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Lessons Learned from Dam Failure

by

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Objectives of the Literature Review

- Insights into lifecycle of the dam:
  1. Design and Engineering
  2. Construction methodolgy
  3. Management
  4. Regulation

- Summarizing causes, impacts, and lessons learned from historic dam failures

- Focus on Indian dam failure incidences for e.g. Machu II Dam of Gujrat, Gararda Dam of Rajasthan, Tigra Dam of M.P., Indira Sagar Dam of M.P. and Annamayya Dam of A.P.

Dam Failure: Lessons learned

- First lesson: Cost of Dam safety measures is much less in comparison to what follow a dam failure.
- Dam failures are catastrophic events
- Loss of life, property damage, environmental degradation
- High hazard dams near populated areas
- Low probability, high consequences of dam failure

Learning from Case histories

- Case histories are vital for dam analysis and design
- Complementing formal engineering education
- Lessons from case histories:
  1. Potential Failure Mode initiation and progression
  2. Intervention methods and effectiveness
  3. Emergency management lessons
- Helps in preventing future incidents through past learning

Modes of Dam Failures

- Shear failure/slope failure:
  Sliding failure of U/s or D/s slope due to Inadequate shear strength or poor construction practices

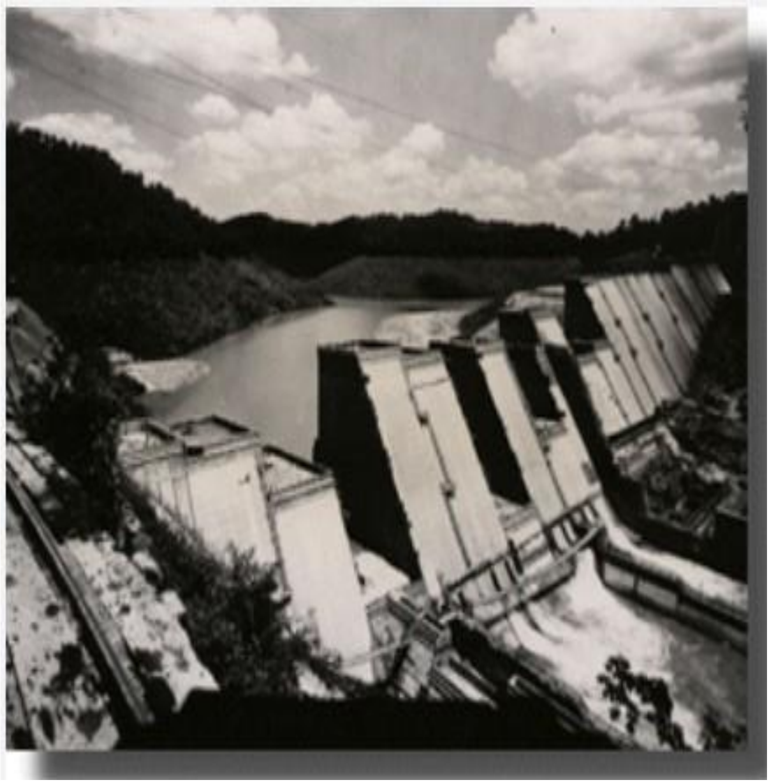
- Overtopping during a flood:
  Surface erosion and downstream slope breach

Modes of Dam Failures

- Internal erosion: Excessive seepage and leakage
- Earthquake-induced failures: Dynamic forces, slope instability, soil liquefaction
- Neglecting maintenance: Gradual deterioration, erosion, vegetation overgrowth, seepage

