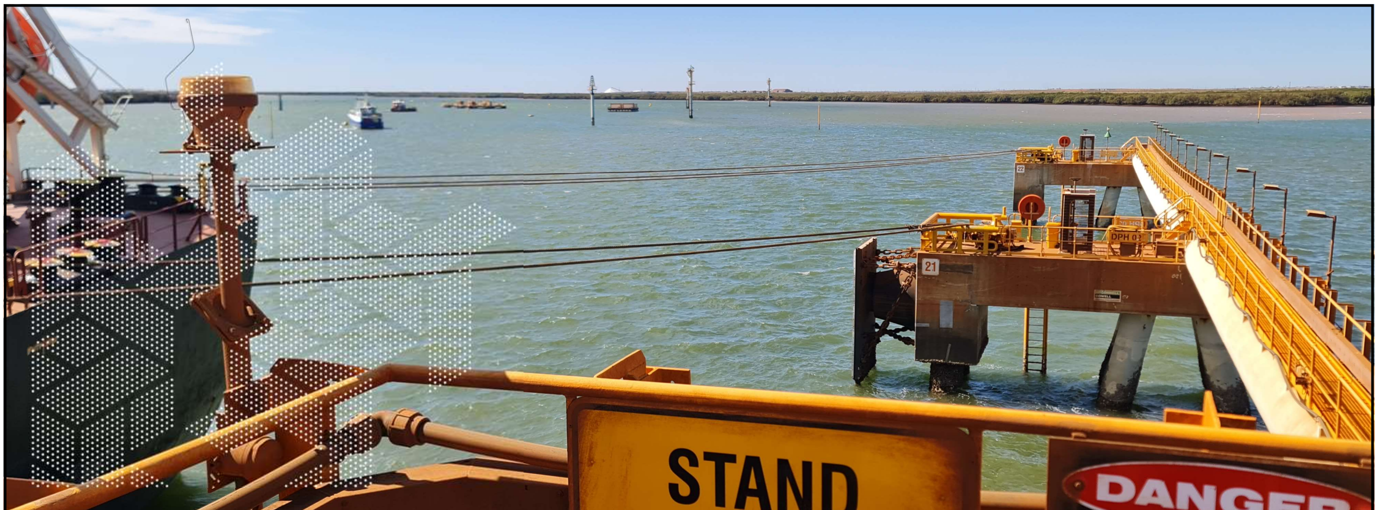

WGA

Mooring Line Barriers – Better Understanding the Risks We're Mitigating

Monday 5 September 2022

1

Introduction

Snapback Risks – How Much are we Mitigating?

What is a Mooring Line Snapback?

- Mooring lines are used to secure ships against a wharf.
- When tension is applied, line stores potential energy.
- If either the condition reduces or the tension increases, the line can break – converting potential energy into kinetic.
- These events are a key danger in a port environment – one in every seven snapped lines results in a fatality.

Risk Management

- The consequences have been understood for sometime, but there is limited industry guidance to assess the risks.
- Various mitigation strategies are used, most visibly in snapback barriers to provide shelter for personnel.
- The key uncertainties are likelihood and energy transfer.
- Each has little guidance within the traditional fields of structural and maritime engineering for assessment.

2

WGA's Previous Work
Industry Experience

Our experience:

WGA have been involved in reviews for a number of clients from 2015 until the present day, including:

- BHP
- Rio Tinto
- FMG
- Southern Ports (Ports of Esperance and Albany)
- Midwest Ports Authority (Port of Geraldton)
- Pilbara Ports Authority (Port of Port Hedland)

The works have included:

- Snapback zone studies.
- Analysis of mooring line energies.
- Structural analysis of mooring line barriers.
- Bollard, ShoreTension and Quick Release Hook design.

We're not alone in the field!

