Afro-Asian Journal of Scientific Research (AAJSR)
المجلة الأفروآسيوية للبحث العلمي
E-ISSN: 2959-6505
Volume 4, Issue 2, 2026
Page No: 306-316
Website: https://aajsr.com/index.php/aajsr/index
SJIFactor 2024: 5.028 ISI 2025: 0.915 معامل التأثير العربي (AIF) 2025: 0.76

Durability of Dams Against Severe Weather Conditions

Amad Deen Abdusalam Alghwail*
Civil Engineering Department, Faculty of Engineering, Elmergib University, Alkhums, Libya.

متانة السدود في مواجهة الظروف الجوية القاسية

عماد الدين عبد السلام الغويل*
قسم الهندسة المدنية، كلية الهندسة، جامعة المرقب، الخمس، ليبيا

*Corresponding author: aaalghwail@elmergib.edu.ly

Received: March 20, 2026 Accepted: May 05, 2026 Published: May 20, 2026

Abstract:

Dams play an essential role in today's water management. However, the vulnerability of dams in case of extreme weather caused by climate change remains a crucial issue. The present literature review analyzes studies on the strength of different dams: earth-fill, concrete gravity, arch, and rockfill. In particular, the paper examines the performance of such structures in terms of floods, heavy rains, earthquakes, fast water-level reduction caused by lengthy drought periods, and significant wind loads. Historical cases of failures of Vajont Dam in Italy (1963), Banqiao Dam in China (1975), Teton Dam in Idaho, United States (1976), Oroville Dam in California, United States (2017), and Derna dam collapses in Libya (2023), as well as recent monitoring findings will be considered. It will be explored how design, building material, functioning of spillways, and maintenance procedures impact the reliability of a structure. Findings indicate that overtopping, especially as a result of incorrect estimation of the Probable Maximum Flood (PMF), is the most frequent reason for failure. Meanwhile, seepage and internal erosion lead to most other cases of dam breakage.

Keywords: Dam safety; Severe weather; Overtopping; seepage; Structural resilience.

الملخص:

تلعب السدود دورًا أساسيًا اليوم في إدارة المياه. ومع ذلك، فإن ضعف السدود في حالة الطقس المتطرف الناجم عن تغير المناخ يظل قضية حاسمة. تحلل مراجعة الأدبيات الحالية الدراسات حول قوة السدود المختلفة: الردم الأرضي، والجاذبية الخرسانية، والقوس، والردم الصخري. وعلى وجه الخصوص، تتناول هذه الورقة أداء هذه الهياكل من حيث الفيضانات والأمطار الغزيرة والزلازل والانخفاض السريع في مستوى المياه الناجم عن فترات الجفاف الطويلة وأحمال الرياح الكبيرة. سيتم النظر في الحالات التاريخية لفشل سد فاجونت في إيطاليا (1963)، وسد بانكياو في الصين (1975)، وسد تيتون في أيداهو، الولايات المتحدة (1976)، وسد أوروفيل في كاليفورنيا، الولايات المتحدة (2017)، وانهيار سد درنة في ليبيا (2023)، بالإضافة إلى نتائج الرصد الأخيرة. سيتم استكشاف كيفية تأثير التصميم ومواد البناء وعمل مجاري تصريف المياه وإجراءات الصيانة على موثوقية الهيكل. تشير النتائج إلى أن التجاوزات، خاصة نتيجة التقدير غير الصحيح للفيضان الأقصى المحتمل (PMF)، هو السبب الأكثر شيوعًا للفشل. وفي الوقت نفسه، يؤدي التسرب والتآكل الداخلي إلى معظم حالات انهيار السدود الأخرى. البحث.

الكلمات المفتاحية: سلامة السدود، الأحوال الجوية القاسية، فيضان المياه، التسرب، المرونة الهيكلية.

Introduction:

Construction of dams has been one of the oldest engineering achievements by humans. From the early Marib Dam in Yemen constructed in around 750 BCE to today's modern structures like the Three Gorges Dam in China, the hydraulic structures have impacted civilizations through providing water for irrigation, management of floods, power generation through hydroelectricity, as well as provision of drinking water (ICOLD, 2020). Presently, there are about 58,700 large dams around the world that store 7,000 km3 of freshwater, which is equivalent to 15% of the annual global flow volume in rivers (World Commission on Dams, 2000). While dams are significant socioeconomically, they can be affected by several forms of weather risks that may impact their structure integrity, sustainability, and safety. Over the past years, more academic attention has been drawn to the effect of weather and climatic factors on dams because of the human-induced climate changes that would bring about more incidences of heavy rainfall, prolonged droughts, and other geophysical issues (IPCC, 2021). Notably, according to ICOLD, overtopping and flooding are the main causes of failure of large dams, accounting for approximately 30-34% of all dam collapses (Foster et al., 2000).

The objectives of this review paper can be stated as threefold: (1) to provide a systematic study of failure mechanisms caused by weather effects on dams of various kinds; (2) to consider important cases of dam failures and nearly failed structures due to the presence of severe weather phenomena; and (3) to evaluate existing and evolving engineering solutions designed to extend dams life cycle. Figure 1 highlights failure mechanisms considered in this review.

