engineering new zealand
te ao rangahau

LESSONS TO BE LEARNED FROM ENGINEERING FAILURES

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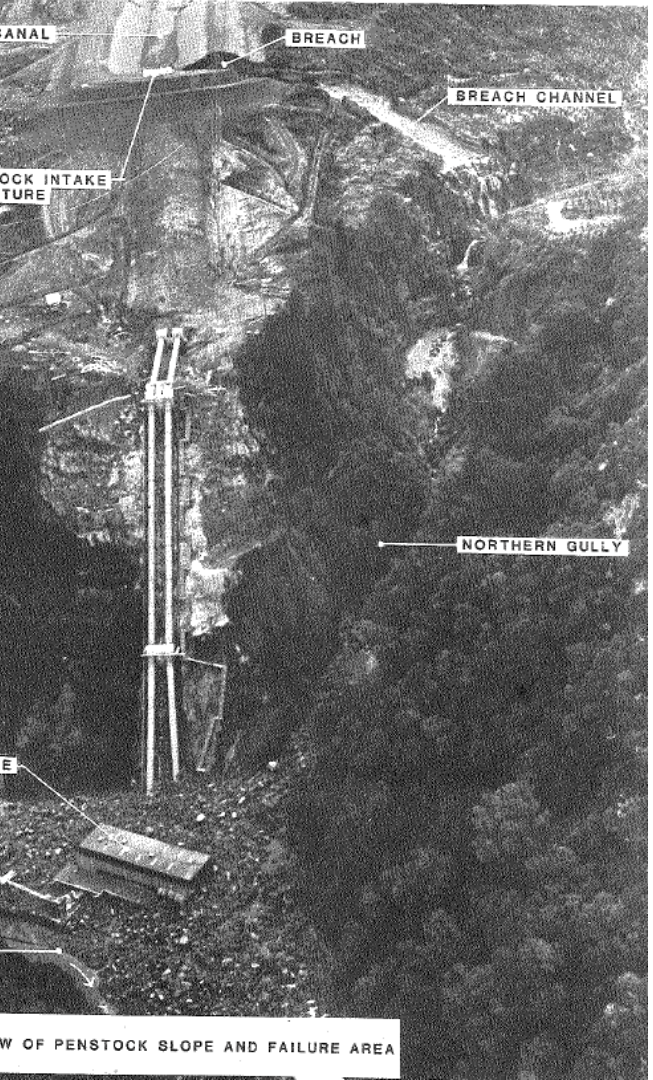


AGENDA.

What is failure?

- Types of failure

Why investigate failure?

General causes of failure

- “Swiss Cheese” model
- Human error
- Group/organisational behaviour

Learning from failures

Introduction success and failure

Not everything in this world is a success – although we'd usually like it to be.

As engineers

- We don't want to see failures in **our own** work
- We're usually happy to take on work for a client to correct **someone else's** failures

While we study successful projects to learn how to emulate them, we're less likely to study **why things go wrong** and to **learn from these lessons.**

Why mistakes occur

- Rushing
- Not understanding the system
- Lack of QA – insufficient first principles
- Lack of fees
- Systemic issues
- Culture
- Lack of peer review

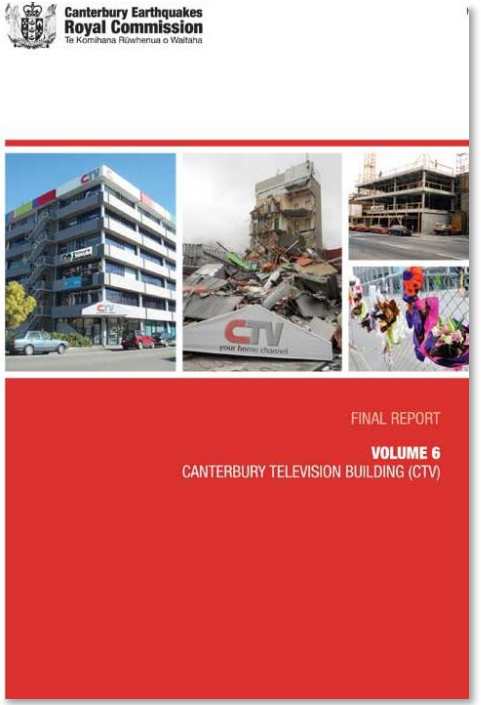
What is failure?