3

WGA's Recent Work
Development of New Assessment Methods

Building on Previous Works

- Work was undertaken to review variety of existing mooring line barriers.
- To design for full energy with conservatism finds most (if not all!) barriers in service are inadequate.
- Data shows that most breakages happen well below the 100% MBL –> design energies may be much lower.

Action and Resistance Models

- 'Action Models' refer to the actions applied to a structural model – transfer of potential energy into applied kinetic energy.
- 'Resistance Models' refer to how that energy is arrested – snapback barriers.

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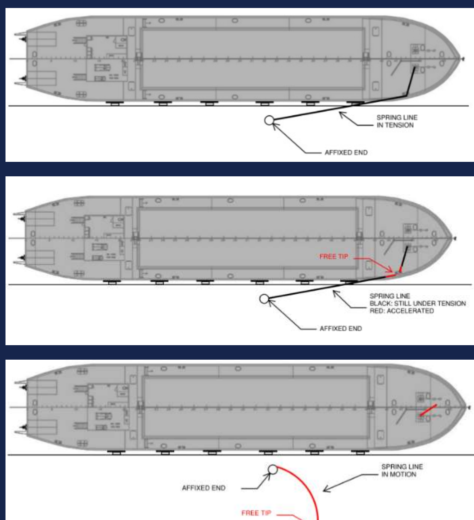
A Recap of the Last Presentation…
Action Model – Energy of a Snapped Mooring Line



Potential Energy Transfer to Kinetic Energy
- Initial potential energy is approximated by Hooke's Law.
- Energy transferred as an acceleration of the rope through the elastic shortening of the line – function of the strain and length of line under tension.
- As the line breaks, force travels at speed of sound in rope – non-uniform acceleration.

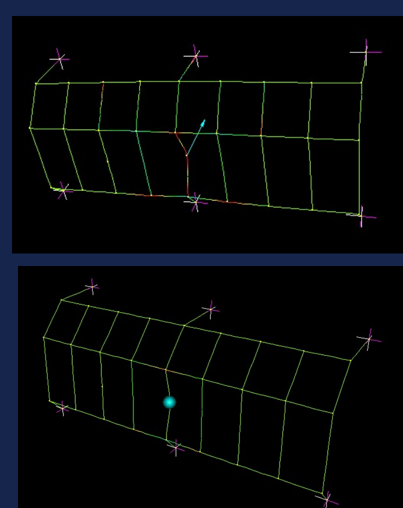
Momentum Transfer
- The end closest to the tip accelerates for the longest time.
- If there is an eccentricity, possible for the free tip of the line to draw line back into tension – results in transfer of momentum up the line (whip crack).
- Non-uniform distribution of energy – last 1% of line can be 13.81% of the total kinetic energy.
- Due to velocities involved (approaching or exceeding Mach 1), drag losses are significant.
- Straight line failures around 20% velocity of a whipping failure.
- Analytical models have been validated against test data.

5

A Recap of the Last Presentation…
Resistance Model

Energy Absorption of a Snapback Barrier
- Traditional methods align with other analyses (e.g. berthing) – adopting a force-displacement model ($E=1/2kx^2$).
- Using non-linear structural behaviour, model considered solved when top of yield curve reached – no additional resistance for increased load.
- Some verification exercises undertaken 'for interest' disagreed wildly with each other.

Dynamic Transient Analysis
- Used a lumped mass applied at an initial velocity as the input energy.
- The relative mass of the two objects was extremely relevant to the behaviour of the barrier – force/displacement can be non-conservative!
- Relied on the work undertaken in the action model to prove – understanding velocity and mass of rope portion that strikes enabled verification of models.