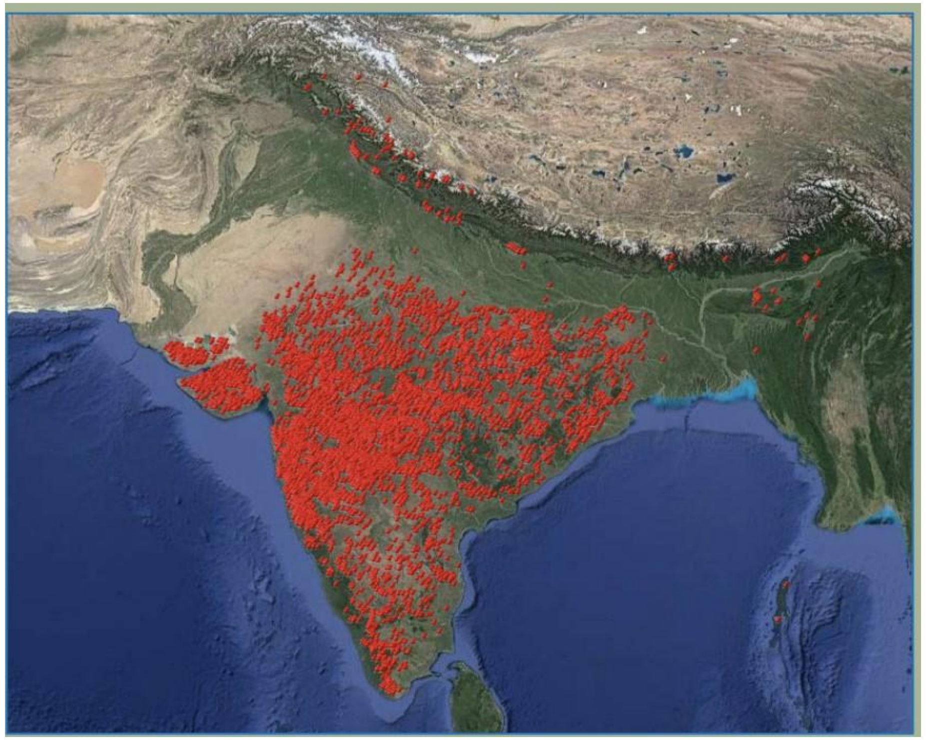
Modes of Dam Failures

- Concrete cracking, Leakage in joints
- Uplift and foundation sliding, Overturning
- Dam breakage, abutment failure



Dam landscape in India

- Total number of large dams in India: 5334
- Majority of serious incidents on Embankment Dams
- Majority built by local agencies with lack of engineering expertise



Dam failure major incident : Machu II Dam

Machhu II dam failure

- Machu II dam failure occurred on August 11, 1979, near the town of Morbi in the state of Gujarat, India
- The dam's collapse resulted in one of the most catastrophic floods in Indian history
- **Cause of Failure: Overtopping of embankment**

Machhu II dam failure… cont

- Abnormal floods and inadequate spillway capacity leading to disintegration of earthen walls of 4km long Machhu dam.

- Actual observed flow reached to 16307m^3/s, thrice of what dam was designed for.

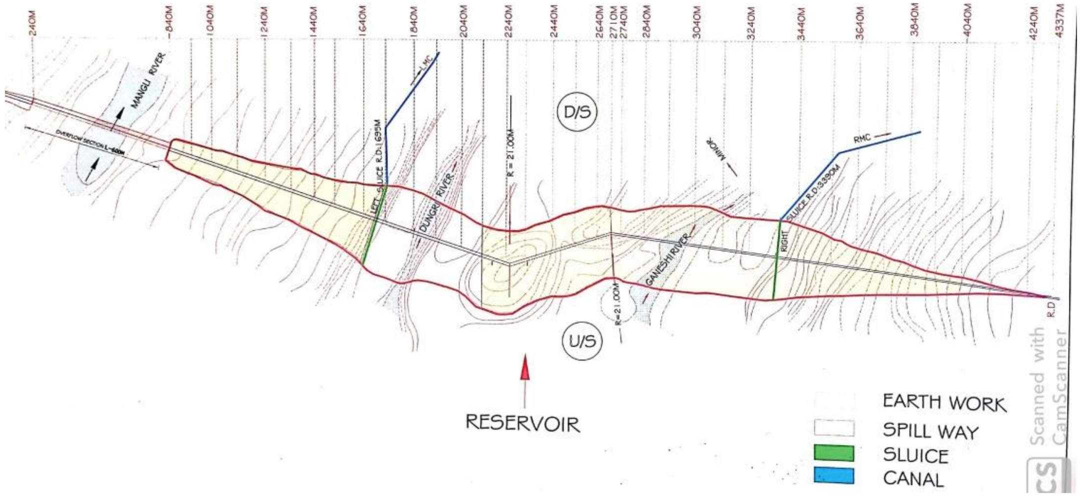
Dam failure major incident : Gararda Dam

Gararda dam failure

- Garada irrigation project, Rajasthan consists of 30m high earthen dam with masonry spillway. Total length of the dam is around 4270 meter

- The Dam taps the discharge of the three Chambal basin drainage channels, namely Mangli Nala towards the left end across which there is a spillway site, Dungi river is in the middle and the Ganeshi nala is at the right end of Dam axis.