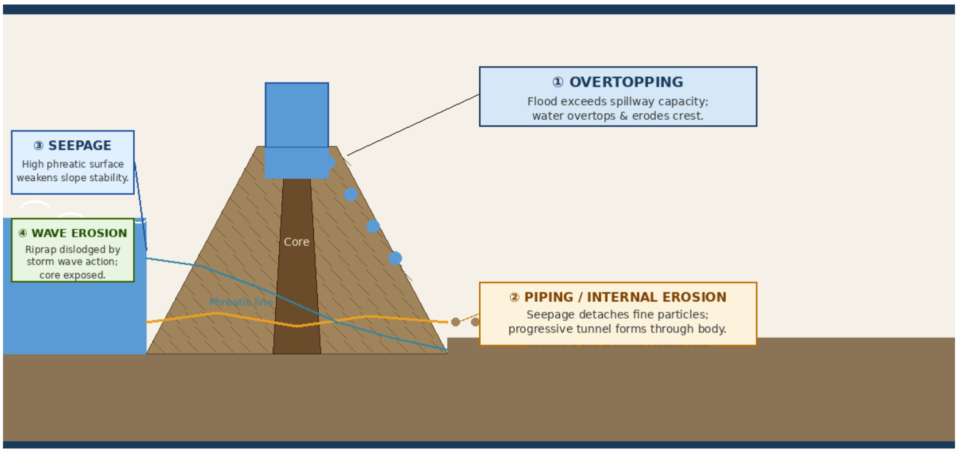

Figure (1): Principal weather-driven dam failure mechanisms: overtopping, piping/internal erosion, seepage & wave erosion.

Dam Typology and Inherent Weather Vulnerabilities:

1. Earth-Fill and Rock-Fill Embankment Dams:

Approximately 70% of all big dams worldwide are embankment dams of the homogeneous earth-fill, zonal earth-fill, and rock-fill types (Foster et al., 2000). Because they are made of compacted materials, these structures are more vulnerable to rainwater erosion, seepage, and internal erosion known as piping. Foster et al. claim that a very high percentage of total embankment dam failures are caused by the phenomenon of piping, which is most common at the interface between the core and filter zones. This is especially true when there is significant water saturation before the event (2003). Because of their concrete impermeable facing slab, CFRDs have a great capacity to stop seepage. However, uneven settlement or earthquakes may cause the latter to fracture, and freeze-thaw processes make high altitudes more susceptible to this impact (Xu et al., 2012).

2. Concrete Gravity Dams:

Concrete gravity dams depend on their weight for resisting hydrostatic pressure and are perceived to be more resistant to overtopping compared to embankment dams. Nonetheless, according to Wieland (2012), one of the factors that may make uplift pressures exerted by water to become dangerous is when there are blockages within the drainage system, thus reducing the weight of the dam and making it prone to sliding across horizontal joints. Another factor that affects durability is alkali-silica reaction (ASR) in which case the growth of expansion resulting from chemical reactions is accelerated when exposed to humidity and temperature variation (Swamy, 1992).

3. Arch Dams:

The curvature of an arch dam transfers the horizontal pressure of the water to the canyon's sides, making the construction of such a dam incredibly cost-effective. However, the high reliance on rock stability makes such dams extremely vulnerable to geomorphic changes due to prolonged saturation of the canyon sides; the Vajont arch dam failure, which resulted from a landslip caused by prolonged rains, is proof of the significance of taking geomorphology into account when analyzing a dam's resist.

Weather-Driven Failure Mechanisms:

1. **Overtopping from Extreme Flood Events:**

When water in a reservoir overflows the dam's crest, it is known as an overtopping. This happens mostly as a result of excessive rainfall and rapid snowmelt, which causes an excess inflow that exceeds the spillway's maximum discharge capacity. About 34% of all embankment dam collapses in the United States are caused by overtopping, according to FEMA (2015). The Probable Maximum Flood (PMF) is the design criterion that should be used to assess a dam's ability to withstand floods. However, a growing body of data indicates that PMFs that were previously estimated likely to underestimate the real quantity of flooding in areas that are undergoing climate change.

2. **Seepage, Piping, and Internal Erosion:**

When seepage rates in embankments or foundations surpass the rates at which tiny particles can be moved outside, internal erosion protection mechanisms such as piping, suffusion, and contact erosion begin. According to Fell et al. (2008), persistent wet circumstances that result in elevated groundwater levels in embankments typically deteriorate the effectiveness of internal filters. According to research by Wan et al. (2004), internal erosion happens even in filters that follow standard procedures, and the critical hydraulic gradient for piping failure varies significantly depending on the gradation characteristics of the soil.

3. **Seismic Loading and Weather Interactions:**

Long-term rainfall is linked to increased pore water pressure, which lowers the embankment and foundation soils' effective stress and shear strength and leaves them vulnerable to deformation during earthquakes (Makdisi & Seed, 1978). The 2008 Sichuan earthquake that severely damaged the Zipingpu Concrete Faced Rockfill Dam was one instance of such a phenomenon. Large face slab cracking and settlements up to 74 cm occurred because to a high reservoir level and ground vibrations (Kong et al., 2011).