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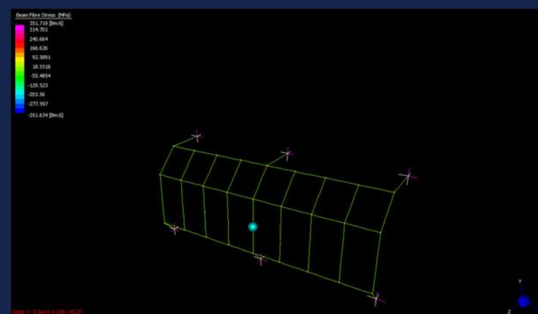
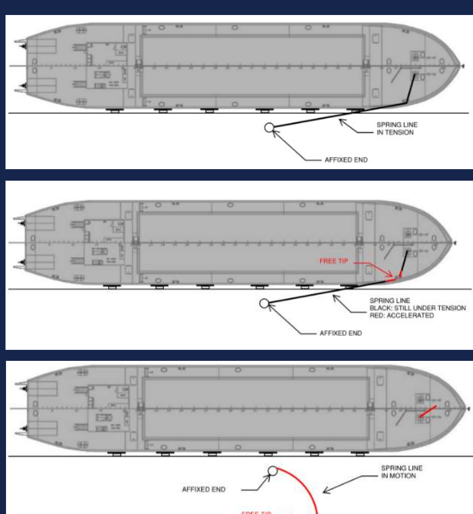
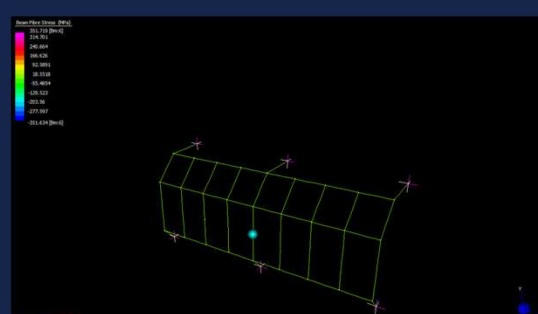


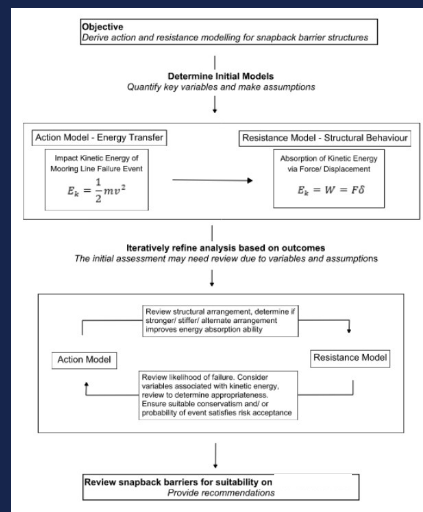
A Recap of the Last Presentation…
Bringing the Models Together!





What Is This All For?
Analytical Methods for Risk Assessment

Aims for the Models
- The initial aims were only to assess the effectiveness of mooring line barriers against design events.
- In trying to define the design event, a much broader understanding of the overall risks could be found.



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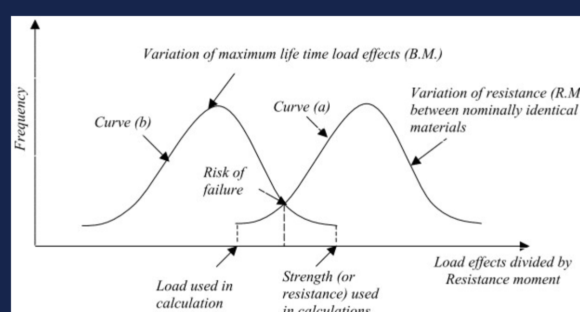
The Implications
- We could now go further and develop quantitative assessments of risk, rather than just qualitative.
- Alignment with the National Construction Code and ISO2394: General Principles on Reliability of Structures.
- Align design with limit state design to determine an ultimate design event.
- Framework allows for iterative refinement – we're not finished yet!



