABRA (C)	1871	PG (M)	43	H3	1927	25-50	EF	SFBD	BD	II MA
Algeria	AFRICA	SIG	1858	PG (M)	21	H2	1885	1-5	EO	SFBD SFFO	NN	II
Algeria	AFRICA	ST-LUCIEN	1861	TE	27	H2	1862	1-5	NC	IEFO	BD	GC
Algeria	AFRICA	TABIA	1876	TE	25	H2	1865	1-5	F	OT	BD	I
Argentina	AMERICA S.	PRESA FRIAS (PARDO) (ZANJON FRIAS)	1940	ER (CFRD)	15	H2	1970	0-1	EF	OT	BM	II
Armenia	EUROPE	ARTIK	1988	TE (Z)	18	H2	1994	1-5	NC	IESU	NN	GC
Armenia	EUROPE	MARMARIK	1974	TE (Z)	64	H41	1974	void	NC	SFBD	BD BC	GC
Australia	AUSTRAL-ASIA	BEDFORD WEIR	1968	PG	16	H2	2008	10-25	NC	DI	BO	HF
Australia	AUSTRAL-ASIA	BRISEIS	1924	TE	24	H2	1929	1-5	F	OT	BD	II
Australia	AUSTRAL-ASIA	CETHANA	1971	ER (Z)	15,2	H2	1968	void	UF	OT	BC	II
Australia	AUSTRAL-ASIA	KIANDRA	1881	TE	15	H2	1962	void	NC	SF	NN	UN

Country	Continent	Dam name	Construction Year	Dam type	Height (m)	Height range	Year Incident	Reservoir range (hm^3)	Incident context	Incident mode	Organi-sational cause	Technical cause
Australia	AUSTRAL-ASIA	LAANECOORIE	1889	TE/PG	22	H2	1909	5-10	F	OT	BD	I
Australia	AUSTRAL-ASIA	LAKE CAWNDILLA	1961	TE	19	H2	1962	500-1000	NC	IESU	BD	GC
Australia	AUSTRAL-ASIA	LYELL DAM	1982	ER	51	H41	1999	25-50	NC	DI	BO	IA HF
Australia	AUSTRAL-ASIA	OAKY	1956	ER/PG	18	H2	2013	1-5	UF	OT	BO	IA HF
Australia	AUSTRAL-ASIA	REDBANK	1899	VA	16	H2		void	UN	DI	NN	UN
Australia	AUSTRAL-ASIA	RETURN CREEK	1900	TE	19	H2	1967	5-10	UN	OT	NN	UN
Bolivia	AMERICA S.	EL SALTO	1975	TE	15	H2	1976	0-1	NC	IEFO	NN	GC
Brazil	AMERICA S.	ACU (Armando Ribeiro Gonçalves)	1983	TE (Z)	40	H3	1981	>1000	NC	SFBD	BD	GC
Brazil	AMERICA S.	ALGODOES	2005	TE	21,6	H2	2009	50-100	UF	OT	BD	GC
Brazil	AMERICA S.	ARMANDO DE SALLES OLIVEIRA	1958	TE (H)	35	H3	1977	25-50	EF	OT	BD	IF
Brazil	AMERICA S.	BANABUIU	1966	ER	57,7	H41	1961	>1000	UF	SF	BD	GC
Brazil	AMERICA S.	BOA ESPERANCA	1976	TE	17	H2	1977	25-50	NC	OT	BD	GC
Brazil	AMERICA S.	CAMARA	2002	PG (RCC)	50	H41	2004	25-50	NC	FF	BD	GC
Brazil	AMERICA S.	EMA	1932	TE	18,5	H2	1940	5-10	NC	IE	BD	GC
Brazil	AMERICA S.	EUCLIDES DA CUNHA	1960	TE	60	H41	1977	10-25	UF	OT	BO	IA HF
Brazil	AMERICA S.	PAMPULHA	1940	TE	16,5	H2	1954	10-25	NC	IE	BD	GC
Brazil	AMERICA S.	SANTA HELENA	1979	ER (H)	28,5	H2	1985	100-500	NC	SF	NN	UN
Bulgaria	EUROPE	IVANOVO	1962	TE	19	H2	2012	1-5	UF UO	OT	BO BD	IA
Canada	AMERICA N.	BATTLE RIVER	1956	TE	14	H1	1956	10-25	UN	IESU	BD	GC
Canada	AMERICA N.	ERINDALE 1 (CREDIT RIVER)	1906	TE (Z)	15,2	H2	1910	void	UF	OT	BC	II
Canada	AMERICA N.	ERINDALE 2 (CREDIT RIVER 2)	1910	TE (Z)	15,2	H2	1912	void	UF	OT	NN	IF