4. **Drought-Induced Drawdown and Thermal Stress:**

Low water levels in dams are caused by drought. Because there will be less stabilizing force applied to the slope by the external water body, it will take less time to release the water that has been stored, which could lead to slope failure. The dam's internal pressures will remain rather high. Additionally, deep dams like gravity and arch dams may experience uneven stress in the event of excessive summertime temperatures because of the temperature differential between the water and the atmosphere.

5. **Wind and Wave Erosion:**

Waves created by persistently high winds will damage upstream erosion prevention covers on embankment dams, such as rip-rap and armor stones. Because large reservoirs have long fetch lengths and considerable wave action, wave run-up is one of the factors to be taken into account when determining suitable freeboard elevations (U.S. Army Corps of Engineers, 1984). Current dams may need to reevaluate their freeboards due to variations in wind patterns that could alter wave motions (Young et al., 2011).

Case Studies of Weather-Related Dam Failures and Near-Failures:

The graph below, titled "Figure 2, Timeline of Major Weather-Related Dam Disasters," chronicles five dam breaches that occurred between 1960 and 2030 and were all brought on by extreme weather. On the horizontal timeline, all accidents are represented by colored dots, with red dots denoting those in which a sizable number of people died. The timeline specifically highlights the collapse of the Teton Dam in the United States in 1976, the Vajont disaster in Italy in 1963, and the accident at the Derna Dam in Libya in 2023, all of which were caused by natural phenomena: the seepage process in the first instance, a massive landslip that caused floods in the second instance, and Medicane Daniel in the latter event, which resulted in approximately 11,300 fatalities. The Oroville case in 2017, when heavy rains forced authorities to evacuate roughly 188,000 inhabitants, and the Banqiao catastrophe in 1975, which was brought on by Typhoon Nina, are the final two disasters listed in the timeline.

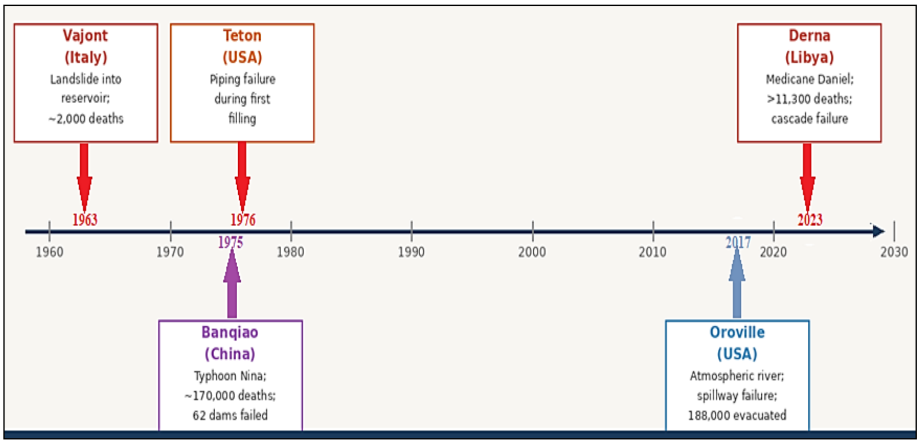

Figure (2): Timeline of major weather-related dam disasters.

Banqiao Dam, China (1975):

One of the worst dam disasters ever documented is the collapse of the Banqiao Dam. The earthen dam, which was built on the Ru River between 1951 and 1954, had a clay core that could withstand floods that would happen once every 1,000 years. However, Typhoon Nina caused the dam to overflow and subsequently collapse, releasing almost 600 million cubic meters of water after delivering nearly 1,060 mm of rainfall in three days—more than double its capacity (Qing, 1998). The catastrophe significantly affected China's dam safety regulations.

When it collapsed, 2.8 million cubic feet of water were discharged at a rate of 2.8 million cubic feet per second, creating a flood wave that stretched over 7 miles across the impacted area, covering an estimated 3 million acres, or the area of the state of Connecticut. All communities downstream were completely destroyed as a result of the inability to warn the people downstream due to malfunctioning communication equipment. The outcomes were catastrophic, even if the exact number of deaths is unknown. According to local estimates, 63.5% of the residents of Qianhu Village died (Reclamation Consequence Estimating Methodology, RCEM, Reclamation 2015).