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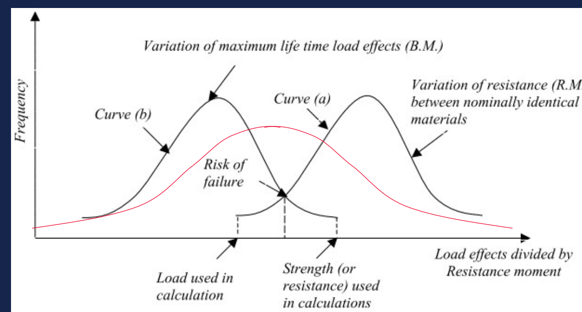


Risk Assessment for Snapback Events
Brief Overview

Risk Assessment Templates

- Consider the consequence and relative likelihood of an event occurring.
- Provide framework for assessing effectiveness of risk controls – either reducing the consequence or the likelihood of an event occurring.
- The guidance varies for different organisations, but the process is standardised.

Risk Assessment Process

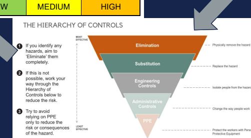
- Define the event – for snapback events, easier said than done!
- Assess the consequences.
- Assess the likelihood.
- Introduce controls to reduce either (or both).
- Re-assess until satisfied that risks are managed to acceptably low level.

RISK RATING TABLES & RISK MATRIX

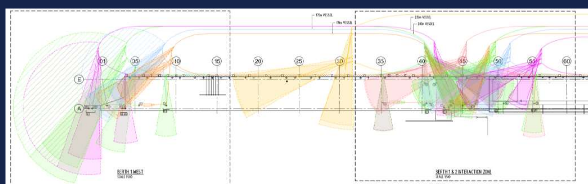
CONSEQUENCE & definitions			LIKELIHOOD & definitions		
E	Catastrophic	People: A death or multiple life-threatening illness/ injuries. Environment: Permanent environmental damage. Finance: \$1m-\$5m impact Reputation: Significant reputational damage with multiple or core clients. Compliance: Significant and widespread non-compliance with internal/external compliance obligations.	5	Very Likely	*Expected to occur*
D	Critical	People: Multiple illness/injuries requiring hospitalisation (LTI). Environment: Long-term, reversible, environmental damage. Finance: \$400k-\$1m impact on business Reputation: Significant reputational damage with a core client. Compliance: Serious and widespread non-compliance with internal/external compliance obligations.	4	Likely	*Likely to occur or has occurred before*
C	Serious	People: Illness/injury to one or more persons requiring hospitalisation = Lost Time Injury (LTI). Environment: Reversible, environmental damage. Finance: \$200k- \$400k impact on business Reputation: Moderate reputational damage with core client. Compliance: Isolated serious non-compliance with internal/external compliance obligations.	3	Possible	*May occur*
B	Moderate	People: Illness/injury to one or more persons requiring medical treatment Medically treated Injury (MTI). Environment: Moderate, short-term reversible environmental damage. Finance: \$50k-\$200k impact on business. Reputation: Minor reputational damage with clients. Compliance: Administrative non-compliances with internal/external compliance obligations.	2	Unlikely	*Known to occur, but only rarely*
A	Low	People: Illness/injury to one or more persons requiring first aid treatment. Environment: Minor environmental impact. Finance: <\$50k impact on business Reputation: N/A any reputational risk is considered MODERATE Compliance: Non-compliances with internal WGA policy/obligations.	1	Very Unlikely	*Conceivable, but only I extreme circumstances*