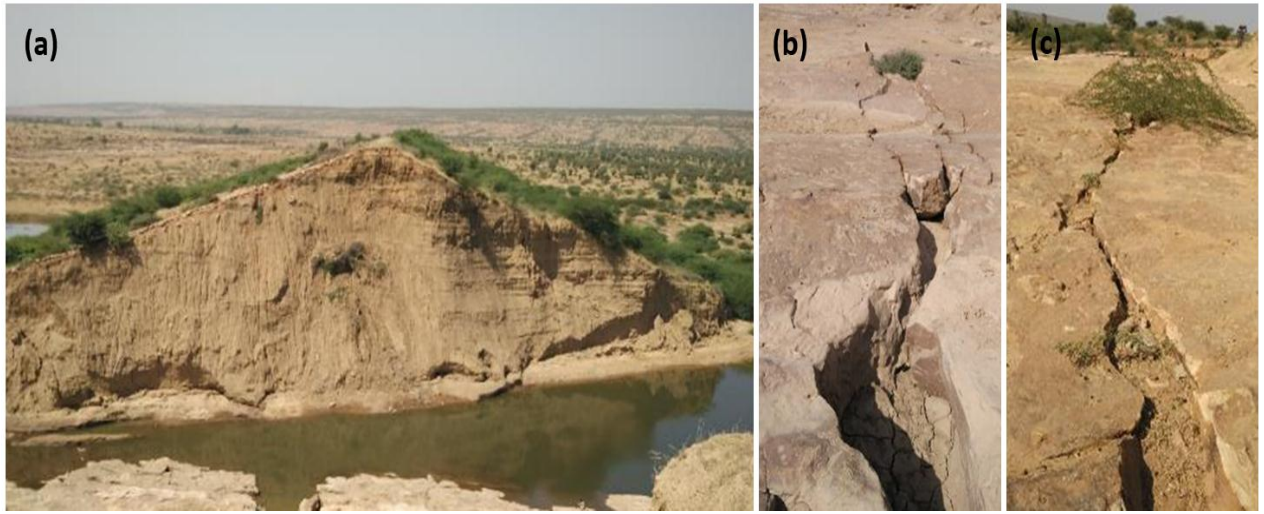
- The Garada dam, a zoned earthfill dam was completed in March, 2010 and subsequently breached on 15.08.2010 during initial filling of the reservoir when it was filled only up to 4.0m below the ungated crest level (FRL).

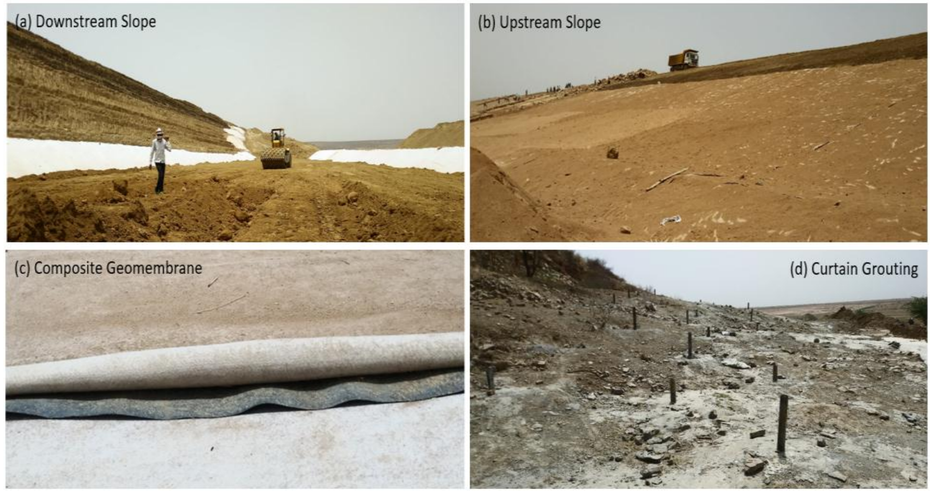


Gararda dam failure

- The Gararda Dam was subjected to an uncontrolled filling. In absence of any arrangements to control the initial reservoir filling, it was not possible to undertake any effective remedial measure, which resulted in dam failure through river closer section.
- Adequate supervision of the works was missing. There were compromises in quality of earthwork – especially on issues of construction, specification of dam materials, layer thickness, laying of filters etc.
- Seepage cut-off arrangement (COT) was not appropriately designed.

