Beca & Auckland Council Healthy Waters

Considerations for Dynamic Flood-Borne Debris Impact Loads

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The New Zealand Water & Wastes Association Waiora Aotearoa

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Problem Review

- Analyses of flood damage to buildings often focus on damage from water contact.
- Flood flows can pick up and carry various objects such as trees, cars, storage tanks, damaged parts of buildings and even entire buildings.

Problem Review

Three different types of flood-borne debris actions (Kelman and Spence, 2004).

- Static load → accumulation of debris mass (e.g. tree branches) – pushing force
- Dynamic load → flow forces floating debris onto a structure – punching force
- Scour

Overall Approach

Literature
- Review different approaches for calculating dynamic debris impact load
- Investigate the application of approaches
- Identify recommended parameters for load calculation

Case Studies
- A residential building
- A low-level pedestrian bridge

Method
- Apply different approaches to the case studies
- Calculate wind load (AS/NZS 1170.2)
- Calculate flood flow loads & debris raft (Bridge Manual – AS5100)
- Compare the dynamic debris impact load with wind and flood flow loads

Framework
- Draw appropriate conclusions from method development
- Draft an appropriate framework for the debris impact assessment

Literature Review

Literature and background information: *flood & tsunami*

- Research papers – notable and recent studies
- Standards & Guidelines - impact loading guidance
- Empirical approaches used to calculate the debris impact force and the key parameters and coefficients.

Debris Impact Force Estimation

Impulse-momentum

$$F_{di} = \frac{m_d u_d}{\Delta t}$$

adopted by the American Society of Civil Engineers

Contact duration of impact

Work-energy

$$F_{di} = k\,\Delta x$$

adopted by Australian Bridge Design Code AS5100

Distance over which force acts

Contact-stiffness

$$F_{di} = u_d\sqrt{k m_d}$$

adopted by the American Association of State Highway and Transportation Officials

Effective contact stiffness of the collision

Debris Impact Force Estimation

Contact-stiffness	$F_{di} = u_d \sqrt{k\,(m_d + C\,m_f)}$ (Haehnel and Daly)	$F_{di} = 1.3\,u_d \sqrt{k\,m_d (1 + c)}$ (FEMA P-646)
Impulse-momentum	$F_{di} = \frac{\pi}{2}\frac{u_d\,m_d}{\Delta t}$ (Haehnel and Daly)	$F_{di} = C_{add} C_u\,C_{sh} C_{DD} C_{ss}\,\frac{\pi}{2}\frac{u_d\,m_d}{\Delta t}$ (Shafiei et al)
	$F_{di} = \frac{\pi}{2}\frac{u_d\,m_d\,C_l\,C_O\,C_D\,C_B\,R_{max}}{\Delta t}$ (ASCE 7)	$F_{di} = u_d\,m_d\,C_D\,C_B\,C_{Str}$ (FEMA P-55)
Work-energy	$F_{di} = \frac{m_d\,{u_d}^2}{S}$ (Haehnel and Daly)	AASHTO
Other Approaches	$\frac{F_{di}}{\gamma_d D^2 L} = 1.6\,C_M \left(\frac{u_d}{\sqrt{g_n D}}\right)^{1.2} \left(\frac{\sigma}{\gamma_d L}\right)^{0.4}$ (Matsutomi)	$\frac{F_{di}}{g\,m_d} = S\,C_M \left(\frac{u_d}{\sqrt{g\,\sqrt{D\,L}}}\right)^{2.5}$ (Ikeno et al)

Debris Impact Force Estimation

Parameters:

- Shape/sizing (Bridge Manual)
- Mass (FEMA-P646)
- Contact-stiffness – effective stiffness (FEMA-P646)
- Impulse-momentum – stopping time/impact duration (ASCE, FEMA P-55)
- Work-energy – stopping distance (AASHTO)