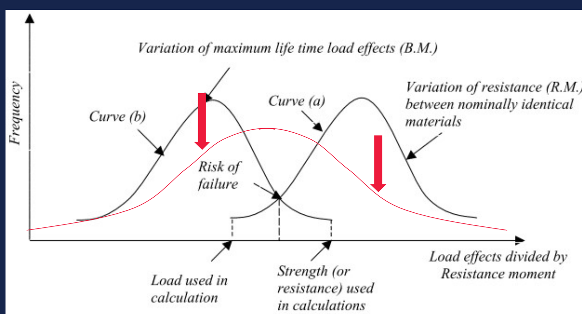
Consequence / Likelihood	A Low	B Moderate	C Serious	D Critical	E Catastrophic
Very Likely (5)	MEDIUM	HIGH	VERY HIGH	VERY HIGH	VERY HIGH
Likely (4)	MEDIUM	HIGH	HIGH	VERY HIGH	VERY HIGH
Possible (3)	LOW	MEDIUM	HIGH	HIGH	VERY HIGH
Unlikely (2)	LOW	LOW	MEDIUM	HIGH	HIGH
Very Unlikely (1)	LOW	LOW	LOW	MEDIUM	HIGH

Control Action Rating	Qualitative Risk Action Description
VERY HIGH	Work is not to start. Project Lead to confer with Regional Manager (and as necessary, client personnel) to identify and implement additional controls to reduce the risk
HIGH	At the job planning phase. Project Lead to confer with Safety personnel to confirm that current industry standards are implemented
MEDIUM	At the job planning phase. Project Lead with field operative/s to assess the identified controls for adequacy and to further reduce the risk.
LOW	Field operative/s to adhere to identified and listed controls



Consequence
What Happens if a Mooring Line Fails?



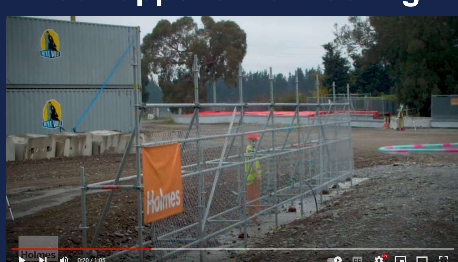


If no-one is there
- Consequences are relatively low – maybe some property damage provided the vessel is still restrained.
- Removing personnel is an effective control; however,
- Expensive and often impractical to remove personnel at all times.

If a barrier is not present
- Relatively straight forward – consequence of an event depends on whether personnel are in the line of fire or not.
- In the absence of a snapback path study, consequences can be up to and including fatality.

If a barrier is present
- Structurally we have to assess the effectiveness of the barrier against the design event.
- The design event is a function of likelihood! Lower energy events are more frequent than higher energy events.

Consequence
What Happens if a Mooring Line Fails?



Source: Holmes Solutions
https://www.youtube.com/watch?v=AHMdYf7XL14

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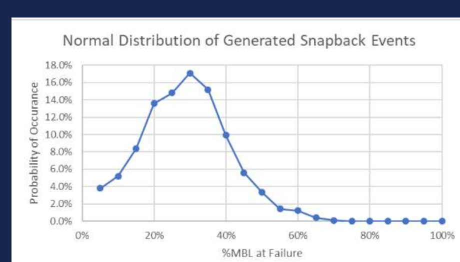
Likelihood
Does a Snapped Line Event Happen?

What we know?
- Snapped line events happen – known problem.
- Data indicates that most events happen well below line MBL.
- Frequency changes port to port, berth to berth.
- Increase in load and/or a decrease in strength in the line.

Contributing factors
- Environmental – tides, wind, wave.
- Vessel interaction.
- Human – line management, vessel monitoring.
- Line condition – wear, chafe.
- Mooring arrangement and infrastructure.

Answering the question
- Review history of events – conditions, tension at break.
- Determine if it's a condition or management of line issue (likely combination).

Material	Construction	GMBL (kN)	Failure Load (kN)	% MBL at Failure
Nylon	DB	885	147	17%
Nylon	DB	885	490	55%
HMPE	P	1410	402	29%
Nylon	P	1870	402	21%
Nylon	DB	885	230	26%
Nylon	DB	885	170	19%
Nylon	DB	995	348	35%
Nylon	DB	995	259	26%
Nylon	DB	894	89.4	10%
Polypropylene	P	814	216	27%



Likelihood
How much energy is in that mooring line?

