Human Factors in Dam Failure & Safety

Case Study: Ka Loko Dam Failure

Presented By

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Outline

- Human Factors Framework
- Ka Loko Dam Failure
  - Dam Description & Timeline
  - Human Factors
- Conclusions

Human Factors Framework

Human Factors

- In engineering, we *always* have interacting physical and human factors
- Physical systems are deterministic → nature doesn't make 'mistakes'
- So failure (unmet expectations) is *fundamentally* due to human factors

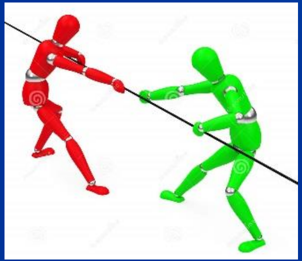
Failure vs. Safety

- Natural tendency is disorder (entropy) and ‘drift into **failure**’
- Human effort is needed to create/maintain order and achieve **safety**
- Human effort sometimes **falls short**
- So humans are both the problem (‘error’) *and solution* (achievement) → two sides of the same coin

Failure vs. Safety

Contributors to Failure

- Pressure from non-safety goals
- Complexity
- Human fallibility and limitations
- Inadequate risk management



Contributors to Safety

- Safety culture
- Best practices
  - General design features
  - Organizational & professional practices
  - Addressing warning signs

Pressure from Non-Safety Goals

- Reduce costs, increase profits
- Schedules
- Competition
- Build & maintain relationships
- Political pressures
- Personal goals

Complexity

System Features

- Components
  - Multiple
  - Physical & human
- Interactions
  - Multiple
  - Nonlinear
  - Feedback loops

Implications

- Lack of predictability
- Large effects from small causes
- Irreversibility
- Difficult to model
- Difficult to control

Human Fallibility & Limitations

- Misperceptions
- Incomplete information
- Inaccurate models & lack of knowledge
- Limited cognitive ability
- Faulty memory
- Use of heuristic shortcuts
- Biases
- Unreliable intuition

Inadequate Risk Management

- **Ignorance** – insufficiently aware of risks due to misperception or lack of knowledge
- **Complacency** – aware of risks, but overly risk tolerant (fatigue, laziness, emotions, indifference, greed, competition, etc.)
- **Overconfidence** – aware of risks, but overestimate ability to manage them (in extreme cases, arrogance or hubris)

CAUTION – Successful track record can foster all three of these!

Safety Culture

- Organizational **safety culture** in which <u>everyone</u> places value on safety at all organizational levels
  - An <u>attitude</u> of being **preoccupied with avoiding failure**

    Aware → Alert → **Vigilant** → Worried → Paranoid → Panicking

  - For safety roles, select people with **suitable personalities** (vigilant, cautious, inquiring, skeptical, meticulous, disciplined, intellectually humble, interpersonally assertive, etc.)

Safety Culture → Best Practices

- Safety culture typically leads to implementing best practices (common in dam engineering)
- 'High-reliability organizations' (HROs) are exemplars
- Best practices → success ⟺ Neglect best practices → failure
- **Failure results from *not doing* what's necessary to succeed, not from *doing* 'special' things to fail**
- **Trying *to* succeed is at least as important as trying *not to* fail**