Country	Continent	Dam name	Construction Year	Dam type	Height (m)	Height range	Year Incident	Reservoir range (hm^3)	Incident context	Incident mode	Organi-sational cause	Technical cause
Canada	AMERICA N.	HINDS LAKE	1980	TE/ER	12	H1	1982	>1000	NC	IEDB	BO	GC
Canada	AMERICA N.	KENOGAMI	1937	TE	21	H2	1996	void	EF	OT	BM	II
Canada	AMERICA N.	LOG FALLS		PG	14	H1	1923	25-50	UN	UN	NN	UN
Canada	AMERICA N.	SCOTT FALLS	1921	TE PG	29	H2	1923	10-25	UF	OT	NN	IF
Canada	AMERICA N.	TESTALINDEN	1937	TE		H1	2010	void	NC	OT	BM	IA
Chile	AMERICA S.	LLIU-LLIU	1934	TE	20	H2	1985	1-5	UQ	SF	NN	ST
Chile	AMERICA S.	MENA	1885	TE	17	H2	1887	0-1	UN	IEDB	NN	GC
China	ASIA	BAIHE (PAIHO)	1960	TE (U)	66,4	H41	1976	>1000	UQ	SF	NN	GC
China	ASIA	BANQIAO	1956	TE	24,5	H2	1975	100-500	EF	OT	BD BO	II IA
China	ASIA	DONGKOUMIAO	1959	TE	22	H2	1971	1-5	NC	IE	NN	GC
China	ASIA	DOUHE	1956	TE (H)	16	H2	1976	void	UQ	SF	NN	GC
China	ASIA	GOUHOU	1989	ER	71	H41	1993	1-5	NC	IEDB	NN	GC
China	ASIA	Hengjiang	1960	TE	48,4	H3	1970	50-100	UN	IE	NN	GC
China	ASIA	Lijaizui	1972	TE	25	H2	1973	1-5	UN	OT	NN	UN
China	ASIA	LIUJATAI	1959	XX	35,9	H3	1963	25-50	F	OT	NN	UN
China	ASIA	MEIHUA	1981	VA (M)	22	H2	1981	0-1	NC	SFBD	BD	ST
China	ASIA	SHIJIAGOU	1973	TE	30	H3	1973	void	F O	OT	NN	IF
China	ASIA	SHIMANTAN	1952	TE	25	H2	1975	50-100	F	OT	BD	II
Colombia	AMERICA S.	DEL MONTE		XX		H1	1976	void	UN	UN	NN	UN
Czechia	EUROPE	BILA DESNA	1915	TE	17	H2	1916	0-1	F	IE	BD BC	GC
Czechia	EUROPE	HUBACOV	1760	TE	6	H1	1974	5-10	UF	OT	BD	II
France	EUROPE	BOUZEY (A)	1880	PG (M)	22,9	H2	1884	5-10	NC	SFFO DI	BD	ST
France	EUROPE	BOUZEY (B)	1880	PG (M)	22,9	H2	1895	5-10	NC	SFBD	BD	ST
France	EUROPE	MALPASSET	1954	VA	66	H41	1959	25-50	UF	SFFO	BD	GC
France	EUROPE	MIRGENBACH	1983	TE	19	H2	1982	void	NC	SFBD	BC	GC
France	EUROPE	MONDELY	1980	TE (H)	24	H2	1981	1-5	NC	SFBD	BC	GC

Country	Continent	Dam name	Construction Year	Dam type	Height (m)	Height range	Year Incident	Reservoir range (hm^3)	Incident context	Incident mode	Organi-sational cause	Technical cause
France	EUROPE	TUILIERES	1912	PG (M)	31	H3	2006	1-5	NC	DI	BM	HF
Germany	EUROPE	EDER	1914	PG (M)	48	H3	1943	100-500	HH	SF	NN	ST
Germany	EUROPE	GLASHUETTE	1953	TE	9,5	H1	2002	0-1	EF	OT	BD	II
Germany	EUROPE	MÖHNE	1913	PG (M)	40	H3	1943	100-500	HH	SF	NN	ST
Germany	EUROPE	MULDENBERG	1925	PG (M)	25	H2	1945	5-10	HH	SF	BO	ST
India	ASIA	AHRAURA	1953	TE	26	H2	1953	50-100	UF	IE	BD	GC
India	ASIA	ASHTI	1881	TE (Z)	22,5	H2	1933	25-50	NC	SFBD	NN	GC
India	ASIA	BHIMLAT RESERVOIR	1958	CB (M)	17	H2	2008	10-25	UF	OT	BD	II
India	ASIA	CHANG	1963	TE (Z)	15,5	H2	2001	5-10	UQ	SF	NN	GC
India	ASIA	CHIKKAHOLE	1966	PG (M)	30	H3	1972	10-25	F	SFBD	BO/BD/BC	ST
India	ASIA	DANTIWADA	1969	TE PG	61	H41	1973	100-500	EF	OT	BD	I
India	ASIA	DHANIBARA	1975	TE	20,7	H2	1976	50-100	UN	OT	NN	UN
India	ASIA	GARARDA	2009	TE	32	H3	2010	25-50	UN	IE		GC
India	ASIA	GUDDAH	1956	TE	28	H2	1956	void	UN	UN	BC	UN
India	ASIA	GURLIJORE	1984	TE PG	12	H1	2004	1-5	EF	IEFO	NN	II
India	ASIA	JASWANT SAGAR	1889	PG (M)	43	H3	2007	25-50	NC	IEFO	NN	GC
India	ASIA	KADDAM	1957	TE	41	H3	1958	100-500	EF	OT	BC	HF IA
India	ASIA	KAILA	1955	TE	26	H2	1959	10-25	UN	SFFO	BD	GC
India	ASIA	KEDAR NALA	1964	TE	20	H2	1964	10-25	NC	IE	BD	GC
India	ASIA	KHADAKWASLA	1879	PG (M)	33	H3	1961	100-500	EF	OT	NN	ST
India	ASIA	KHARAGPUR	1956	TE	24	H2	1961	50-100	F	OT	BD	II
India	ASIA	KODAGANAR	1983	TE	16	H2	1977	10-25	UF	OT	NN	II
India	ASIA	KOHODIAR (Shetrunji)	1963	TE PG	36	H3	1983	25-50	UN	UN	BD	UN
India	ASIA	KUNDLI	1924	PG (M)	45	H3	1925	1-5	F	SF	BC	ST
India	ASIA	LOWER KHAJURI	1949	TE PG (M)	16	H2	1949	25-50	NC	IEFO	BD BC	GC