What we know?
- Energy dependent on many factors.
- Energy is not distributed evenly!
- Frequency changes port to port, berth to berth.

Contributing factors
- Line properties – material, diameter, elongations, strength.
- Line geometry – length, orientation, mooring infrastructure.
- Condition at break – how much capacity has the line got. 100% MBL is unlikely, but what strength depends on the factors that contribute to the break (question 1).

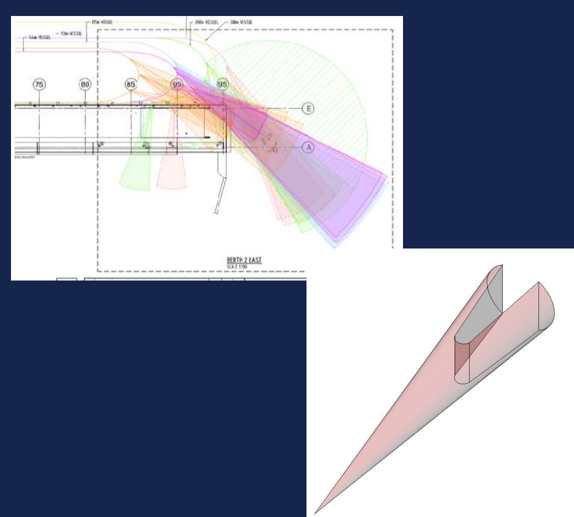
Answering the question
- Identify a 'design line' – type, properties. Easier on single-use berths rather than multi-user facilities.
- Line length is an important variable – usually longest lines have more energy, but shorter lines are stiffer.
- Determine a %MBL at break – this part is difficult! Work in the 'does a line break' section will help define.

Likelihood
Does a line strike a work area, and is there a barrier?

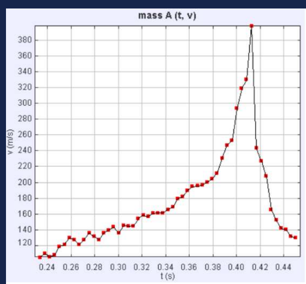
What we know?
- Snapback paths are complex!
- Work areas can be defined by proximity to mooring infrastructure, may not be a true representation.
- Mooring arrangements vary.

Contributing factors
- Guidance is limited, usually defined by cones reflected.
- Operations procedures define when.
- Safety training and culture alerts workers to the risks and limits their times in danger zones.

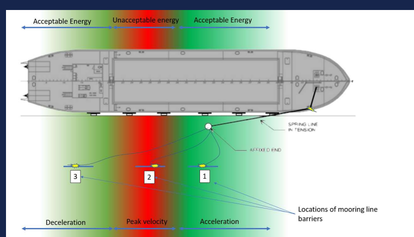
Answering the question
- Berth-specific studies needed.
- Getting this wrong can actually increase risk – false sense of safety.
- Further work can identify high risk, low risk and no risk areas – painting high-risk bullseyes spatially which are no-go zones.



Likelihood
What is the residual energy in a line at the time it reaches a barrier?



Actual tip velocity for a 70m line under tension (Li = 60m) with bend at 50m. Source – Holmes Solution (2021)



What we know?
- Snapback events are highly transient events.
- Potential energy = peak kinetic energy.
- This is not necessarily the kinetic energy at impact!

Contributing factors
- Berth geometry and the location of the impact into a barrier.
- Direct strikes have greater impact than glancing blows.

Answering the question
- Berth-specific studies needed.
- The results feed into the probabilistic assessment of the 'design event' – designing for the peak kinetic energy may not be practicable or necessary.

Likelihood
Is the mooring line barrier effective at stopping a broken mooring line?