(At least) four types of failure:

1. Objectives not met
   eg insufficient traffic on toll bridge
2. Objectives OK but undesirable side-effects
   eg unsafe spoils from mining operation
3. Inappropriate objectives
   eg New Zealand Building Code saves lives but not buildings?
4. Designed failures
   eg shrinkage joints deliberately cut into slabs

Failures take many forms

Loss of life



Failures take many forms

Loss of property

Wellington landslip under watch

1:47 PM Monday Jun 3, 2013 ☆ Save 3 2

Experts are closely monitoring a landslip in Wellington for any further signs of movement today.

Eight houses are still off-limits after the slip in Priscilla Cres and Breton Grove in Berhampore early on Saturday morning, with three homes precariously hanging over the slip.

Wellington City Council spokesman Richard MacLean said surveyors from GNS Science were monitoring the slip face and the site around it with sophisticated surveying equipment.

Experts say the possibility of rain affecting the slip will keep residents out for some time yet. Photo / Ross Setford, SNPA

"The aim is just to keep an eye on whether there's any ground movement going on. So far, fingers crossed, there doesn't appear to be any significant movement," he said.

"What they tell us will be important to guide us in terms of whether we can allow the residents back into some of the eight houses that have been evacuated.

"We're hoping we might be able to make a call in the next couple of days as to whether we can get some people into those houses."

Rain is forecast for Wellington from tomorrow, and Mr MacLean said that was causing some concern, which was why there could be no quick decision on allowing residents back into houses.

Failures take many forms

Loss of normal levels of service

Council baffled by E coli outbreak

ASHLEIGH STEWART AND TINA LAW

Last updated 13:52 13/05/2013

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LATEST: About 9000 people will have to boil their water for at least three days after bacteria was found in a bore feeding a water supply.

The Selwyn District Council yesterday advised Rolleston residents to boil water after a higher than recommended E coli level was found in a bore 195 metres deep in the Izone business park.

The affected water supply feeds Izone and the Rolleston urban area, where there are about 3000 properties and up to 9000 residents.

A council spokeswoman said the bore fed into the town's main water supply, but has since been isolated and switched off to prevent further contamination.

The council has begun chlorinating the water supply, but it will take three days of clear results before the boil water notice will be lifted, the spokeswoman said.

Yesterday's test came back clear.

E coli is an organism which can cause sickness, including vomiting and diarrhoea.

Environment Canterbury groundwater quality team leader Carl Hanson said he had "never seen E coli in a well this deep".

"It seems odd. Generally we don't see ground water contamination in a well deeper than 50m deep," he said.

While he could not draw a definite conclusion as to how the water was contaminated, there could have been a number

Failures take many forms

Loss of time

Commuters face slow trip home on Auckland's North Shore
8 Jul 2013 – NZ Transport Agency and Auckland Transport say congestion will be extremely heavy around the Constellation Drive interchange on Auckland's Northern Motorway (State Highway 1) during this afternoon's peak.

The Police have closed the northbound lanes of the motorway over Constellation Drive while they continue investigations into a fatal shooting.

The Transport Agency's Regional Traffic Operations Manager, Kathryn Musgrave, says the northbound section of the motorway from Tristram Avenue has been re-opened only as far as the Constellation Drive interchange. All traffic will be diverted down the off-ramp at the interchange, across Constellation Drive, and on to the northbound on-ramp to rejoin the motorway again.

Aspects of failure

- Failures may occur at different project stages
  - Feasibility, design, construction, operation
  - Usually easier to fix at earlier stages
- Something may have multiple types of failures
  - eg project cost over-runs and toxic waste
- One person’s failure may be another’s success
  - eg successful waste treatment but too noisy

Example: new subdivision

Greenfields Development

- New housing
- Local shops and schools
- New roads and paths
- Water/waste pipes
- Stormwater/flood treatment
- Parks and reserves
- River bridges
- Electrical power supply

What could possibly go wrong?