Type of debris	Mass (kg)	Debris stiffness (N/mm)
Lumber or wood log (orientated longitudinally)	450	2.4 x 10^6
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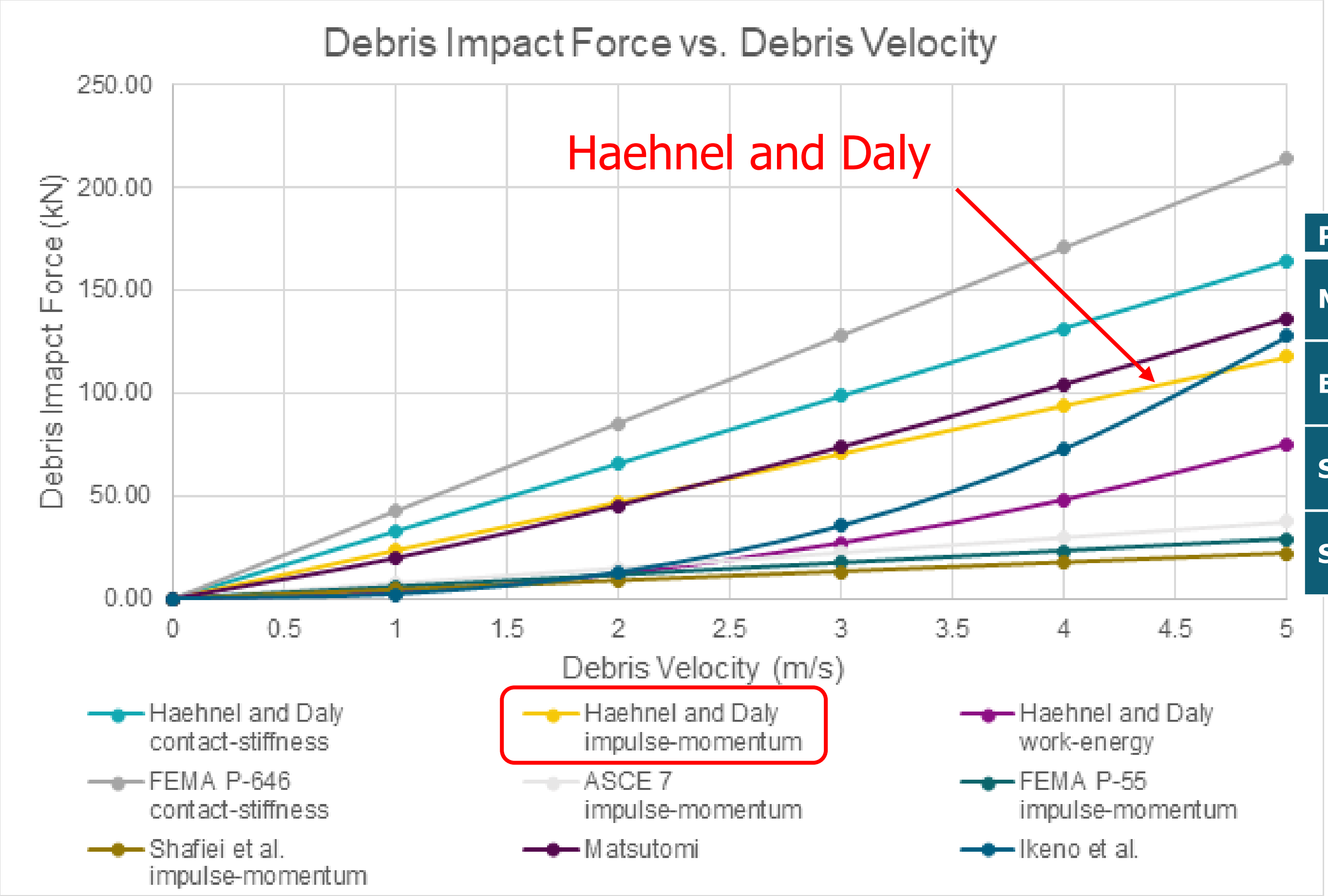
Approach Comparison



