Geosyntec consultants

Estimated Rates of Failure for Dams in the United States

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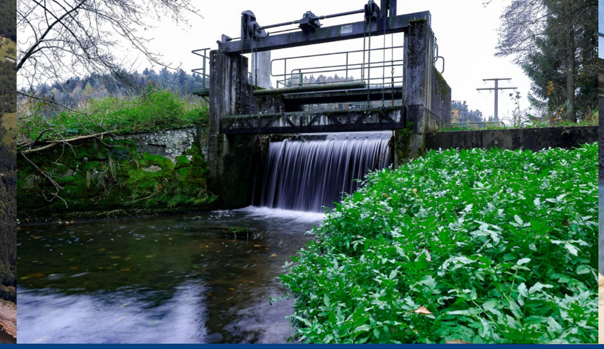

Abstract

Annual rates of failure which consider the effect of dam type, construction era, and dam age were estimated for dams in the United States by examining the National Inventory of Dams and the Worldwide Historical Dam Failures Database. We estimate there has been a total of 5,628,516 years of service from all dams (dam-years), 2,694 dam failures, and thus 0.00048 dam failures per dam-year. Concrete and earthfill dams both have less than 0.0005 failures per dam-year; masonry and rockfill dams have more than 0.001 failures per dam-year and timber dams have more than 0.0035 failures per dam-year. For all dam types, failure rates are greatest in the first five years after construction and steadily decrease with increasing dam age except for earthfill and rockfill dams, which shown an increase in failure rates after 50 years of age.

Data Resources

We used two datasets for this analysis:

Worldwide Historical Dam Failures Database

- https://borealisdata.ca/dataset.xhtml?persistentId=doi:10.5683/SP2/E7Z09B
- Data for 2,543 recorded dam failures in the United States
- Used to compute "failures" in each subcategory
- A failure corresponds to any uncontrolled release, regardless of severity
- Applied a catalogue completeness correction for missing historical failures

National Inventory of Dams

- https://nid.sec.usace.army.mil/#/downloads
- Data for over 90,000 dams in the United States
- Used to compute "dam-years", in each subcategory
- Dam-years computed as the sum of service lives for all dams, i.e., exposure

$$Failure\ Rate = \frac{Failures}{Dam\ Years} \qquad (1)$$

Catalogue Completeness Correction

It is likely that some older records of dam failures that resulted in no fatalities were not recorded. This is analogous to the catalogue completeness issue in earthquake ground motion databases for which a magnitude of completeness is used to express the minimum magnitude for which all earthquakes are recorded. In this study, we adopt a similar approach and assume a fatality of completeness whereby the failures database is assumed to be complete for all failures which resulted in at least one fatality.

A transfer function, which is dependent on failure year, was applied to all failures in the failures database to scale up the number of failures to current levels of failure reporting and mitigate the effect of missing historical failures; this increased the total number of failures by 6%, from 2,543 to 2,694 failures.

Failure Rates of Aging Dams

Both datasets contain data on the type of dams, which were harmonized into the following dam types: concrete (including gravity, roller-compacted, buttress, multiple-arch, and arch), earthfill, masonry, rockfill, timber, and other (including stone, steel, and others). We considered five construction eras and dam ages were grouped into five stages analyzed in Figures 1 and 2.