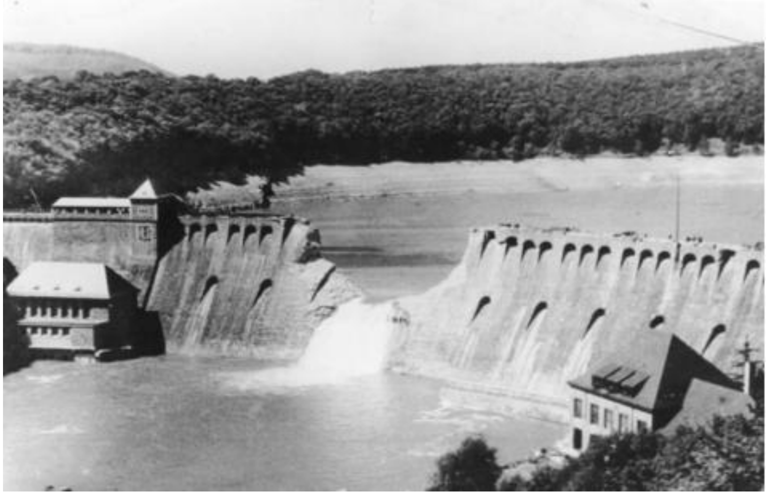

Figure (3): View of Banqiao Dam failure in August 1975.

Teton Dam, USA (1976):

The Teton Dam breach is thought to have been caused by improperly designed critical trenches in the abutment section made of loessial soils that are prone to internal erosion (Independent Panel to Review Cause of Teton Dam Failure, 1976). After an unusually wet spring, the building fell during its initial filling. Because of this tragedy, the National Dam Inspection Act of 1972 officially established the U.S. Federal Dam Safety Program (U.S. Army Corps of Engineers, 1984).

A. Beginning of Teton Dam breach **B**. After the Teton Dam breach

Figure (4): Teton Dam breach sequence, U.S. Bureau of Reclamation.

Oroville Dam Spillway Incident, USA (2017):

After a protracted drought, the Feather River watershed experienced extraordinary rainfall in February 2017 due to the greatest atmospheric river event ever recorded in California (White et al., 2019). A structural flaw in the foundation was revealed by excessive flows across the main concrete spillway, which also created an erosion hole that was almost 45 meters deep. Erosion started moving upstream after the emergency spillway was utilized, endangering the spillway weir's structural integrity. About 188,000 people who lived downstream had to be evacuated as a result, and the repair costs came to $1.1 billion (White et al., 2019). The image shows that the earthen emergency spillway lies to the left of the main spillway, which is damaged and has split in two.

Figure (5): Oroville Dam spillway failures, February 2017

Abu Mansur and Bilad Dams, Derna, Libya (2023):

In the evening of September 10–11, 2023, a catastrophic failure occurred in the upper and lower Abu Mansur and Bilad, respectively, in the Wadi Derna valley in northeastern Libya, resulting in the worst dam disaster in the present century. With a capacity of between 22.5 and 1.5 million cubic meters of water, this kind of earth fill dam, which was constructed between 1973 and 1977 with Yugoslavian technical assistance, had not been maintained or inspected on a regular basis for at least 20 years (Paron et al., 2023; UN Human Rights, 2023).

The abrupt development of a Mediterranean cyclone dubbed Daniel on September 10th, when the weather system intensified due to unusually warm water temperatures in the central Mediterranean Sea, was what immediately caused this horrific calamity. Over the Al-Jabal Al-Akhdar highland, which is upstream of the town of Derna, it produced 414 millimeters of precipitation in less than a day, which is much more than the area's average annual rainfall amount with a frequency of more than 500 years (Nanditha et al., 2024).

Figure (6): Derna before and after the dam failures of 10–11 September 2023

Research has demonstrated that human-caused climate change rendered Medicane Daniel far worse than it otherwise would have been. This kind of incident is really thought to be roughly twice as likely to occur now as it was before to the Industrial Revolution. The first dam to collapse was the Abu Mansur dam, which could not withstand the enormous volume of water that flooded over it. The Bilad dam collapsed as a result of the floodwaters rushing downstream when it failed. As a result, the city of Derna was hit by a massive, devastating wave that carried a variety of debris and even carried some of it into the Mediterranean Sea.

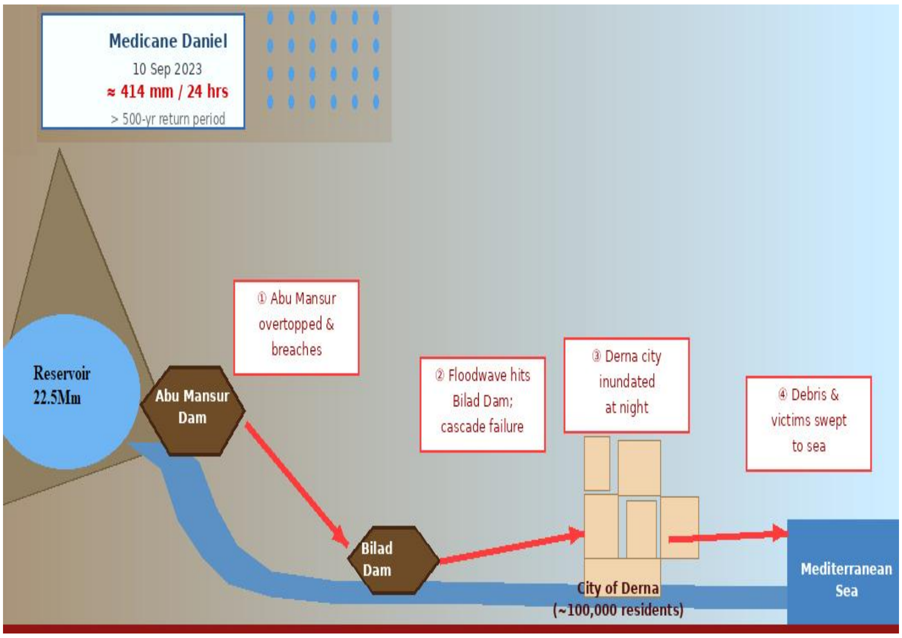

Figure (7): Schematic diagram of the Derna cascade failure sequence, 10–11 September 2023

Based on different official sources, enough data can be built about studied dams to present a comprehensive table of the relevant information, as shown in table 1.