Country	Continent	Dam name	Construction Year	Dam type	Height (m)	Height range	Year Incident	Reservoir range (hm^3)	Incident context	Incident mode	Organi-sational cause	Technical cause
India	ASIA	MACCHU-II	1972	TE PG (M)	24,7	H2	1979	50-100	UF	OT	BD	II
India	ASIA	MANIVALI	1975	TE	18,4	H2	1976	1-5	UN	IE	NN	UN
India	ASIA	MITTI	1982	TE	17	H2	1988	10-25	UN	OT	NN	UN
India	ASIA	NANAK SAGAR	1962	TE (H)	16,5	H2	1967	100-500	NC	IEFO	NN	UN
India	ASIA	NANDGAVHAN	1977	PG (M) TE	19	H2	2005	1-5	UF	SFBD	NN	II
India	ASIA	PAGARA	1927	TE PG (M)	30	H3	1943	50-100	UF	SF	BD	II
India	ASIA	PALEM VAGU	2008	TE	46	H3	2008	25-50	NC	IEFO	BD	GC
India	ASIA	PANSHET	1961	TE	49	H3	1961	100-500	EF	OT	BC	GC
India	ASIA	TAPPAR	1976	TE (H)	15,5	H2	2001	25-50	UQ	SFBD	NN	GC
India	ASIA	TIGRA	1917	PG (M)	25	H2	1917	100-500	UF	OT	BD	GC
India	ASIA	WAGHAD	1883	TE	32	H3	1883	10-25	UN	OT	NN	UN
Indonesia	ASIA	SEMPOR	1967	ER	54	H41	1967	50-100	F	OT	BD	UN
Indonesia	ASIA	SITU GINTUNG	1932	TE/ER	16	H2	2009	1-5	F	OT	BM	GC
Iran	ASIA	GOTVAND	1977	ER	22	H2	1980	void	UN	OT	BD	UN
Iran	ASIA	SAVEH	1300	PG (M)	25	H2	1380	void	UN	IEFO	NN	ST
Iraq	ASIA	CHAQ-CHAQ	2005	TE	14,5	H1	2006	1-5	F	OT	BD	GC
Iraq	ASIA	DIBBIS (DIBIS)	1966	ER	17	H2	1984	25-50	F	OT	BM	IA
Italy	EUROPE	GLENO	1923	MV PG(M)	29	H2	1923	1-5	NC	SFBD	BD	ST
Italy	EUROPE	RUTTE	1952	MV	15	H2	1965	0-1	NC	IE	NN	GC
Italy	EUROPE	SUBIACO	60	PG (M)	40	H3	1305	void	UN	SFFO	NN	ST
Italy	EUROPE	VAJONT RESERVOIR	1960	VA	265,5	H5	1963	void	NC	NN	BD	GC
Italy	EUROPE	ZERBINO	1924	PG	16	H2	1935	5-10	EF	OT	BD	GC
Japan	ASIA	ASHIZAWA	1912	TE	15	H2	1956	void	EF	OT	BD	II
Japan	ASIA	FUJINUMA-IKE	1949	TE	18,5	H2	2011	1-5	EQ	SFBD	BD	GC
Japan	ASIA	HEIWA IKE	1949	TE	19,6	H2	1951	0-1	EF	OT	BD	II

Country	Continent	Dam name	Construction Year	Dam type	Height (m)	Height range	Year Incident	Reservoir range (hm^3)	Incident context	Incident mode	Organi-sational cause	Technical cause
Japan	ASIA	IRUKA - IKE (A)	1633	TE	26	H2	1868	10-25	UF	OT	BD	GC
Japan	ASIA	KOMORO	1927	CB	15	H2	1928	0-1	NC	FF	BD	GC
Japan	ASIA	OGAYARINDO TAMEIKE	1944	TE	19	H2	1963	0-1	UF UO	OT	BO	II IA
Kenya	AFRICA	SOLAI	1980	TE	25	H2	2018	0-1	UF	IE OT	BD BM	GC
Korea (S)	ASIA	HWACHON	1944	PG	81,4	H42	1951	>1000	HH	DI	NN	UN
Korea (S)	ASIA	HYOGIRI	1940	TE	15,6	H2	1961	0-1	F	IE	NN	UN
Laos	ASIA	NAM AO 7	2017	TE		H1	2017	void	F	UN	NN	UN
Laos	ASIA	XE NAMNOY saddle dam	2018	TE	16	H2	2018	500-1000	UF	IE	NN	UN
Lesotho	AFRICA	MAFETENG	1988	TE	17	H2	1987	void	NC	IESU	BD BC	GC
Libya	AFRICA	GHATTARA	1972	TE	38,5	H3	1977	5-10	UN	IE	BD	GC
Mexico	AMERICA S.	EL ESTRIBON	1946	TE	21	H2	1963	void	NC	SFBD	BD	GC
Mexico	AMERICA S.	LA LAGUNA DAM, HGO	1912	TE	17	H2	1969	25-50	NC	IE	BD	GC
Mexico	AMERICA S.	LA PAZ		TE	10	H1	1976	void	EF	OT	BD	I
Mexico	AMERICA S.	SANTA ANA ACAXOCHITLAN	1910	TE	12	H1	1925	5-10	NC	SF	BD	GC
Mexico	AMERICA S.	SANTA CATALINA		PG (M)	15	H2	1906	void	F	OT	NN	I
Nepal	ASIA	KOSHI (KOSI)	1962	ER		H1	2008	void	UF	OT	NN	UN
Netherlands	EUROPE	Secondary dyke Wilnis	1700	TE	5	H1	2003	10-25	UO	SFBD	BO	GC
New Zealand	AUSTRAL-ASIA	OPUHA	1999	TE	50	H41	1997	50-100	F	OT	BO	UN
New Zealand	AUSTRAL-ASIA	RUAHIHI	1981	ER	32	H3	1981	25-50	NC	IE	NN	GC
Nigeria	AFRICA	BAGAUDA	1970	TE	20	H2	1988	10-25	UN	OT	NN	UN