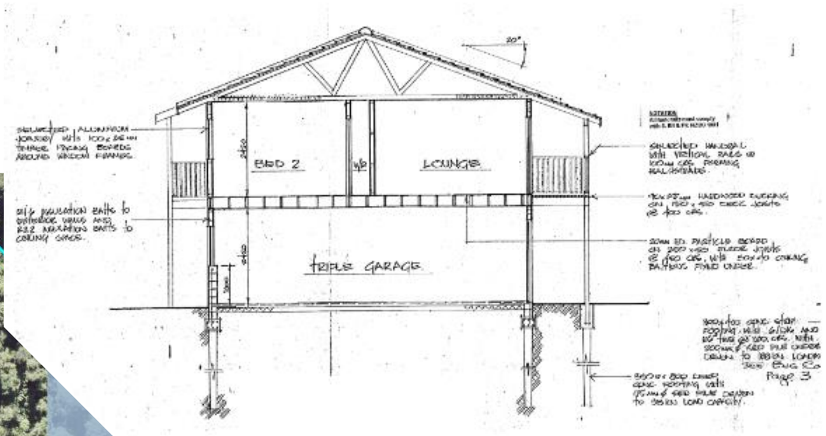
Parameter	Value	Reference
Mass, m	450kg	FEMA P-646 (section 2.3 of this report)
Effective contact stiffness, k	2.4 x 10^6 N/mm	FEMA P-646 (section 2.3 of this report)
Stopping time, Δt	0.03s	ASCE 7-16 (section 2.4 of this report)
Stopping distance, S	0.15m	AS5100 (section 2.5 of this report)