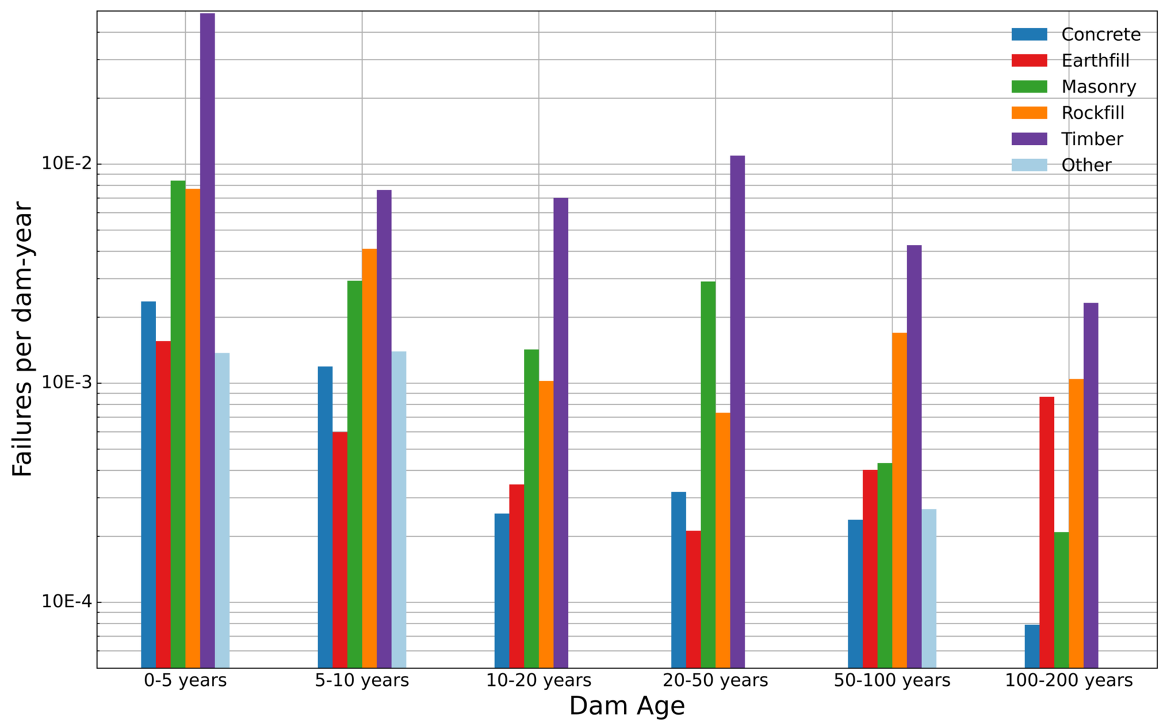

FIGURE 1: Failure rates by dam age for various types of dams.

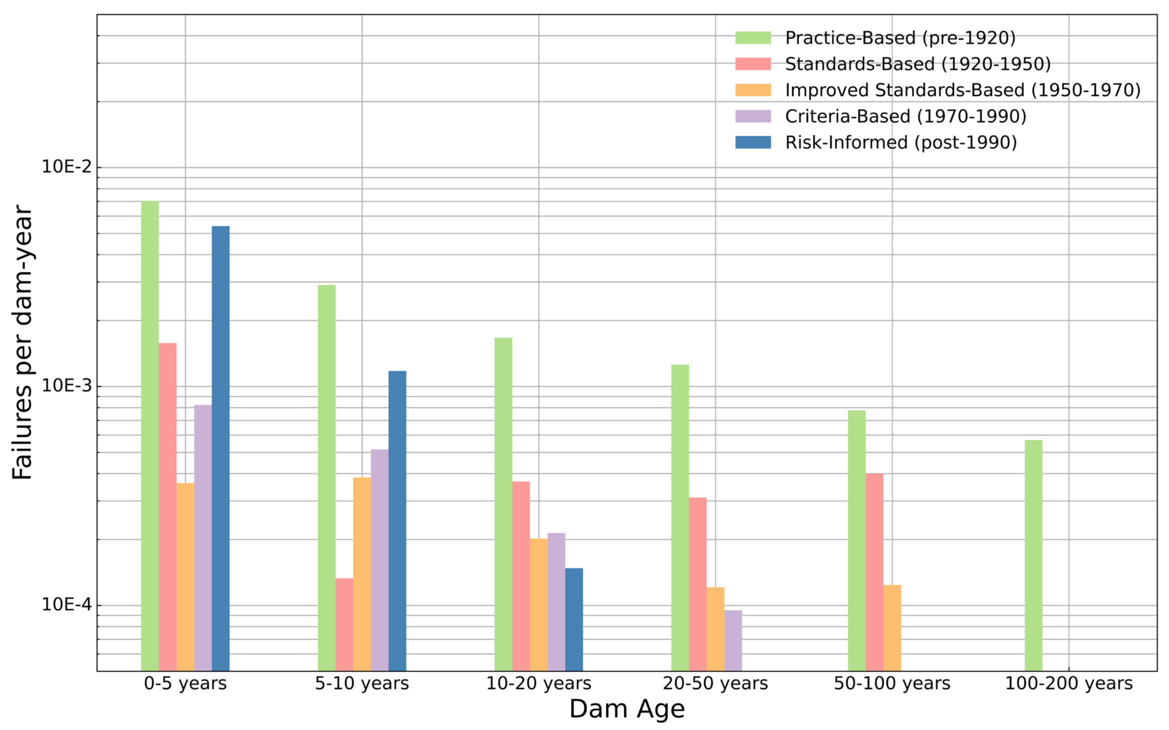

FIGURE 2: Failure rates by dam age for various construction eras.