Country	Continent	Dam name	Construction Year	Dam type	Height (m)	Height range	Year Incident	Reservoir range (hm^3)	Incident context	Incident mode	Organi-sational cause	Technical cause
Nigeria	AFRICA	CHAM	1992	TE (Z)		H1	1998	5-10	UN	OT IE SFBD	BD	GC
Nigeria	AFRICA	GUSAU		ER	5	H1	2006	void	EF	OT	BO	IA HF
Norway	EUROPE	ROPPA	1975	TE (Z)	9,6	H1	1976	1-5	NC	IEDB	BD BC	GC
Norway	EUROPE	STORVATN DAM	1920	PG	10	H1	1979	1-5	UF	OT	BO	HF IA
Pakistan	ASIA	BOLAN	1960	TE/ER	19	H2	1976	50-100	F	OT	BD	II
Pakistan	ASIA	SHAKIDOR	2003	ER		H1	2005	void	EF	OT	NN	GC
Paraguay	AMERICA S.	RINCON	1945	TE/ER	50	H41	1959	>1000	UN	OT	NN	UN
Philippinas	ASIA	SANTO TOMAS	1951	TE	43	H3	1976	void	UN	OT	NN	UN
Poland	EUROPE	NIEDOW (WITKA)	1962	TE PG	16,7	H2	2010	1-5	F	OT	BO	HF IA
Rhodesia	AFRICA	MSINJE FARM	1970	TE	16	H2	1974	0-1	UN	SF	BD	GC
Romania	EUROPE	BELCI	1963	PG TE	18	H2	1991	10-25	F	OT	BO	HF IA
Russia	EUROPE	NIZHNE SVIRSKAYA	1934	TE	28	H2	1935	>1000	EO HH	SF	BO	GC
Russia	EUROPE	SARGAZONSKAYA	1980	TE	23	H2	1987	1-5	UN	OT	NN	UN
Slovenia	EUROPE	FORMIN	1977	PG TE	49	H3	2012	10-25	F	IEDB	BD	GC
Slovenia	EUROPE	PRIGORICA	1990	TE	9,6	H1	1992	void	NC	IE/SF	BD	GC
South Africa	AFRICA	BELLAIR	1922	TE	16	H2	2003	5-10	EF	OT	BD	II
South Africa	AFRICA	BON ACCORD	1925	TE	18	H2	1937	5-10	NC	SF	BO	GC
South Africa	AFRICA	DADELVLAK		TE		H1	1998	0-1	NC	IE	BD	GC
South Africa	AFRICA	FRY	1967	TE	21	H2	2000	1-5	EF	OT	BD	I
South Africa	AFRICA	GLEN UNA	1983	TE	15	H2	1988	void	EF	OT	NN	II
South Africa	AFRICA	KOOS DE BEER (Welgevonden N°1)	1967	XX	15	H2	2000	0-1	EF	OT	BD	II
South Africa	AFRICA	KRUIN	1982	TE	22	H2	1994	0-1	NC	IEDB IESU	BD BC	GC

Country	Continent	Dam name	Construction Year	Dam type	Height (m)	Height range	Year Incident	Reservoir range (hm^3)	Incident context	Incident mode	Organi-sational cause	Technical cause
South Africa	AFRICA	LEBEA	1963	TE/VA	18	H2	2000	10-25	EF	OT	BD	II
South Africa	AFRICA	LEEU GAMKA	1920	TE	15	H2	1928	5-10	NC	IEDB	BD	GC
South Africa	AFRICA	MAMBEDI LOWER	1985	TE	22	H2	2000	5-10	EF	DI	BD	ST
South Africa	AFRICA	MOLTENO RESERVOIR	1881	TE	15	H2	1882	0-1	NC	IEDB	BD BC	GC ST
South Africa	AFRICA	SMARTT SYNDICATE	1912	TE	28	H2	1961	50-100	UF	IE OT	NN	GC
South Africa	AFRICA	SPITSKOP	1974	TE	19	H2	1988	50-100	EF	OT	BC	II
South Africa	AFRICA	TIERPOORT	1922	TE	19	H2	1988	25-50	EF	OT	NN	II
South Africa	AFRICA	XONXA	1974	TE/ER	48	H3	1972	100-500	UF	OT	BC	II
South Africa	AFRICA	ZOEKNOG		TE	38	H3	1993	5-10	NC	IEDB	BD BC	GC
Spain	EUROPE	FONSAGRADA	1958	MV	20	H2	1987	0-1	NC	DI	BD BC	MA
Spain	EUROPE	GASCO	1796	PG (M)	54	H41	1796	1-5	UF	SF	BD	UN
Spain	EUROPE	GRANADILLAR (Toscón)	1932	PG (M)	26	H2	1934	0-1	UF	IEFO	BD	GC
Spain	EUROPE	ODIEL	1970	ER	35	H3	1968	1-5	UF	OT	BD BO	IF II
Spain	EUROPE	ORJALES	1958	MV (M)	13,1	H1	1994	0-1	NC	SF	BC	MA
Spain	EUROPE	PUENTES II	1791	PG (M)	50	H41	1802	10-25	NC	IEFO	BD	GC
Spain	EUROPE	TOUS	1978	ER	70,5	H41	1982	50-100	UF	OT	BO	IA HF
Spain	EUROPE	VEGA DE TERA	1956	CB (M)	34	H3	1959	5-10	NC	SF	BD	ST
Spain	EUROPE	XURIGUERA	1902	PG (M)	42	H3	1944	1-5	UF	OT	BO	IA
Sri Lanka	ASIA	KANTALE	1869	TE	18,3	H2	1986	100-500	NC	IE	BM	ST
Sweden	EUROPE	HÄSTBERGA	1953	TE	14	H1	2010	1-5	UF	OT	BO BM	IA HF
Sweden	EUROPE	NOPPIKOSKI	1967	TE (Z)	18	H2	1985	0-1	UF	OT	BO	HF II
Sweden	EUROPE	SELSFORS	1944	CB	20	H2	1943	5-10	NC	IEFO SFFO	BD	GC