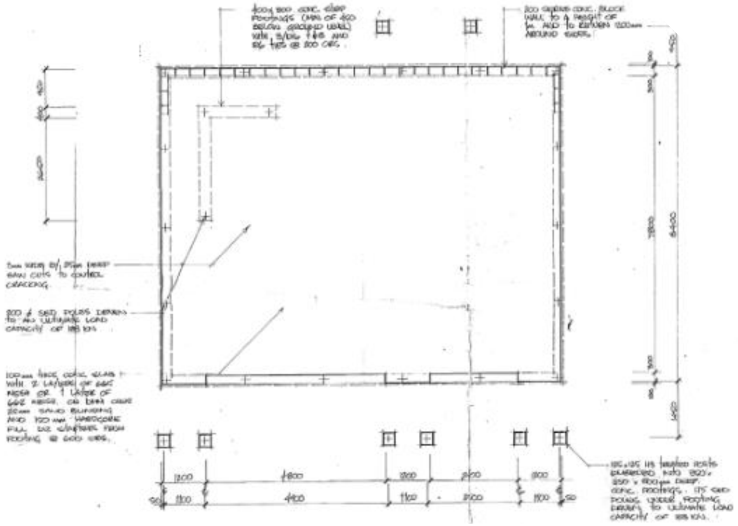
Approach Comparison

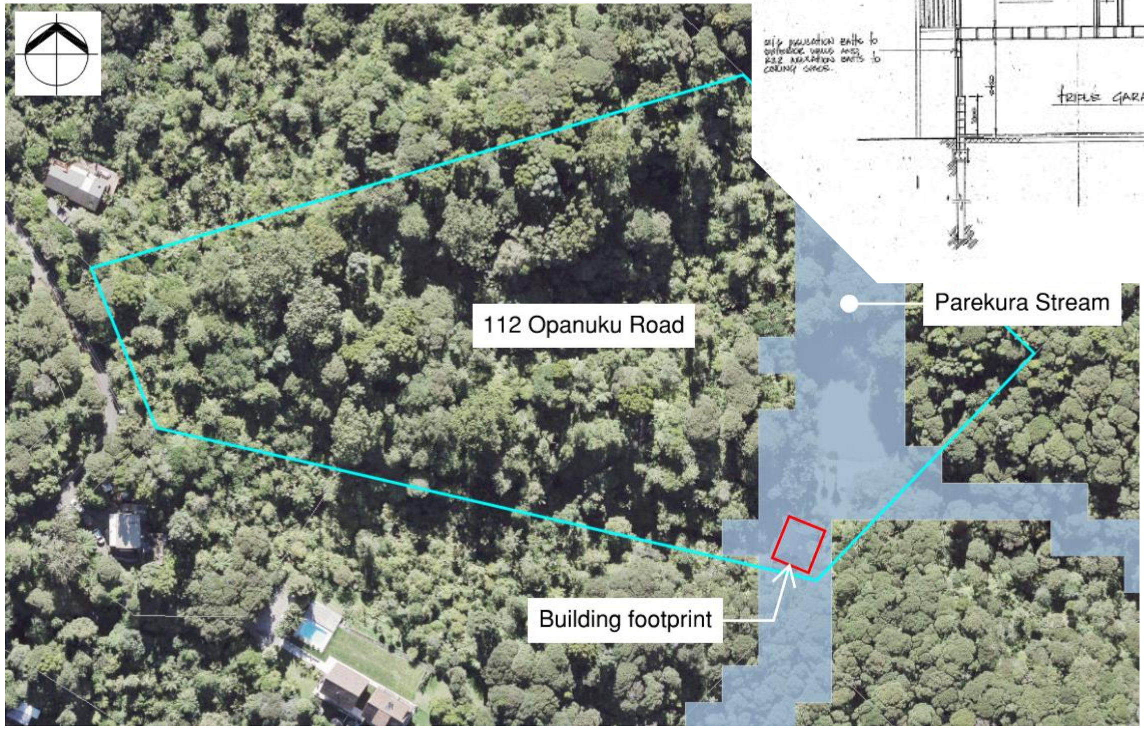
Haehnel and Daly's Impulse-Momentum approach has been identified as the most appropriate approach for the following reasons:

- Average result among plotted approaches → falls within a reasonable range of outcomes.
- Adoption by well-regarded standards→ ASCE7-16 and FEMA P-55, which adds credibility to this decision.
- Input parameters → the ease of finding the necessary input parameters for the calculation.