Highest failure rates occur in the first 5 years after initial reservoir filling

Failure rates generally decrease with dam age; however, failure rates for earthfill and rockfill dams increase after 50 years of age

Timber dams have the highest failure rates; concrete dams have the lowest failure rates

Decrease of failure rates from pre-1920 onwards is attributed to improved engineering & construction methods

Increase of failure rates from 1970 to post-1990 for dam ages of 0–10 years is attributed to improved monitoring & reporting of newly constructed failure-prone dams

Categorical Results

For all dam types, Figures 3 and 4 show the total failures, failures per dam-year, and total dam-years for each construction era and dam age subcategory, respectively.

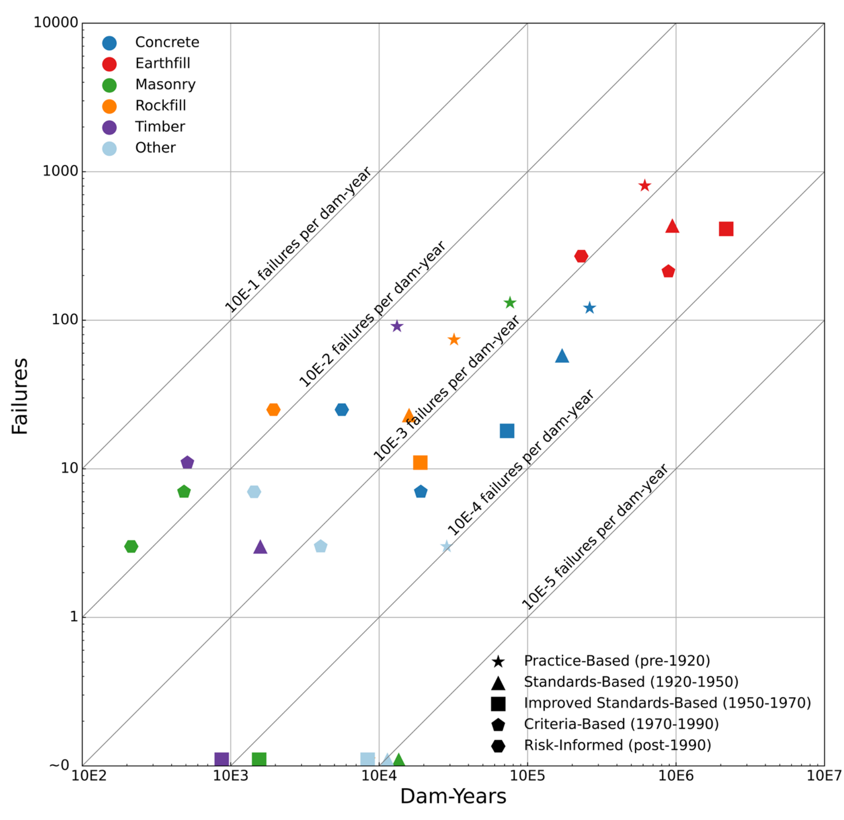

FIGURE 3: Failures, failure rates, and dam-years for various dam types and construction eras.