Country	Continent	Dam name	Construction Year	Dam type	Height (m)	Height range	Year Incident	Reservoir range (hm^3)	Incident context	Incident mode	Organi-sational cause	Technical cause
Syria	ASIA	ZEIZOUN	1999	ER/TE (Z)	32	H3	2002	50-100	F	OT	NN	UN
Taiwan	ASIA	SHIH KANG	1997	PG	25	H2	1999	1-5	EQ	SFFO	BD	ST
Turkey	EUROPE	ELMALI I	1892	PG(M) TE	23	H2	1916	1-5	F	OT	NN	UN
Ukraine	EUROPE	BABII YAR		TE		H1	1961	0-1	UF	OT	BD	UN
Ukraine	EUROPE	DNJEPROSTROJ (A)	1932	PG	43	H3	1941	>1000	HH	SFBD	NN	UN
United Kingdom	EUROPE	BALDERHEAD	1965	TE/ER	48	H3	1967	10-25	NC	IEDB	BD	GC
United Kingdom	EUROPE	BILBERRY	1845	TE	20	H2	1852	0-1	EF	OT	BD	GC I
United Kingdom	EUROPE	BLACKBROOK I	1797	TE	28	H2	1799	0-1	NC	IESU SF OT	BD	GC
United Kingdom	EUROPE	BLACKBROOK II	1801	PG (M)		H1	1804	void	UN	UN	BD	GC
United Kingdom	EUROPE	COETDY	1924	ER	11	H1	1925	0-1	EF	OT	NN	UN
United Kingdom	EUROPE	DALE DYKE	1863	TE	29	H2	1864	1-5	NC	SFBD OT	BD	GC
United Kingdom	EUROPE	EIGIAU	1908	PG	10,7	H1	1925	1-5	NC	IEFO	BD BC	ST
United Kingdom	EUROPE	KILLINGTON	1820	TE	18	H2	1836	1-5	UN	OT	NN	UN
United Kingdom	EUROPE	LAMBIELETHAM	1899	TE	15	H2	1984	void	UF	IEDB	BD	GC
United Kingdom	EUROPE	MAICH WATER	1850	TE	9	H1	2008	0-1	UF	OT	BD	II
United Kingdom	EUROPE	NANT Y GRO	1900	PG (M)	9,1	H1	1942	0-1	NC	SF	NN	ST

Country	Continent	Dam name	Construction Year	Dam type	Height (m)	Height range	Year Incident	Reservoir range (hm^3)	Incident context	Incident mode	Organi-sational cause	Technical cause
United Kingdom	EUROPE	RHODESWORTH	1855	TE	21	H2	1852	1-5	UN	UN	NN	UN
United Kingdom	EUROPE	TORSIDE	1855	TE	31	H3	1854	5-10	UN	OT	NN	UN
United Kingdom	EUROPE	WARMWITHENS	1870	TE	10	H1	1970	0-1	NC	IESU	BD	GC
United Kingdom	EUROPE	WHINHILL	1828	TE	12	H1	1835	0-1	UF	IEDB	BD	GC
USA	AMERICA N.	ALEXANDER	1930	TE	29	H2	1930	1-5	NC	SF	BC	GC
USA	AMERICA N.	ANACONDA	1898	TE	22	H2	1938	0-1	UN	IE	NN	GC
USA	AMERICA N.	ANGELS		PG (M)	15,6	H2	1895	void	UN	IEFO	NN	GC
USA	AMERICA N.	APISHAPA	1920	TE (H)	35	H3	1923	10-25	NC	IEDB	BC	GC
USA	AMERICA N.	ASHLEY DAM (PITTSFIELD)	1908	CB	18	H2	1909	0-1	NC	IEFO	BD	GC
USA	AMERICA N.	AUSTIN I	1893	PG (M)	18,3	H2	1893	void	NC	SFFO	NN	ST
USA	AMERICA N.	AUSTIN II	1915	CB (M)	20,7	H2	1915	10-25	F	OT	NN	UN
USA	AMERICA N.	AUSTRIAN DAM (Lake Elsman)	1950	TE (H)	56,4	H41	1989	5-10	EQ	SFBD	NN	GC
USA	AMERICA N.	AVALON I	1889	TE/ER	17,5	H2	1893	void	UF	OT	NN	II
USA	AMERICA N.	AVALON II	1894	TE/ER	18	H2	1905	void	NC	IE	NN	GC
USA	AMERICA N.	B.EVERETT JORDAN	1974	TE (Z)		H1	1972	50-100	UN	IE	BD	GC
USA	AMERICA N.	BALDWIN HILLS	1951	TE	71	H41	1963	10-25	NC	IEFO SFBD	NN	GC
USA	AMERICA N.	BALSAM	1927	TE	18	H2	1929	void	UF	OT	BD	GC
USA	AMERICA N.	BAYLESS II	1909	PG	15,8	H2	1910	1-5	UF	SFFO	BD	ST
USA	AMERICA N.	BIG BAY	1992	TE	17,4	H2	2004	25-50	NC	IESU	BD BC BM	GC