Example: new subdivision

Possible problems

- Environmental contamination during construction
- Construction injury/death
- Project over time/cost
- Poor ground conditions
- Poor building quality

Example: new subdivision

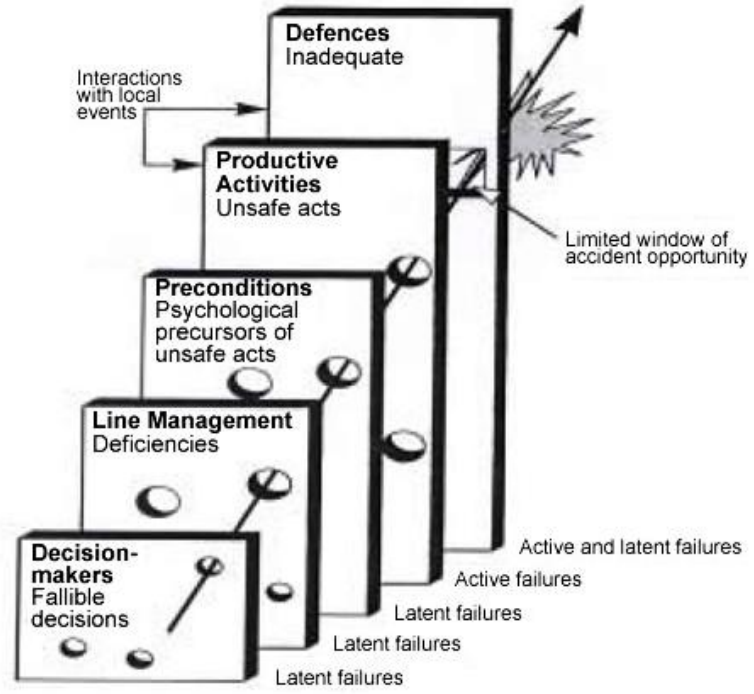
Possible problems

- Insufficient water/waste pipe capacity
- Not enough demand for schools/shops
- New traffic congestion
- Insufficient electric power capacity

“Swiss Cheese” model
Active vs latent failures

- **Active** – occurred at the time of the failure
- **Latent** – prior failure lying “dormant”

Often have both present



Investigating failures

Investigation of failures requires an understanding of common contributors

- Can then remove, mitigate or at least know how to respond to these

Many unique engineering failures

- There are common systemic reasons why most things fail
- Humans are a common element in many key reasons for failures

Why investigate failure?

1. To find out **what went wrong**
2. To **blame/punish** those who made the mistakes that led to the failure
3. To identify **how to avoid** another similar failure in the future

"A mistake is an indicator of a gap in one's knowledge. Learning takes place. When a mistake is identified, its producers are identified and it is corrected"

– R.L. Ackoff (1994), *Systems Practice*

Learning from failures

A lot of engineering knowledge comes from observing failures eg update of design standards/codes following major disasters.

Formal inquiries can be useful, but

- They can take years to complete, potentially losing public/political pressure
- There may be a hiatus on any preventative action while an Inquiry is underway
- There may not be any mandatory requirement to take action from inquiry recommendations

Does the memory of failures fade with time?

– Henry Petroski, “Success through Failure”, 2006

Apparent sequence of bridge failures

- New design techniques → success
- More daring designs → still successful
- Push the limits too far → failure (new type of)

Does the memory of failures fade with time?