Table (1): Detailed comparison of five major dam disasters: Vajont, Banqiao, Teton, Oroville and Derna, covering dam dimensions, flood data, casualties, and damage.

Dam / event	Date	Dam height	Dam type	Reservoir capacity	Water released	Deaths
Vajont Vajont River, Italy	Oct 9, 1963	262 m	Concrete double-arch	168.7 Mm^3	~50 Mm^3 overtopped	~1,900–2,500 5 towns destroyed; 94% fatality rate in Longarone
Banqiao Ru River, Henan, China	Aug 8–9, 1975	24.5 m	Clay-core / sand-shell earthfill	492 Mm^3	~500,000 acre-ft; peak flow 78,800 m^3/s	26,000–240,000 62 dams failed; 10.15 M people affected; 5–6.8 M homes destroyed
Teton Teton River, Idaho, USA	Jun 5, 1976	93 m	Zoned earthfill embankment	355.5 Mm^3	~173,000 acre-ft in ~2.5 hrs; peak 1 M ft^3/s	11 confirmed 25,000 homeless; 20,000 livestock killed; flood 8 mi wide, 20 mi downstream
Oroville Feather River, California, USA	Feb 7–12, 2017	235 m	Earthfill embankment (tallest in USA)	4,364 Mm^3 (Lake Oroville)	Spillway erosion; no full breach; ~100,000 cfs released	0 deaths 188,000 evacuated from 3 counties; no casualties
Derna (Abu Mansour + Al-Bilad) Wadi Derna, Libya	Sep 10–11, 2023	75 m + 25 m (two dams)	Clay-core rockfill earthfill (built 1973–77)	22.5 Mm^3 (Abu Mansour) + 1.5 Mm^3 (Al-Bilad)	~30 Mm^3 released; ~400 mm rain in 24 hrs	4,540 officials; ~11,000–12,000 estimated 3,297 officially missing; ~25% of Derna destroyed; 90,000 city population

Engineering Strategies for Enhanced Durability Against Severe Weather:

1. Revised Hydrological Design Standards:

According to Vogel et al. (2011), the assumption of stationarity, or a continuation of historical climate trends, does not apply to the case of manmade climate change. They suggest systematically considering climatic model outputs while calculating the probable maximum flood (PMF). As a result, several countries' organizations responsible for dam safety have changed their policies, incorporating consideration of climate change scenarios into the dam safety assessment process (ICOLD, 2020). The incident at Derna serves as a good example of the problem: the excessive rainfall caused by Medicane Daniel, a flood that happens once every five centuries (Nanditha et al., 2024).

2. Spillway Capacity Enhancement:

Labyrinth and piano-key weirs can be used when enhanced hydrologic analysis demonstrates that a dam's spillway capacity is inadequate because they provide a flow rate per width that is two to four times greater than that of traditional ogee weirs with the same crest length (Lempňère & Ouamane, 2003). Many large dams in Europe and North America have implemented passive fuse-plug auxiliary spillways, which are activated at predefined flood levels, providing an additional method of releasing floodwater without requiring the physical operation of any gates. Regarding the Derna dams, overtopping might have been prevented with even a slight increase in spillway capacity and appropriate gate operation to lower the water level before a significant rainfall event.

3. Structural Monitoring and Early Warning Systems:

Continuous evaluation of seepage, deformation, and variations in pore water pressure is made possible by health monitoring systems that employ piezometers, inclinometers, settlement meters, and fiber-optic sensing devices. According to Farrar and Worden (2012), a dam's atypical behavior can be detected days before any clear indications of its approaching collapse thanks to machine learning-based analysis of data from such systems. Proper early warning also requires the integration of local emergency planning and flood models, as demonstrated by the Derna instance.

4. Concrete Face and Surface Protection:

Silane/siloxane sealer treatments can be applied to a concrete gravity and arch dam that is failing because of surface deterioration caused by ASR, freeze-thaw cycles, or chemical exposure. This kind of treatment has the ability to stop additional ASR damage and lessen water infiltration (Swamy, 1992). In Norway and Switzerland, HPFRC overlay systems have been used for upstream repairs on the face of concrete dams to improve resilience to wave erosion (Wieland, 2012).

5. Embankment Slope Protection and Filter Improvement

Compared to loose riprap, ACB systems and grouted riprap are significantly more resistant to wave displacement (U.S. Army Corps of Engineers, 1984). Internal filter repair using compaction grouting or jet grouting has been recommended when inspection reveals poor filter gradation but reservoir level decrease is not feasible (Fell et al., 2008).