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USA	AMERICA N.	BLACK ROCK (ZUNI)	1907	ER	21	H2	1909	10-25	NC	IE	BD	GC
USA	AMERICA N.	BULLY CREEK	1913	ER (Z)	38,1	H3	1925	10-25	UF	OT	BC	II
USA	AMERICA N.	CALAVERAS (A)	1918	TE	67	H41	1918	100-500	NC	SF	BD	GC
USA	AMERICA N.	CANYON LAKE		TE	7	H1	1972	void	EF	OT	BO	UN
USA	AMERICA N.	CASTLEWOOD	1890	ER	28	H2	1933	1-5	UN	IE OT	NN	UN
USA	AMERICA N.	CAULK LAKE	1950	TE	20	H2	1973	0-1	NC	IE	BD	GC
USA	AMERICA N.	CAZADERO	1906	ER	21	H2	1965	10-25	UF	OT	BD	ST
USA	AMERICA N.	CENTER CREEK NO. 1	1869	TE (H)	19	H2	1973	0-1	UF	OT	BO	IA
USA	AMERICA N.	CHAMBERS LAKE I	1885	TE	15	H2	1891	void	UN	OT	NN	UN
USA	AMERICA N.	CHAMBERS LAKE II	1885	TE	15	H2	1907	5-10	UN	OT	NN	UN
USA	AMERICA N.	CHEOHA CREEK		TE	28	H2	1970	10-25	F	OT	NN	UN
USA	AMERICA N.	CORPUS CHRISTI (LA FRUTTA DAM)	1930	TE	19	H2	1930	50-100	NC	IEFO	BD	GC
USA	AMERICA N.	CRYSTAL LAKE	1860	TE	15,2	H2	1961	void	NC	IE	NN	UN
USA	AMERICA N.	CUBA	1851	TE	15,7	H2	1868	0-1	UN	IE	NN	UN
USA	AMERICA N.	D.M.A.D. Dam	1960	TE	10	H1	1983	10-25	EF	SFFO	NN	GC
USA	AMERICA N.	DELHI (Hartwick dam)	1929	TE PG	18	H2	2010	1-5	F	OT	BO BD BM	IA HF
USA	AMERICA N.	DYKSTRA	1903	ER	15,2	H2	1926	void	F	OT	NN	UN
USA	AMERICA N.	ELWHA (Olympic Power Company Dam)	1911	PG (M)	34	H3	1912	25-50	NC	IEFO	BD	GC
USA	AMERICA N.	EMERY (A)	1850	TE	16	H2	1904	0-1	NC	IE	BD	GC

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USA	AMERICA N.	EMERY (B)	1948	TE	16	H2	1966	0-1	NC	IE	BD BM	GC
USA	AMERICA N.	ENGLISH	1878	ER	30,5	H3	1883	10-25	NC	UN	NN	GC
USA	AMERICA N.	FORSYTHE	1920	TE	20	H2	1921	void	NC	IESU SFBD	BD	HF
USA	AMERICA N.	FORT PECK	1940	TE	76	H42	1938	>1000	NC	SFFO	BD	GC
USA	AMERICA N.	FRED BURR	1947	TE (Z)	16	H2	1948	0-1	NC	IEDB	NN	GC
USA	AMERICA N.	FRUIT GROWERS	1898	TE	12,2	H1	1937	1-5	F	SFBD	BD	GC
USA	AMERICA N.	GALLINAS	1910	PG (M)	29	H2	1957	0-1	F	UN	NN	UN
USA	AMERICA N.	GOOSE CREEK	1900	ER	20	H2	1900	void	F	OT	BD	UN
USA	AMERICA N.	GRAHAM LAKE	1922	TE	34	H3	1923	100-500	UN	IE	BD	GC
USA	AMERICA N.	GREENLICK	1901	TE	19	H2	1904	0-1	NC	IEDB IEFO	BD	GC
USA	AMERICA N.	HATCHTOWN	1908	TE	18,9	H2	1914	10-25	NC	IE	NN	UN
USA	AMERICA N.	HAUSER LAKE I	1906	XX	21	H2	1908	50-100	NC	IEFO	BD	GC
USA	AMERICA N.	HAUSER LAKE II	1911	PG (M)	40	H3	1969	100-500	UN	UN	NN	UN
USA	AMERICA N.	HEBRON (A)	1913	TE	17	H2	1914	void	NC	IEDB	BD	GC
USA	AMERICA N.	HEBRON (B)	1913	TE	17	H2	1942	void	NC	SF OT	BD	GC
USA	AMERICA N.	HELL HOLE (lower)	1966	ER	30	H3	1964	100-500	UF	OT	BC	II
USA	AMERICA N.	HORSE CREEK	1912	TE	16,9	H2	1914	10-25	UN	IE	NN	GC
USA	AMERICA N.	JACKSON'S BLUFF	1930	TE	9	H1	1957	25-50	EF	SFBD	BM	GC
USA	AMERICA N.	JENNING CREEK N° 16	1960	TE	17	H2	1964	0-1	EF	IEFO	BD	GC
USA	AMERICA N.	JENNING CREEK N° 3	1962	TE	21	H2	1963	0-1	NC	IEFO	BD	GC
USA	AMERICA N.	JULESBURG (B)	1905	TE	18	H2	1910	25-50	NC	IEFO	BD	GC
USA	AMERICA N.	KA LOKO	1890	TE/ER	15	H2	2006	void	F	OT	BM	IA