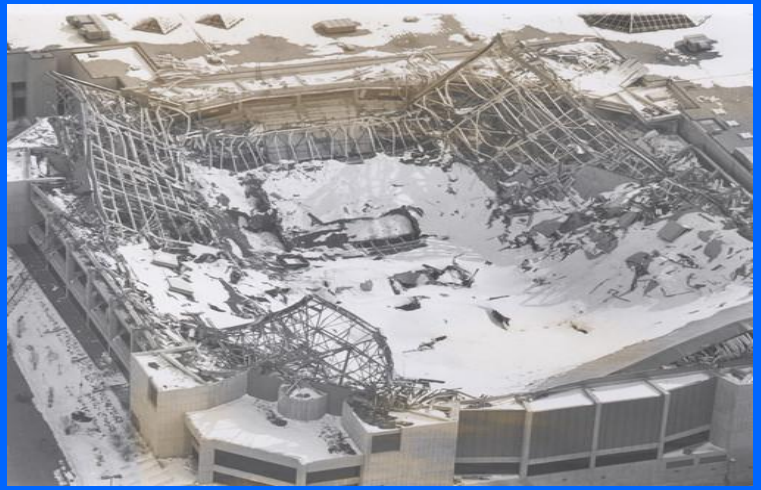
– Henry Petroski, “Success through Failure”, 2006

Average gap between new category failures was approx. 30 years

- Time for one “generation” of engineers to move on and a new cohort to lead the way

Is there a gap in institutional memory?

“This will never happen again”



Hartford Civic Centre 1978

Stadium Southland 2010

Patterns of failures

Notable new bridge failures

1847: Dee Bridge (truss girder)

1879: Tay Bridge (truss)

1907: Quebec Bridge (cantilever)

1940: Tacoma Narrows (suspension)

1970: Westgate Bridge (steel box girder)

2000: Millennium Footbridge (cable)

2030: Cable stay? Concrete box girder?)

Critical success factors in projects

Key requirements

- Project Goals clearly defined
- Resources are sufficient
- Control mechanisms in place and used
- Project has support of top m'gmt
- Communication channels are adequate

Critical success factors in projects

Key requirements cont.

- There is capability for feedback
- Contractors are responsive to clients
- Project manager is competent
- Project team is competent

Threats to project success

Main threats to project success

- Cost escalation
- Delays in completion
- Public/client dissatisfaction with outcome

More “spectacular” failures (loss of life, physical failure) are less likely – but similar principles of failure apply

Recall: some parties may view a project as a “success” while others see it as a failure

Human error

Defining error

- Were the actions directed by some prior action?
- Did the actions proceed as planned?
- Did they achieve their desired result?

"Error is a generic term to encompass all those occasions in which a planned sequence of mental or physical activities fails to achieve its intended outcome, and when these failures cannot be attributed to the intervention of some chance agency."
– James Reason

Levels of human error

1. Skill-based errors
    - Basic skills and tasks learnt by practice/training
    - Sub-conscious patterns of behaviour
2. Rule-based errors
    - Patterns for dealing with familiar scenarios
    - Routine decision-making – "if… then…"
3. Knowledge-based errors
    - Dealing with unfamiliar/novel situations
    - Using basic principles to determine way forward
    - Develop a plan, try it, and see if it works

1. Skill-based errors ("action slips/lapses")

Usually due to "inattention"/"overattention"

- Capture errors: old habits override new task
- Parallel activities: switching tasks and objects
- Perceptual confusion: acting on a similar object
- Data-driven error: using distracting info instead
- Interruptions: failing to complete original task

1. Skill-based errors ("action slips/lapses") cont.

- Misplaced goals: forgetting reason for next step
- Omissions: missing out an action step
- Repetitions: repeating a completed step
- Reversals: undoing previously completed step

Usually quick to identify and rectify

2. Rule-based errors (“mistake”)

- Applying a strong but wrong rule
  - Lack of experience may lead to the obvious-but-wrong choice of rule
- Ignoring later counter-indicators
  - May already have a "world view" about best course of action based on earlier indicators
- Overload
  - Too much information, fail to notice crucial info
  - Lack of experience to know what is crucial info

Training can improve rule-based skills

3. Knowledge-based errors

Often most crucial to major failures

- Selectivity (attending to wrong info)
- Mental limitations (using wrong concept model)
- Out of sight/mind (ignoring data not present)
- Confirmation bias (sticking to original decision)
- Over-confidence (in knowledge of self/group)