Case Study 1 - 112 Opanuku Road, Waitakere







Case Study 1 - 112 Opanuku Road, Waitakere

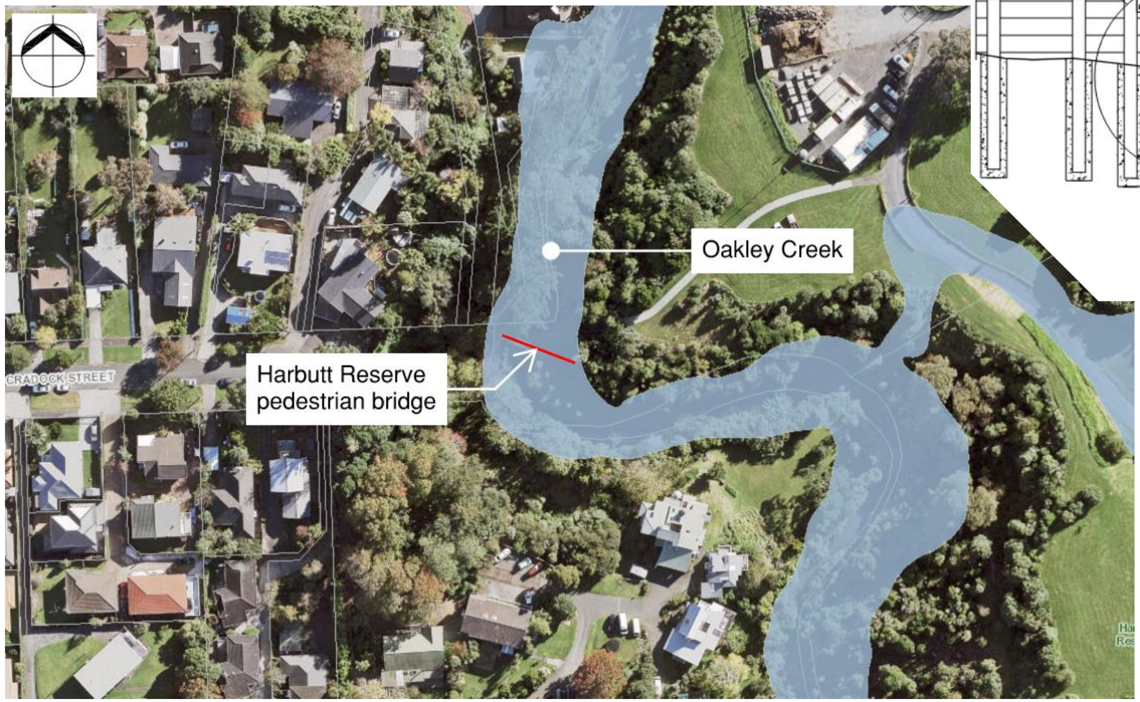
Case Study 1 Parameters

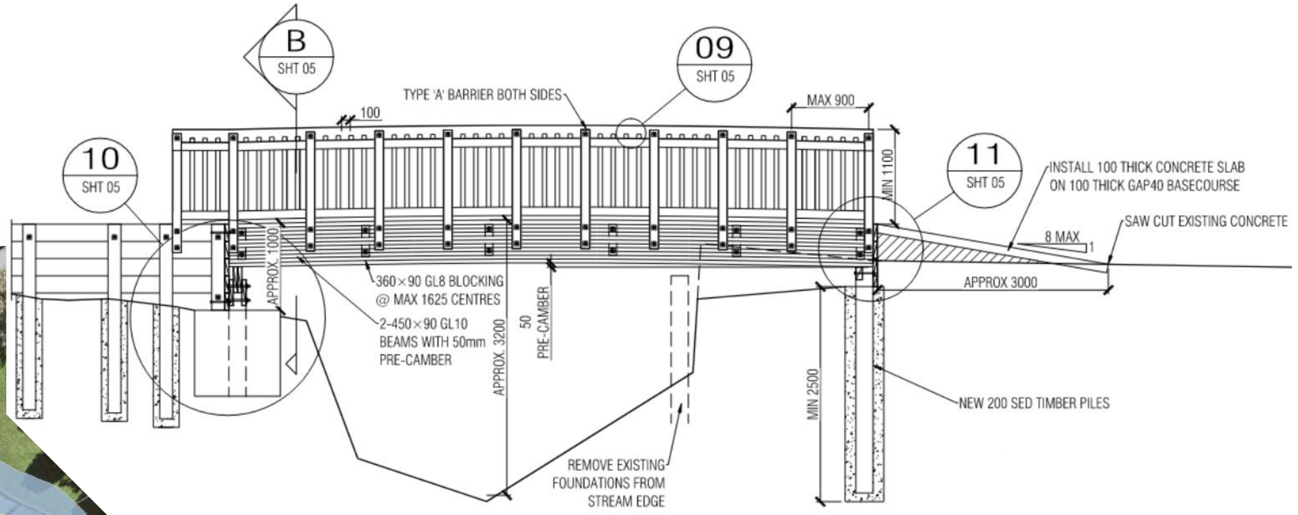
Parameter	Value	Reference
Flood velocity	2.15 m/s	100-year flood ARI flood
Flood depth	0.47 m	100-year flood ARI flood
Debris mass	450 kg	FEMA P-646
Debris raft area	5 m^2	Building consent drawings / NZTA Bridge Manual

Case Study 1 Forces

Load	Load Distribution	Magnitude
Debris Raft/Mat	Distributed across debris raft	23.1 kN (4.6 kPa)
Debris Impact Load	Point load	50.7 kN
Flood	Distributed across submerged face	15 kN (3.0 kPa)
Wind	Distributed across windward face	63.5 kN (1.3 kPa)