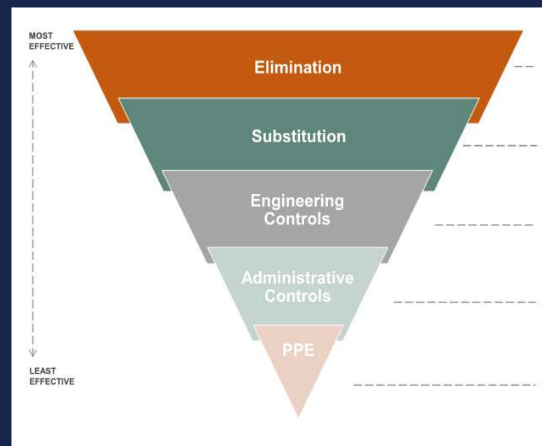
What we know?
- Force-displacement design is not appropriate.
- Designing for the peak event may not be practical or necessary.

Contributing factors
- Dependent on the residual energy at strike.
- Many barriers not appropriately designed for dynamic event – centre sections fail before the foundations feel it.
- Consider inertial models to arrest momentum and absorb energy.

Answering the question
- Define the ultimate design event.
- Undertake analysis that models this design event.
- Undertake physical testing to validate analysis.
- Identify residual risks and determine if acceptable.

How can this be used?
Assessment of control combinations

- Alternative mooring methods
- Personnel restrictions
- Maintenance practices (shutdown only, drones, etc.)
- Alternative lines (materials, MBL guidance)
- Line inspection and rejection
- Alternative mooring arrangements
- Improved line angles
- Quick release hooks (set at %MBL)
- Fenced off restricted zones
- Mooring line barriers
- Whip chocks
- Shock absorbers
- Bits, bollards and chocks review
- Chafe guard
- Snapback path studies
- Load sensing pins
- LIDAR monitoring
- Environmental monitoring
- Passing vessel interaction studies
- Defining safe work areas
- Training
- Ownership of vessel lines
- Visual aids and signage
- Safe working times (avoiding top of tide, weather limits, etc.)



Overall probability of event exceedance = x?

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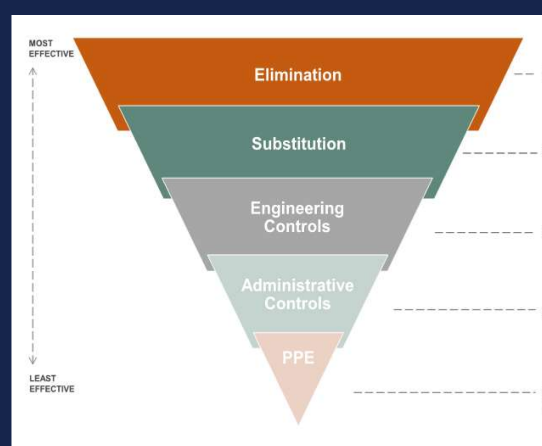

Overall probability of event exceedance = y?

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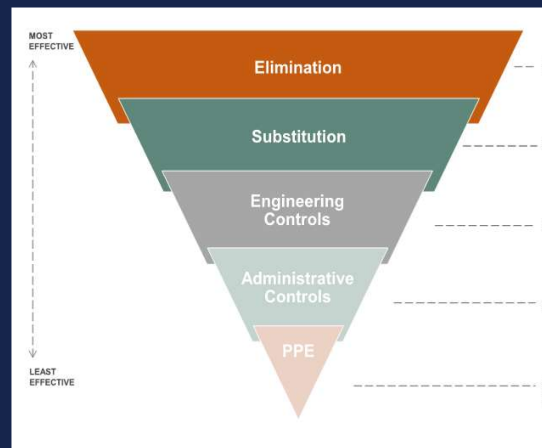

Overall probability of event exceedance = =z?

Acknowledgements and Thankyou

Many acknowledgments required, from clients we've been working with:

- BHP
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- Southern Ports
- Midwest Ports Authority
- Pilbara Ports Authority

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- Holmes Solutions
- Baird Australia
- AECOM

Within WGA, Luke Campbell, Jordan Butler, Stephan Dickinson, Andrew Wharton and Ryan Donaldson

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