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USA	AMERICA N.	KELLY BARNES	1899	TE	13	H1	1977	0-1	UF	SFBD	BD	GC
USA	AMERICA N.	KETNER	1911	TE	13,7	H1	1912	void	F	OT	NN	UN
USA	AMERICA N.	LAKE BARCROFT DAM	1913	PG TE	22,5	H2	1972	1-5	F	OT	BD	UN
USA	AMERICA N.	LAKE DELTON	1926	ER	9	H1	2008	1-5	EF	OT	NN	I
USA	AMERICA N.	LAKE FRANCIS I	1899	TE	15	H2	1899	0-1	NC	IEDB	NN	UN
USA	AMERICA N.	LAKE HEMET	1893	TE	45	H3	1927	10-25	UF	OT	BD	I
USA	AMERICA N.	LAKE LITCHFIELD	1975	TE (H)	19	H2	1975	500-1000	NC	SFBD	BC	GC
USA	AMERICA N.	LAKE TOXAWAY	1902	TE	18,9	H2	1916	10-25	NC	IEDB	BD	GC
USA	AMERICA N.	LAKE VERA	1880	ER	15	H2	1905	void	UN	OT	NN	UN
USA	AMERICA N.	LAKE WAXAMACHIE	1956	TE		H1	1968	void	UN	SFBD	BD	GC
USA	AMERICA N.	LAUREL RUN	1919	TE	13	H1	1977	0-1	EF	OT	BD	II
USA	AMERICA N.	LITTLE DEER CREEK	1962	TE	26	H2	1963	1-5	NC	IEDB	BD	GC
USA	AMERICA N.	LITTLE FIELD	1929	ER	37	H3	1929	void	NC	SFBD	BD	GC
USA	AMERICA N.	LONG TOM	1906	TE	18	H2	1916	void	NC	IESU	BD	GC
USA	AMERICA N.	LOOKOUT SHOALS	1915	TE	25	H2	1916	25-50	UF	OT	BD	II
USA	AMERICA N.	LOWER IDAHO FALLS	1914	ER/PG	15,2	H2	1976	void	EO	OT	NN	II
USA	AMERICA N.	LOWER OTAY	1901	ER	46,6	H3	1916	50-100	UF	OT	NN	I
USA	AMERICA N.	LOWER SAN FERNANDO DAM (B)	1921	TE	43	H3	1971	25-50	UQ	SFBD	BD	GC
USA	AMERICA N.	LYMAN (A)	1913	TE	20	H2	1915	25-50	NC	IEFO	BD	GC
USA	AMERICA N.	MAMMOTH	1916	TE	23	H2	1917	10-25	UF	OT	BD	II

Country	Continent	Dam name	Construction Year	Dam type	Height (m)	Height range	Year Incident	Reservoir range (hm^3)	Incident context	Incident mode	Organi-sational cause	Technical cause
USA	AMERICA N.	MANCHESTER		XX (M)	15,2	H2	1902	void	UN	IEFO	NN	UN
USA	AMERICA N.	MASTERSON	1950	TE/ER	18	H2	1951	void	UF	IEDB	BD	GC
USA	AMERICA N.	MC MAHON GULCH	1924	TE	17	H2	1926	0-1	UF	OT	BD	GC
USA	AMERICA N.	MEADOW POND	1990	ER	12	H1	1996	void	UO	IEDB	BD BC	GC
USA	AMERICA N.	MILL CREEK CALIFORNIA	1899	TE	20	H2	1957	0-1	NC	IEDB	BD BM	GC ST
USA	AMERICA N.	MILL RIVER	1865	TE	13	H1	1874	void	NC	IE SFDB	BD	GC
USA	AMERICA N.	MOUNT PISGAH	1910	TE	23	H2	1928	void	NC	SFBD	BD BO	GC
USA	AMERICA N.	MOYIE DAM / EILEEN DAM	1923	VA	16	H2	1925	0-1	F	OT	NN	GC
USA	AMERICA N.	NORTH LAKE	1957	TE	20	H2	1974	0-1	UN	SF	BD	GC
USA	AMERICA N.	OVERHOLSER	1918	CB/ER	17	H2	1923	10-25	F	OT	BD	I
USA	AMERICA N.	OWEN	1915	TE	17	H2	1914	50-100	UN	IE	BD	GC
USA	AMERICA N.	PROSPECT		TE	14	H1	1980	5-10	NC	IE	NN	GC
USA	AMERICA N.	QUAIL CREEK DIKE	1985	TE	24	H2	1989	25-50	NC	IE	BD	GC
USA	AMERICA N.	RED ROCK DAM (Turkey Creek)	1910	TE (U)	32	H3	1910	10-25	F	OT	NN	II
USA	AMERICA N.	SAINT FRANCIS	1926	PG	62,5	H41	1928	25-50	NC	IEFO SFFO	BD BC	GC
USA	AMERICA N.	SALUDA (LAKE MURRAY)	1930	TE	63	H41	1930	>1000	UN	IE SFBD	BD	GC
USA	AMERICA N.	SCHAEFFER	1911	TE	30	H3	1921	void	F	SFBD OT	NN	UN
USA	AMERICA N.	SEPULVEDA CANYON	1909	TE (Z)	20	H2	1914	void	UF	OT	BD	II