Best Practices

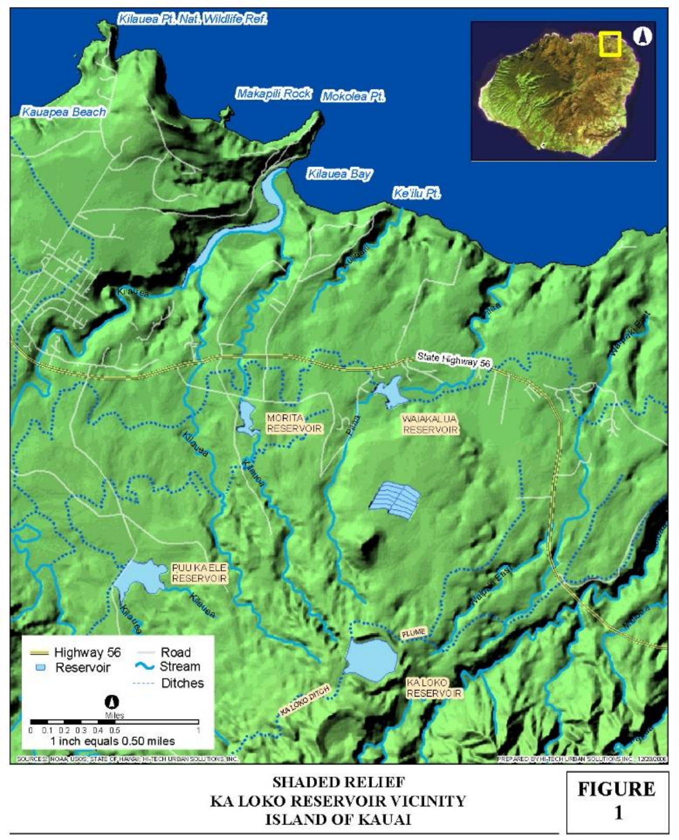
General Design Features	Organizational & Professional Practices	Warning Signs
• Conservative safety margins • Redundancy, robustness, and resilience • Progressive and controllable failure with warning signs, including accurate hazard classification and emergency action planning • Customization to project sites, including scenario planning during design and testing/adaptation during construction	• Safety culture & safety-oriented personnel selection • Peer review & cross-checking • Information sharing (allowing dissent) to ‘connect the dots’, including thorough documentation • Diverse teams, but with leadership, continuity, and avoiding ‘diffusion of responsibility’ • Recognizing knowledge limitations and deferring to expertise • Use of checklists • Appropriate system models (possibly including human factors) and failure modes, and careful software use • Professional, ethical, and legal/regulatory standards • Learning from failures and incidents	• Look for them actively and monitor, including after unusual events • Investigate to understand their significance • Address promptly and properly, with verification of follow-up • Be suspicious during ‘quiet periods’

Case Study: Ka Loko Dam Failure

Dam Description & Timeline

Description of Ka Loko Dam

- Built ~1890 in Kauai, Hawaii (part of water supply for sugarcane industry)
- Embankment dam, relatively homogenous, mostly clayey silt, partly or entirely hydraulic fill
- Originally 30’ high, raised to 42’ in ~1912
- 770’ crest length
- Over 1200 acre-feet
- Failed in 2006

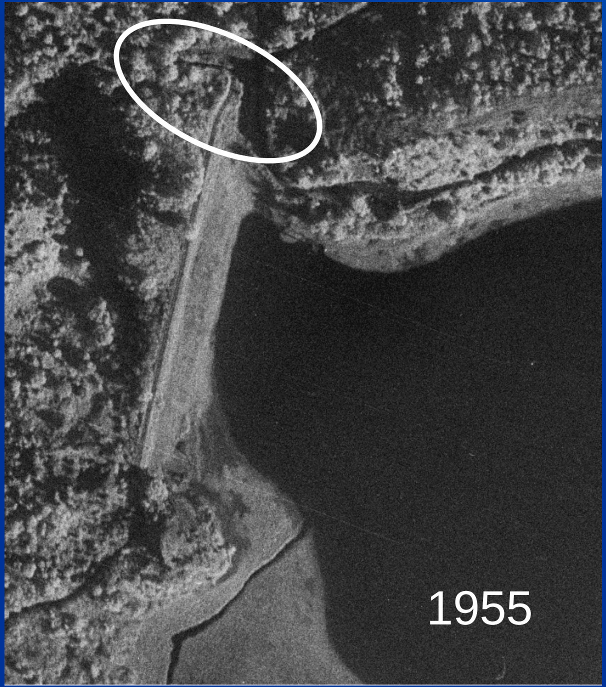


Outlet and Spillway for Ka Loko Dam

- Primary outlet: multi-pipe riser, 18” pipe conduit in tunnel with valve at mid-length
- Spillway: 1.5’ (?) x ~15’ channel (concrete lining in 1950s)
- 1940 to 1953 – Reservoir reached spillway at least 20 times, for periods up to 1 month; no evidence of dam distress