Gararda dam failure





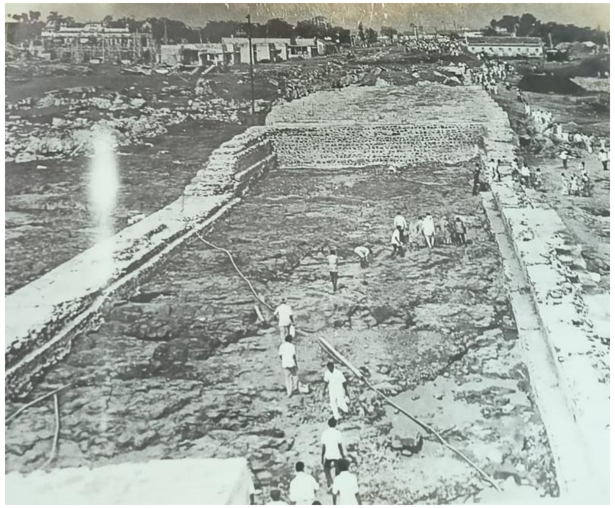
CWC redesigned the rehabilitation of the dam and used first time Geomembrane and geotextile in an earthen dam for its rehabilitation. The Rehabilitated dam got filled in 2022

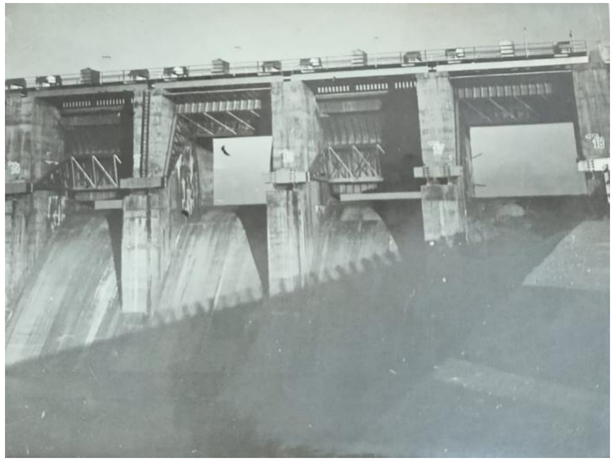
Dam Failure: Tigra Dam, MP

- Tigra Dam was first constructed between 1913 and 1917 to provide an irrigation and water supply source for the nearby major city of Gwalior, India in the central state of Madhya Pradesh.

- The dam failed tragically during a flood event on August 4, 1917, shortly after first filling.

- The 86-foot high, 4,400-foot long masonry gravity dam impounded a massive storage volume of 106,041 acre-feet. The structure was composed of a rubble masonry interior placed with lime mortar and faced with stacked masonry with cement mortar joints. The dam had a vertical upstream face and a 2:3 downstream slope.





Dam Failure: Tigra Dam, MP

- The dam was founded on stratified sandstone with near horizontal bedding planes. Excavation for the dam was limited to about a 2-foot depth although weaker zones in the sandstone were reportedly excavated deeper and filled with concrete.

- There were apparently no additional seepage control or cutoff measures installed in the dam foundation.

- Records indicate that the spillway activated during the monsoon season each year during construction, and cracking of the masonry structure was noted prior to the planned first filling of the reservoir.

Dam Failure: Tigra Dam, MP

- On 4th August, 1917, the water surface elevation in the reservoir rose to a historic level and overtopped the dam by about one foot from abutment to abutment.