Case Study 2 – Harbutt Reserve Bridge, Mt Albert





Case Study 2 – Harbutt Reserve Bridge, Mt Albert

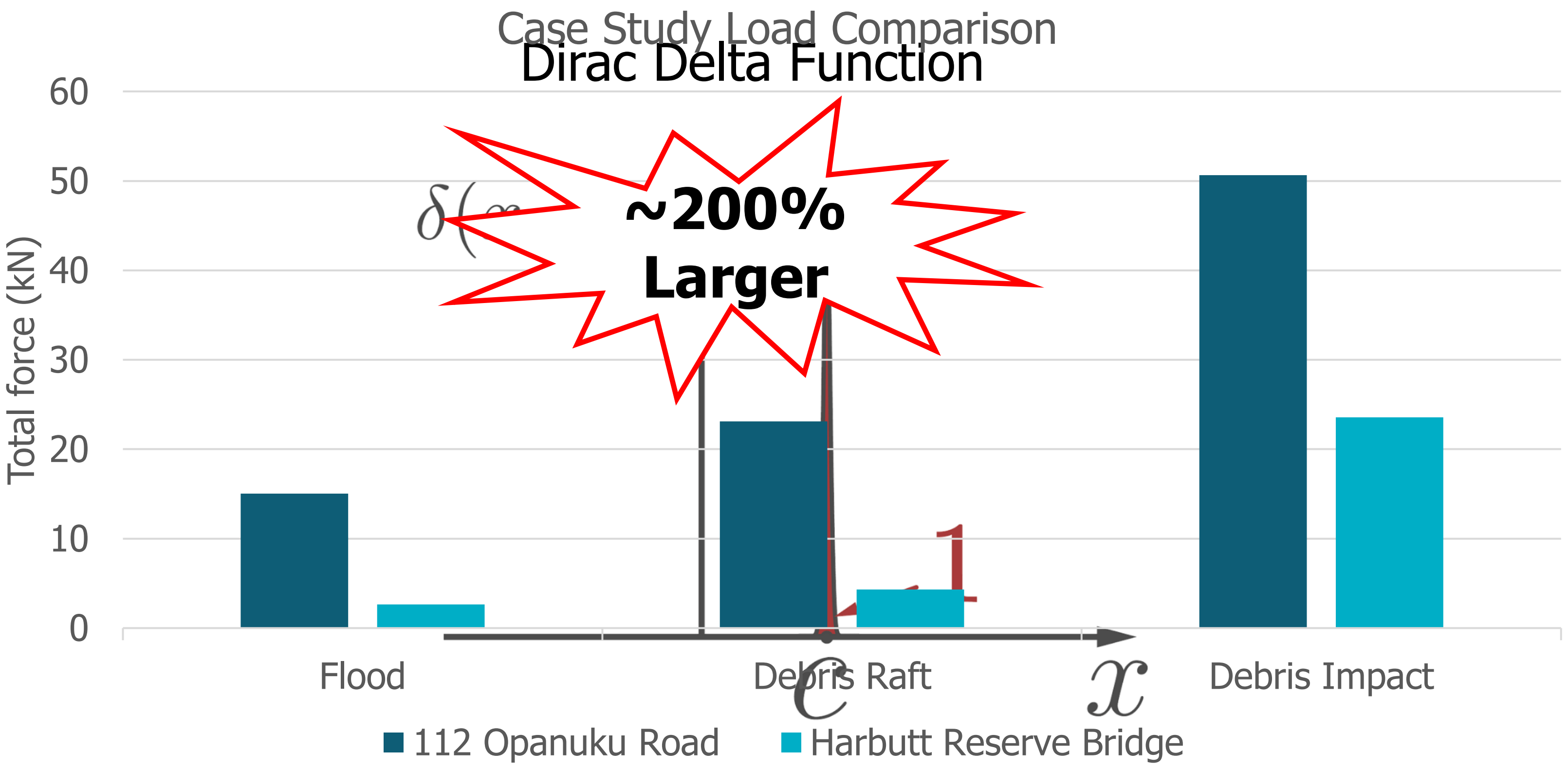
Case Study 2 Parameters

Parameter	Value	Reference
Flood velocity	1.00 m/s	100-year flood ARI flood
Wetted depth of superstructure	0.5m (fully submerged)	100-year flood ARI flood
Debris mass	450 kg	FEMA P-646
Debris raft area	3.75 m^2	Design plans / NZTA Bridge Manual

Case Study 2 Forces

Load	Load Distribution	Magnitude
Debris Raft/Mat	Distributed across debris raft	4.3 kN (1.2 kPa)
Debris Impact Load	Point load	23.6 kN
Flood	Distributed across submerged face	2.7 kN (0.7 kPa)