6. Governance and Institutional Frameworks

The sixth aspect of dam resilience which is occasionally overlooked in technical discussions is revealed by the tragedy of Derna. Even the most technically sound dams could become major hazards if the safety supervision system fails due to a disagreement, a lack of financing, or political unrest. Instead of viewing dam safety as a one-time engineering effort, ICOLD (2020) emphasizes the need for institutions to be permanently involved in the matter. The lack of an international control system for dams in crisis-prone governments is the current issue with the current global framework for dam safety.

Climate Change Implications for Dam Safety:

There is a very high probability that climate change would aggravate the water cycle globally, according to the IPCC's sixth assessment report from 2021. Most parts of the world will have more frequent and powerful rainstorms as a result of climate change, whereas middle-latitude continents would see longer and more severe droughts. This increases the dams' vulnerability to floods and damage as a result of a protracted dry spell.

Hirabayashi et al. predict that by 2050, there will be floods in parts of East Africa, South Asia, and Southeast Asia that happen once every fifty years, once every hundred years, or even sooner. This suggests that the majority of current dams built according to certain standards will probably suffer more negative consequences than anticipated over their lifetime. Furthermore, as demonstrated in 2023 during the creation of Medicane Daniel, the observed rise in Mediterranean surface temperatures causes an increase in medicane production (Tous & Romero, 2013; Faranda et al., 2023). Dams in the Middle East and North Africa are particularly problematic since they were constructed on erroneous weather data.

For instance, seasonal water influxes have changed in mountainous regions where there is less snow storage in the catchments that result in massive dams, causing extra pressures (Barnett et al., 2005). Therefore, dam safety assessments need to reflect changeable conditions and not design flood levels (ICOLD, 2020).

Conclusions and Recommendations:

This analysis demonstrates that ensuring dams can resist extreme weather entails a complex interplay of hydrology, geotechnical and structural engineering, materials research, and operational management**. Important conclusions include:**

- **First,** the primary cause of dam failure globally is still overtopping brought on by floods that exceed design capacity. A crucial gap in safety procedures is being created by mounting evidence that climate change is increasing flood severity more quickly than current techniques for updating probable maximum flood (PMF) forecasts.
- **Second,** the majority of non-overtopping failures are caused by internal erosion and cracking, which are frequently brought on by prolonged high-water tables during protracted wet periods. These hazards highlight the necessity of meticulous filter design, quality control during construction, and continuous seepage monitoring following construction.
- **Third,** case studies of Banqiao, Teton, Vajont, Oroville, and Derna highlight a persistent institutional flaw: infrequent but physically feasible climatic phenomena have disproved presumptions about the upper bounds of weather extremes. The Derna tragedy serves as an example of how institutional failure and structural flaws combine to increase risk; even in cases where extreme rainfall is predicted with accuracy, the lack of operational safety mechanisms and emergency procedures can result in a significant death toll. This emphasizes the need for better probabilistic risk models that evaluate the effects of weather events outside of historical records.
- **Fourth,** there are tried-and-true technical solutions that can reduce the dangers associated with weather events, like improved spillways, real-time structural health monitoring, climate-resilient hydrologic criteria, and protective surface technologies. Financial constraints or bureaucratic hold-ups may limit these strategies, especially when it comes to large, older dams. Derna also emphasizes the significance of international regulations to guarantee safety at dams in states that are vulnerable and those that have recently experienced a conflict.

As a result, the following suggestions should be taken into consideration: (1) national regulators should incorporate climate scenario analysis with estimates of medicane and atmospheric rivers becoming more intense in the risk evaluation process for all dams; (2) an ensemble of climate models with a quantitative uncertainty assessment rather than fixed engineering standards should be used when reviewing spillway capacity; (3) real-time sensors and management systems accounting for weather impacts should be deployed at dams where this technology is most needed; (4) information on pre-failure indications and near misses should be routinated internationally; and (5) an international system for evaluating and rehabilitating dams in order to prevent future.

References:

1. ACAPS. (2023, September 15). Libya: Update on the impact of Storm Daniel in Derna district. ReliefWeb. https://reliefweb.int/report/libya/acaps-thematic-report-libya
2. American Rivers. (2020, March 4). Dam safety for downstream safety: Revisiting the Oroville Dam spillway failure. https://www.americanrivers.org/2020/03/dam-safety-for-downstream-safety-revisiting-the-oroville-dam-spillway-failure/
3. Association of State Dam Safety Officials. Abu Mansour & Al-Bilad Dams (Libya, 2023). ASDSO Dam Failures and Lessons Learned. https://damfailures.org/case-study/abu-mansour-al-bilad-dams-libya-2023
4. Association of State Dam Safety Officials. Banqiao Dam (China, 1975). ASDSO Dam Failures and Lessons Learned. https://damfailures.org/case-study/banqiao-dam-china-1975
5. Association of State Dam Safety Officials. Dam failure case study: Teton Dam (Idaho, 1976). ASDSO Dam Failures and Lessons Learned. https://damfailures.org/case-study/teton-dam-idaho-1976.
6. Association of State Dam Safety Officials. Oroville Dam (California, 2017). ASDSO Dam Failures and Lessons Learned. https://damfailures.org/case-study/oroville-dam-california-2017
7. Association of State Dam Safety Officials. Vajont Dam (Italy, 1963). ASDSO Dam Failures and Lessons Learned. https://damfailures.org/case-study/vajont-dam-italy-1963
8. Barnett, T. P., Adam, J. C., & Lettenmaier, D. P. (2005). Potential impacts of a warming climate on water availability in snow-dominated regions. Nature, 438(7066), 303–309. https://doi.org/10.1038/nature04141
9. Britannica, T. Editors of Encyclopaedia. (2025). Typhoon Nina–Banqiao dam failure. Encyclopaedia Britannica. https://www.britannica.com/event/Typhoon-Nina-Banqiao-dam-failure
10. Cooke, J. B. (1984). Progress in rockfill dams. Journal of Geotechnical Engineering, 110(10), 1389–1414. https://doi.org/10.1061/(ASCE)0733-9410(1984)110:10(1389)
11. Faranda, D., Pascale, S., & Bulut, B. (2023). Increasing occurrence and severity of some meteorological extreme events with anthropogenic climate change. npj Climate and Atmospheric Science, 6, 125. https://doi.org/10.1038/s41612-023-00462-2
12. Farrar, C. R., & Worden, K. (2012). Structural health monitoring: A machine learning perspective. John Wiley & Sons.
13. Federal Emergency Management Agency (FEMA). (2015). Federal guidelines for dam safety risk management (FEMA P-1025). U.S. Department of Homeland Security.
14. Fell, R., MacGregor, P., Stapledon, D., Bell, G., & Foster, M. (2008). Geotechnical engineering of dams (2nd ed.). CRC Press.
15. Fell, R., Wan, C. F., Cyganiewicz, J., & Foster, M. (2003). Time for development of internal erosion and piping in embankment dams. Journal of Geotechnical and Geoenvironmental Engineering, 129(4), 307–314. https://doi.org/10.1061/(ASCE)1090-0241(2003)129:4(307)
16. Foster, M., Fell, R., & Spannagle, M. (2000). The statistics of embankment dam failures and accidents. Canadian Geotechnical Journal, 37(5), 1000–1024. https://doi.org/10.1139/t00-030
17. Hendron, A. J., & Patton, F. D. (1985). The Vaiont slide: A geotechnical analysis based on new geologic observations of the failure surface. U.S. Army Corps of Engineers Technical Report GL-85-5.
18. Henn, B., Musselman, K., & colleagues. (2020, July 22). Researchers identify factor behind 2017 Oroville Dam spillways incident. Scripps Institution of Oceanography, UC San Diego. https://scripps.ucsd.edu/news/researchers-identify-factor-behind-2017-oroville-dam-spillways-incident
19. Hirabayashi, Y., Mahendran, R., Koirala, S., Konoshima, L., Yamazaki, D., Watanabe, S., Kim, H., & Kanae, S. (2013). Global flood risk under climate change. Nature Climate Change, 3(9), 816–821. https://doi.org/10.1038/nclimate1911
20. Idaho Office of Emergency Management. (2019, May 20). Dam collapse. A history of Idaho disasters. https://ioem.idaho.gov/news/a-history-of-idaho-disasters/dam-collapse/
21. Independent Panel to Review Cause of Teton Dam Failure. (1976). Report to U.S. Department of the Interior and State of Idaho on failure of Teton Dam. U.S. Government Printing Office.
22. Intergovernmental Panel on Climate Change (IPCC). (2021). Climate change 2021: The physical science basis. Cambridge University Press. https://doi.org/10.1017/9781009157896