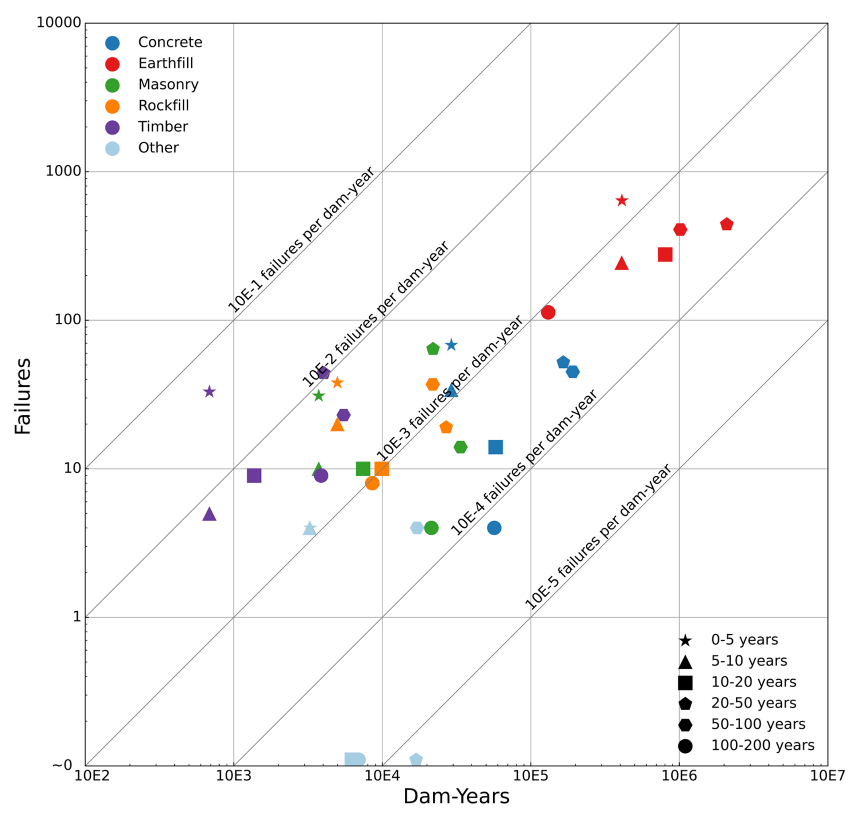

FIGURE 4: Failures, failure rates, and dam-years for various dam types and dam ages.

Regression Analysis

Dummy variables, with values of either 0 or 1, were used represent the categorical variables for dam type, construction era, and dam age. Ordinary least squares linear regression analysis was done in log-space with each subcategory constituting a single data point in the regression. Two different versions of this regression analysis were done: (i) considering dam type, construction era, and dam age as shown in Equation 2 and Table 2; and (ii) considering dam type and dam age only, as shown in Equation 3 and Table 2.

$$Failure\ Rate = e^{a+b+c+y_0} \qquad (2)$$

$$Failure\ Rate = e^{a+c+y_0} \qquad (3)$$

TABLE 1: Coefficients and standard errors for the ordinary least squares linear regression including the effects of dam type, construction era, and dam age.

Dam Type Parameter, a	**Value**	**Standard error**
Concrete	-0.73	0.61
Earthfill	-1.16	0.59
Masonry	0.73	0.63
Rockfill	0.82	0.62
Timber	2.14	0.65
Other	0	0.62
Construction Era Parameter, b	**Value**	**Standard error**
Practice-Based (pre-1920)	-0.82	0.37
Standards-Based (1920-1950)	-1.28	0.44
Improved Standards-Based (1950-1970)	-1.67	0.47
Criteria-Based (1970-1990)	-0.41	0.44
Risk-Informed (post-1990)	0	0.43
Dam Age Parameter, c	**Value**	**Standard error**
0-5 years	3.09	0.51
5-10 years	2.08	0.51
10-20 years	1.31	0.52
20-50 years	1.35	0.51
50-100 years	0.97	0.52
100-200 years	0	0.51
Constant, y_0	**Value**	**Standard error**
All dams	-8.76	0.76

TABLE 2: Coefficients and standard errors for the ordinary least squares linear regression including the effects of dam type and dam age only.

Dam Type Parameter, a	**Value**	**Standard error**
Concrete	-1.16	0.65
Earthfill	-1.70	0.63
Masonry	0.48	0.69
Rockfill	0.41	0.67
Timber	1.79	0.70
Other	0	0.67
Dam Age Parameter, c	**Value**	**Standard error**
0-5 years	3.30	0.53
5-10 years	2.15	0.53
10-20 years	1.47	0.55
20-50 years	1.21	0.53
50-100 years	0.74	0.56
100-200 years	0	0.53
Constant, y_0	**Value**	**Standard error**
All dams	-9.19	0.76

Limitations

The main limitations in this study are: (i) completeness, or lack thereof, of the two datasets considered; and (ii) that no distinction is made between the types, causes, severity, and consequences of dam failures.

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