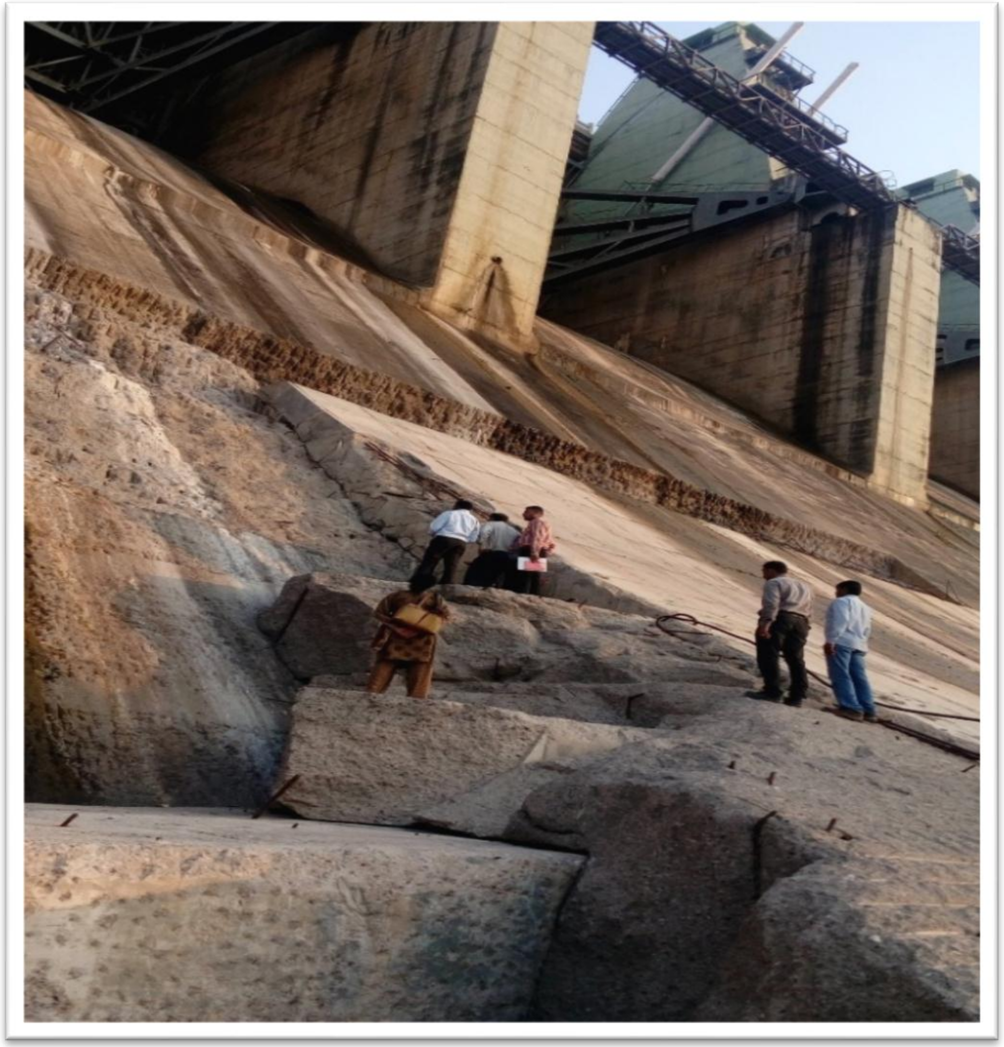
- During the overtopping event, two of the spillway monoliths were moved several hundred feet downstream resulting in an uncontrolled release of the reservoir. These two monoliths still stand today at the site as a distinct reminder of the dam failure.

- The cause of failure is generally agreed to be the result of sliding of sections of the gravity dam along the untreated, stratified foundation. The development of excessive uplift pressures creating tension at the heel of the dam and downstream scour due to overtopping likely contributed to the ability of the dam to slide.

Dam incident at Indira Sagar Dam, MP

- Indira Sagar Dam is 653 m long and 92 m in height and was built on the River Narmada in Madhya Pradesh.
- The main and auxiliary spillway comprises 12 and 8 spans respectively and is designed to dispose of a Probable Maximum Flood of 83,400 m^3/s.
- The energy dissipator provided was original in the form of a slotted roller bucket.
- The project is in operation from 2004-2005. Discharges of the magnitude 30,000 m^3/s were released during the monsoon of 2013 and then it was observed that the entire slotted roller bucket in front of spans 6 to 12 was washed away.
- The teeth of the roller bucket were overturned and thrown away by the flood waters.
- Theoretical analysis for actual discharges passed over the spillway from 2006 to 2012 indicated that the roller action was not forming for these conditions and instead ski action was taking place due to deficient tailwater levels.
- There was also a transition from ski action to roller action for increasing discharges till the tailwater build was realized.
- In fact, this is the inherent shortcoming of roller bucket type of energy dissipators and damages to the bucket have been reported elsewhere also.

Dam incident at Indira Sagar Dam, MP



Dam incident at Indira Sagar Dam, MP

- Slotted roller bucket type energy dissipators are provided for spillways when the tailwater depth is 1.2 times the sequent depth required for the formation of a hydraulic jump.