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USA	AMERICA N.	SHEEP CREEK DAM	1969	TE	18	H2	1970	1-5	UF	IESU	BD	HF
USA	AMERICA N.	SILVER LAKE	1896	TE	9	H1	2003	void	F	OT	BD	I
USA	AMERICA N.	SINKER CREEK	1919	TE	21	H2	1943	1-5	UN	IE	BD	GC
USA	AMERICA N.	SNAKE RAVINE	1893	XX	19	H2	1898	void	UN	UN	BC	UN
USA	AMERICA N.	SOUTH FORK	1852	TE/ER	22	H2	1889	10-25	F	OT	BD BO	II
USA	AMERICA N.	STANLEY	1912	TE	34	H3	1916	50-100	UN	SF	BD	GC
USA	AMERICA N.	STOCKTON CREEK	1949	TE	29	H2	1950	0-1	UN	SF IE	BD BC	GC ST
USA	AMERICA N.	STONY RIVER	1913	CB	16	H2	1914	5-10	NC	IEFO SFFO	BD BC	GC
USA	AMERICA N.	SWEETWATER MAIN	1888	TE	36	H3	1916	25-50	UN	OT	NN	UN
USA	AMERICA N.	SWIFT	1914	ER TE	57	H41	1964	25-50	F	OT	BD	II
USA	AMERICA N.	TABLE ROCK COVE	1927	TE	43	H3	1928	25-50	NC	IE	BD	GC
USA	AMERICA N.	TAUM SAUK	1960	TE/ER	25	H2	2005	void	NC	OT	BO	HF IF IA
USA	AMERICA N.	TERRACE	1912	TE	48	H3	1957	10-25	NC	IE	BD	GC
USA	AMERICA N.	TETON	1976	TE/ER	93	H42	1976	100-500	NC	IE	BD BC	GC
USA	AMERICA N.	TOA VACA	1972	TE/ER	66	H41	1970	50-100	UN	OT	NN	UN
USA	AMERICA N.	TORESON	1898	TE	15	H2	1953	1-5	UN	IE	BO	UN
USA	AMERICA N.	TUPELO BAYOU	1973	TE	15	H2	1973	1-5	NC	SF IE	BD	GC
USA	AMERICA N.	UTICA	1873	TE	21	H2	1902	void	UN	SF	NN	GC
USA	AMERICA N.	VAUGHN CREEK	1926	VA	19	H2	1926	void	NC	IEFO SF	BD	GC
USA	AMERICA N.	WACHUSETT NORTH DIKE	1904	TE	25	H2	1907	100-500	NC	SFBD	NN	GC
USA	AMERICA N.	WAGNER (Wagner Creek)	1918	TE	15	H2	1938	0-1	NC	IESU	NN	ST

Country	Continent	Dam name	Construction Year	Dam type	Height (m)	Height range	Year Incident	Reservoir range (hm^3)	Incident context	Incident mode	Organi-sational cause	Technical cause
USA	AMERICA N.	WALNUT GROVE	1888	ER	33	H3	1890	10-25	UF	OT	NN	UN
USA	AMERICA N.	WALTER BOULDING DAM	1967	TE	50	H41	1972	void	NC	SFBD	BM	GC
USA	AMERICA N.	WAVERLY	1880	TE	21	H2	1973	0-1	NC	SFBD	NN	GC
USA	AMERICA N.	WHITEWATER BROOK UPPER	1949	TE	19	H2	1972	0-1	UF	OT IESU SFBD	BC	GC
USA	AMERICA N.	WISCONSIN DELLS	1909	TE	18	H2	1911	10-25	F	OT	NN	I
USA	AMERICA N.	WOODRAT KNOB	1956	TE	26	H2	1961	5-10	NC	SFBD	BD	GC
USA	AMERICA N.	WYANDOTTE COUNTY (=Marshall Creek)	1941	TE	28	H2	1937	5-10	NC	SFFO	BD	GC
Venezuela	AMERICA S.	EL GUAPO (FERNANDO TRIAS - EL GUAPO)	1980	TE (Z)	60	H41	1999	100-500	UF	OT	BD	IF
Vietnam	ASIA	HA DONG	2011	TE	27,5	H2	2014	10-25	UF	OT	NN	I
Vietnam	ASIA	KREL_2	2013	TE (H)	27	H2	2014	void	UF	OT	BD BC	GC
Yugoslavia	EUROPE	IDBAR	1959	VA	39	H3	1959	1-5	NC	IEFO	BD	GC
Yugoslavia	EUROPE	OVCAR BANJA	1952	TE/PG	27	H2	1965	1-5	EF	OT	BO	II
Zambia	AFRICA	MUZUMA	1969	PG	15	H2	1969	void	F	OT	BD BC	ST