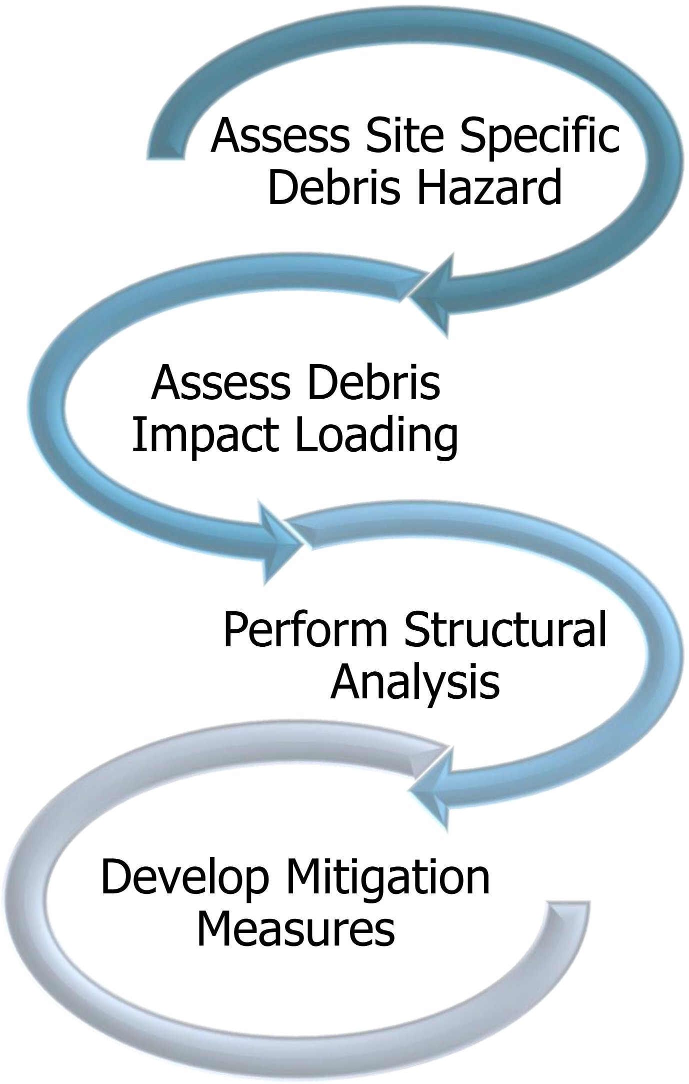
Force Comparison



Summary: Assessment Framework

Understand Risk → Evaluate Consequence → Develop Measures

Summary: Assessment Framework



Following the approach adopted by Bridge Manual

- Desktop study

Implement Haehnel and Daly Impulse-Momentum Equation

- Impact duration of 0.03 s
- Debris mass and velocity from site assessment

- Incorporate the calculated debris loading into the structural analysis

This may include:

- Provision of debris impact barriers
- Strengthening vulnerable structural components
- Employing resilient construction materials

Thank you!
Questions? Patai?