Spillway of Ka Loko Dam

- Likely location shown, though location couldn't be confirmed after the breach



Timeline for Ka Loko Dam

- 1890 and 1912 – Dam built and raised
- 1950s – Spillway lined with concrete
- 1971 – Sugarcane operations cease, facilities maintenance reduced
- 1973 – Portion of reservoir deeded to Mary Lucas Trust, with James Pflueger as beneficiary and trustee (wealthy)
- 1978 to 1981 – Corps inspects high-hazard dams, but Ka Loko classified as low hazard
- 1987 – Pflueger buys remaining portion of reservoir, taking overall control of reservoir and dam
- 1987 – Dept. of Land & Natural Resources (DLNR) becomes lead state agency for dam safety

Timeline for Ka Loko Dam

- 1993 to 1998 – Consultants assist DLNR with high-hazard dam inspections, Ka Loko still classified as low-hazard
- 1997 – Grading at reservoir without permit, County orders stop work, Mayor has County back off (Pflueger reportedly donated $9K to Mayor)
- 1997 – Further grading, including filling spillway; Pflueger cautioned by subcontractor that spillway is a ‘safety feature’ which needs to be restored, but Pflueger reportedly says ‘mind your own business’
- 1998 – Pflueger cautioned by local real estate agent (by fax) that spillway has been filled (8’ to 10’?), which will result in overtopping, and recommends restoring spillway, but no response from Pflueger

Timeline for Ka Loko Dam

- 1999 to 2001 – DLNR sends three letters to Pflueger to schedule dam inspection, and letter recommending review or development of EAP; no responses from Pflueger, no inspections, no EAP (still low-hazard classification, but regulations required inspection every 5 years)

- 1999 to 2006 – DLNR loses funding in 1999 for consultant inspections, loses more funding in coming years, supervisor retires in 2005 (leaving ~1.5 FTE for dam safety vs 6.5 FTE recommended by ASDSO), no inspections in 2005 nor early 2006

- 2002 to 2006 – 2002 inspection of grading violations by federal and state agencies, lack of spillway not noted, felony counts and ~$12M fines for environmental damages in 2006 (days before failure)

Timeline for Ka Loko Dam

- February/March 2006 – 42 days of heavy rain, 2nd or 3rd wettest such period over past ~50 years
- Late February 2006 – Small bridge destroyed by flood near reservoir, several people (not DLNR) inspect dam and lack of spillway not noted
- March 14, 2006, 5:00 am – 24 days into period of heavy rain, dam breaches, apparently due to ~2' max overtopping near former spillway (no spillway found after breach), flood depth ~10' to 30', causing 7 fatalities (including pregnant woman) ~16 min after breach