23. International Commission on Large Dams (ICOLD). (2020). Dam safety management: Operational phase of the dam life cycle (Bulletin 154).
24. Kong, X., Liu, J., & Zou, D. (2011). Numerical simulation of the dynamic response of Zipingpu concrete-faced rockfill dam during the Wenchuan earthquake. Science China Technological Sciences, 54(2), 5–15. https://doi.org/10.1007/s11431-011-4660-6
25. Lane, P. A., & Griffiths, D. V. (2000). Assessment of stability of slopes under drawdown conditions. Journal of Geotechnical and Geoenvironmental Engineering, 126(5), 443–450. https://doi.org/10.1061/(ASCE)1090-0241(2000)126:5(443)
26. Léger, P., & Leclerc, M. (2007). Hydrostatic, temperature, time-displacement model for concrete dams. Journal of Engineering Mechanics, 133(3), 267–277. https://doi.org/10.1061/(ASCE)0733-9399(2007)133:3(267)
27. Lempérière, F., & Ouamane, A. (2003). The piano keys weir: A new cost-effective solution for spillways. International Journal on Hydropower and Dams, 10(5), 144–149.
28. Makdisi, F. I., & Seed, H. B. (1978). Simplified procedure for estimating dam and embankment earthquake-induced deformations. Journal of the Geotechnical Engineering Division, ASCE, 104(7), 849–867.
29. Meehl, G. A., & Tebaldi, C. (2004). More intense, more frequent, and longer lasting heat waves in the 21st century. Science, 305(5686), 994–997. https://doi.org/10.1126/science.1098704
30. Nanditha, J. S., Kushwaha, A. P., Singh, R., Malik, I., Solanki, H., Chuphal, D. S., Dangar, S., Mahto, S. S., Vegad, U., & Mishra, V. (2024). The Libya flood of 10–11 September 2023: Roles of the atmospheric system, infrastructure failure, and climate change. Earth's Future, 12(1), e2023EF004180. https://doi.org/10.1029/2023EF004180
31. National Weather Service. (2020, June 3). Tragedy at Teton: 1976 dam break disaster. NWS Heritage – Virtual Lab. https://vlab.noaa.gov/web/nws-heritage/-/tragedy-at-teton-1976-dam-break-disaster
32. Paron, P., Albano, R., Mazzariello, A., & Sole, A. (2023). The Derna catastrophe in Libya: Hydrometeorological analysis and failure assessment of the Wadi Derna dams. EGUsphere [Preprint]. https://doi.org/10.5194/egusphere-2023-2705
33. Petley, D. (2008, December 11). The Vaiont (Vajont) landslide of 1963. The Landslide Blog, AGU Blogosphere. https://blogs.agu.org/landslideblog/2008/12/11/the-vaiont-vajont-landslide-of-1963/
34. Petley, D. (2023, September 13). The failed dams in Wadi Derna in Libya. The Landslide Blog, AGU/EOS. https://eos.org/thelandslideblog/the-failed-dams-in-wadi-derna-in-libya
35. Qing, D. (1998). The river dragon has come! The three gorges dam and the fate of China's Yangtze River and its people. M. E. Sharpe.
36. Rucci, A., Ferretti, A., Notti, D., & colleagues. (2025). Aging dams, political instability, poor human decisions and climate change: Recipe for human disaster. npj Natural Hazards. https://www.nature.com/articles/s44304-024-00056-1
37. Swamy, R. N. (1992). The alkali-silica reaction in concrete, Blackie.
38. Tous, M., & Romero, R. (2013). Meteorological environments associated with medicane development. International Journal of Climatology, 33(1), 1–14. https://doi.org/10.1002/joc.3428
39. U.S. Army Corps of Engineers. (1984). Shore protection manual (4th ed.). Coastal Engineering Research Center.
40. U.S. Bureau of Reclamation. Teton Dam history https://www.usbr.gov/pn/snakeriver/dams/uppersnake/teton/index.html
41. UN Human Rights. (2023). Libya: UN experts call for immediate international assistance and accountability for the dam collapse disaster. United Nations Office of the High Commissioner for Human Rights. https://www.ohchr.org/en/press-releases/2023/09/libya
42. United Nations Office for the Coordination of Humanitarian Affairs (OCHA). (2023). Libya: Flash update #12- Floods (15 October 2023). OCHA. https://reliefweb.int/report/libya/libya-flash-update-12-floods-15-october-2023
43. Vogel, R. M., Yaindl, C., & Walter, M. (2011). Nonstationarity: Flood magnification and recurrence reduction factors in the United States. Journal of the American Water Resources Association, 47(3), 464–474. https://doi.org/10.1111/j.1752-1688.2011.00541.x
44. Wan, C. F., & Fell, R. (2004). Investigation of rate of erosion of soils in embankment dams. Journal of Geotechnical and Geoenvironmental Engineering, 130(4), 373–380. https://doi.org/10.1061/(ASCE)1090-0241(2004)130:4(373)
45. White, A. B., Moore, B. J., Gottas, D. J., & Neiman, P. J. (2019). Winter storm conditions leading to excessive runoff above California's Oroville Dam during January and February 2017. Bulletin of the American Meteorological Society, 100(1), 55–70. https://doi.org/10.1175/BAMS-D-18-0091.1

46. Wieland, M. (2012). Safety aspects of sustainable storage dams and earthquake safety of existing large dams. Engineering, 8(3), 288–304. https://doi.org/10.4236/eng.2012.812B008
47. Witze, A. (2013, December 15). Benchmarks: October 9, 1963: The Vajont landslide kills 2,500 in Italy. Earth Magazine. https://www.earthmagazine.org/article/benchmarks-october-9-1963-vajont-landslide-kills-2500-italy
48. World Commission on Dams. (2000). Dams and development: A new framework for decision-making, Earthscan.
49. Xu, B., Zou, D., Kong, X., Hu, Z., & Zhou, Y. (2012). Dynamic damage evaluation on the slabs of the concrete-faced rockfill dam with the plastic-damage model. Computers and Geotechnics, 65, 258–265. https://doi.org/10.1016/j.compgeo.2014.12.015
50. Young, I. R., Zieger, S., & Babanin, A. V. (2011). Global trends in wind speed and wave height. Science, 332(6028), 451–455. https://doi.org/10.1126/science.1197219