3. Knowledge-based errors cont.

- Biased reviewing (not thorough checking back)
- Illusory correlation (false cause & effect)
- Halo effects (general opinions influence ratings)
- Causality (oversimplifying relationships)

Ultimately problems of complexity/diagnosis

Reduction of errors (or their effects)

1. Error detection and removal

- Slips are the easiest to detect, often by oneself
- Strange/unusual feature of “success” may raise suspicions
- May have undetected (latent) errors – only reveal themselves at critical times?
- “Fresh pair of eyes” can sometimes find error

Error detection requires

- A feedback mechanism
- Some discrepancy between expected/observed

Reduction of errors (or their effects) cont.

2. Error prevention

- Training and practice will improve skills
- The right environment makes a difference
- Simulators may help practise KB problems
- Good design of instruments, tools, software, etc
- Checklists, “challenge-response” systems
- Use constraints that guide user to next task
- Standardise actions, outcomes, layouts etc

But humans will still make mistakes and lapses

Allowing for human errors

Design for human fallibility and vulnerability

- Backup systems or built-in redundancy/checks (human or machine)
- Limiters/locks preventing unsafe action
- Minimise number of concurrent unsafe activities
- Extra factor of safety past the “danger” level
- Automate tasks
- Extra protection equipment in case of failure

People in groups

- Engineering failures are rarely about just one person – we largely work in teams
- Group dynamics can be a powerful factor in understanding contributors to failures
- While strong groups can improve general productivity and decision-making they can also stifle individual feedback or concerns

  = “Groupthink”

Characteristics of ”groupthink"

- Over-estimate the group’s power
  - Illusion of invulnerability – taking risks
  - Belief in group’s morality – ignore ethics
- Close-mindedness
  - Collective efforts to discount warnings
  - Stereotyped views of opposition as too weak
- Pressures towards uniformity
  - Self-censorship of deviation from consensus
  - Shared illusion of unanimity
  - Pressure on doubters to confirm loyalty

Organisational behaviour

Organisations can contribute to failures through:

- Rigidity in organizational perceptions and beliefs
- Poor information/communication channels
- “Decoy problems”
- Employees may devalue opinions and concerns expressed by outsiders
- Involvement of non-employees on site
- Failure to comply with statutory regulations
- Downplaying the threat of emergent dangers
- Assuming future problems will be similar in form

Risk management for projects/activities

1. Identify risks
   - What/how/who
2. Prioritise risks
   - Likelihood x consequence
3. Consider options to manage risk
   - Avoid (change project/activity)
   - Reduce (likelihood)
   - Mitigate (consequences)
   - Transfer (responsibility)
   - Accept (do nothing)

Learning opportunities

- Accessibility – Resources from Engineering New Zealand
- Understanding – The whole system
- Desire – Changing behaviour
- CROSS-AUS – Confidential reporting
- Improving Q.A. – Don’t make it hard

Learning opportunities

- Accessibility – resources from Engineering New Zealand
- Understanding the whole system
- Desire – changing behaviour
- CROSS-AUS
- Improving QA

Reinforcing professionalism

- Share in your workplace
- Share in discussion groups
- Share with your technical or special interest group
- Subscribe to CROSS or similar newsletters
- Promote a ‘just’ culture
- Don’t agree to confidentiality agreements unless there’s a provision to share learnings

Creating a ‘just’ culture

A culture in which frontline operators or others are not punished for actions, omissions and decisions taken by them that are in line with their experience and training, but where gross negligence, wilful violations and destructive acts are not tolerated.

CONCLUSIONS

Additional resources

Crane collapse in New Zealand – tinyurl.com/y5mnd4to

Harrington St Carpark – tinyurl.com/yxmb6fbn

NASA Space Shuttle – tinyurl.com/yb8juduk

Fonterra contamination – tinyurl.com/y3mdubgp

Rocket Lab launch failure – tinyurl.com/yxtubcm8

1988 Greymouth floods – tinyurl.com/yxmwomz2

Just culture – tinyurl.com/y2n64bse


THANKS!