Breach of Ka Loko Dam

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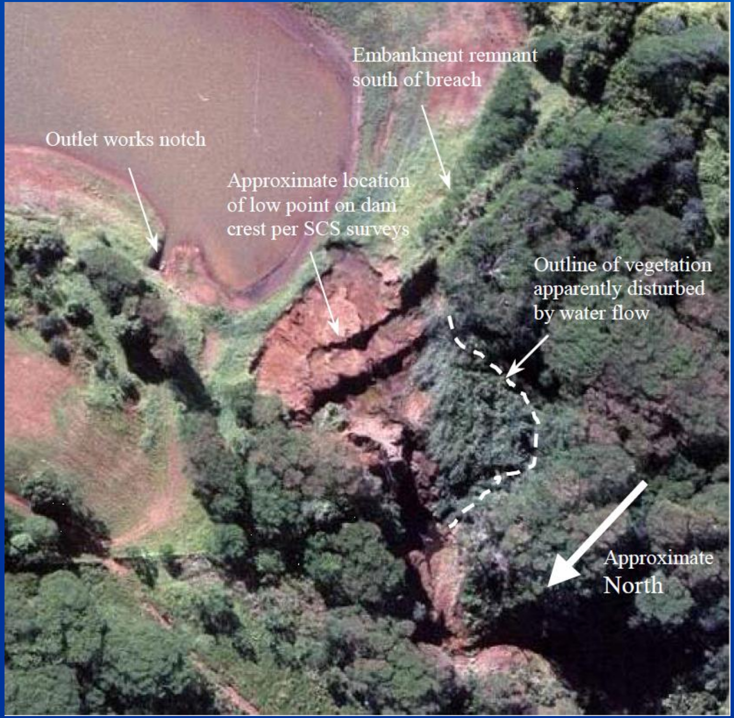

Victims of Ka Loko Dam Failure

Aftermath of Ka Loko Dam Failure

- 2008 – ‘Global settlement’ of $25M to be paid to victim’s families and property owners by Pflueger and others; Pflueger may have defaulted on some or all of his payment

- 2008 to 2015 – Pflueger charged with manslaughter, convicted of reckless endangerment, sentenced in 2014 to 7 months prison but served only 1 month due to medical issues (age 89) with remainder at home; reportedly spent $46M on his defense

- Pre-2006 to 2012 – IRS investigation of Pflueger for tax fraud begun before 2006, pleaded guilty in 2012 (reportedly worth $71M in 2007, excluding $15M transferred to Swiss bank account)

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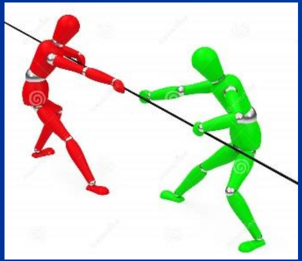

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Key Human Factors for Ka Loko Dam Failure

- Many parties were involved in reservoir and dam ownership, operation, maintenance, water use, and regulation, leading to unclear roles/responsibilities and many conflicts (**complexity**)

- Pflueger illegally made grading decisions on his own, despite lacking dam expertise (**lack of safety culture and not following many best practices: peer review, documentation, information sharing, diverse team, deference to expertise, and professional / ethical / legal standards**)

- Grading was apparently done to increase property value and create scenic location for a home (**profit pressure** and **personal goal**)

Key Human Factors for Ka Loko Dam Failure

- Mayor received contribution from Pflueger and blocked County's effort to stop grading (**political pressure** and **risk ignorance/complacency**)
- Pflueger and many others appeared to not understand the need for a spillway (**unreliable intuition** and **risk ignorance**), which greatly reduced design safety margin and redundancy and contributed to rapid failure (**compromised general design**)
- The two people who *did* understand the risk of filling the spillway expressed their concern only to Pflueger (**risk complacency** and **personal relationship**), but Pflueger ignored their warnings (**risk complacency** and **missed warning sign**)

Key Human Factors for Ka Loko Dam Failure

- DLNR had funding cuts and was very understaffed, hence no inspection of Ka Loko Dam despite required 5-year interval (**cost and schedule pressure** and **falling short of legal standard**), and such inspection would very likely have identified the lack of spillway (**missed warning sign**)
- Government agencies (other than DLNR) inspected grading violations, but focused on environmental damage rather than dam safety (**missed warning sign**)
- DLNR and Pflueger were apparently unaware of downstream development warranting high-hazard classification (**risk ignorance** and **complexity**)

Conclusions

Conclusions

- Dam failures are fundamentally driven by human factors related to non-safety goals, complexity, human fallibility and limitations, and inadequate risk management

- But dam safety ***can*** be maintained by **diligent application of best practices**, in the context of safety cultures which are vigilant about both avoiding failure and achieving success

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Questions? Comments?

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Acknowledgements

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