- In slotted roller buckets, the dissipation of energy occurs by the lateral spreading of jet passing through bucket slots in addition to the formation of two complementary rollers as in the solid bucket.

- These are provided for spillways where the downstream river bed is of sound rock. However, when the tailwater levels are not realized during the release of floods over the spillway and surface and ground rollers are not formed, it results in a possible sweep of the flood out of the bucket.

- Deficient tailwater levels during the initial period of operation of the bucket leading to ski action, generation of high hydrodynamic pressures during roller formation due to very high incoming velocities and occurrence of negative pressures on the bucket teeth, are some of the hydraulic parameters that lead to damage to the slotted roller bucket.

Dam incident at Indira Sagar Dam, MP

- CWC redesigned the Energy Dissipation arrangements and provided shear keys at two locations.
- Redesigned glacis
- Performed well in handling flood discharges in 2019 and subsequent years

Annamayya Dam, AP failure

- Medium Irrigation Project across Cheyyeru River, a tributary of Pennar River. Construction started in 1976-77 and completed in 2001.

- 336 m long earth dam along with 94 m long concrete Ogee spillway with 5 radial gates

- Designed for discharging 8069 cumec (200-year return period flood), however, model studies indicated discharging capacity of 6144 cumec only. Discharging capacity further reduced to 5097 cumec (with 5 gates operational) due to problems of right wing wall.

- 5^{th} spillway gate was damaged during cyclone NIVAR in Nov. 2020. Observed peak flood = 9200 cumec

- On 19. Nov. 2021, reported inflow of about 9061 cumec sustained over 2 hours, overtopped the embankment dam causing its breach in entire length.

Annamayya Dam, AP failure

- Unprecedented inflow of more than 9065 cumec
- Few units of stoplogs washed away during Nivar cyclone. Rectification works were not carried out and thus one radial gates remained in-operational.
- Energy dissipation not taking place in the stilling basin effectively
- As per Indian Standard IS 11223:1985, the project qualifies for Probable Maximum Flood of 23,296 cumec as its design flood.
- As per clause 3.6 of Indian Standard IS 11223: 1985 for mechanical and human failure a contingency of 10% of the spillway gates inoperative may be considered as an emergency condition (like earthquake) for safety of the dam and energy dissipation arrangements. As per the above clause, the flood shall pass safely with only 4 gates in operation.
- In case of Annamayya dam, the water levels in the reservoir with 10% inoperative gates (i.e. one gate inoperative) have been computed to be far above the TBL which is highly undesirable
- Discharging capacity of the spillway provided at dam was inadequate to handle such a large flood. Embankment dams are highly vulnerable to overtopping.
- Due to inadequacy of the spillway, overtopping of Annamayya embankment dam was inevitable for the inflow flood encountered in November, 2021. The entire embankment dam was washed out, first by erosion of downstream toe and subsequently by overtopping & breach of Embankment dam.

Lessons learned from Dam failure incidences

- Importance of Hydrological studies: Hydrological studies are vital in design of spillways and dam height.

- Design and Construction Quality: Proper design and construction practices, including compaction of embankment materials, selection of suitable materials, and adequate foundation preparation, are crucial to ensuring dam stability and longevity.

- Importance of Maintenance: Neglected maintenance can lead to the deterioration of dam structures, increasing the risk of failure during extreme events

- Risk Assessment: Need for accurate risk assessments that consider the potential consequences of dam failure

Lessons learned from Dam failure incidences… Contd.

- Seismic Design: Considering seismic factors in dam design and retrofitting is crucial in regions prone to earthquakes, as dynamic forces can significantly impact dam stability

- Regulatory Oversight & Community Awareness: The disaster emphasized the importance of educating communities living downstream about the potential risks associated with dams

- Emergency Preparedness: The dam disasters everywhere highlighted the necessity of well-structured emergency response plans and communication systems

Lessons learned from Dam failure incidences… Contd.

- Adaptive Management: The ability to adjust dam operations and maintenance practices based on changing conditions, such as climate patterns or geological shifts, enhances dam resilience.

- Collaboration: Collaboration among interdisciplinary teams, including geologists, hydrologists, engineers, and local communities, is essential to address the multifaceted challenges associated with dam safety.

- Learning from Failures: The analysis of past dam failures provides valuable insights that inform engineering practices, risk assessments, and regulations to prevent similar incidents in the future.

Thank You