CSA M424.3-25

Braking performance standard

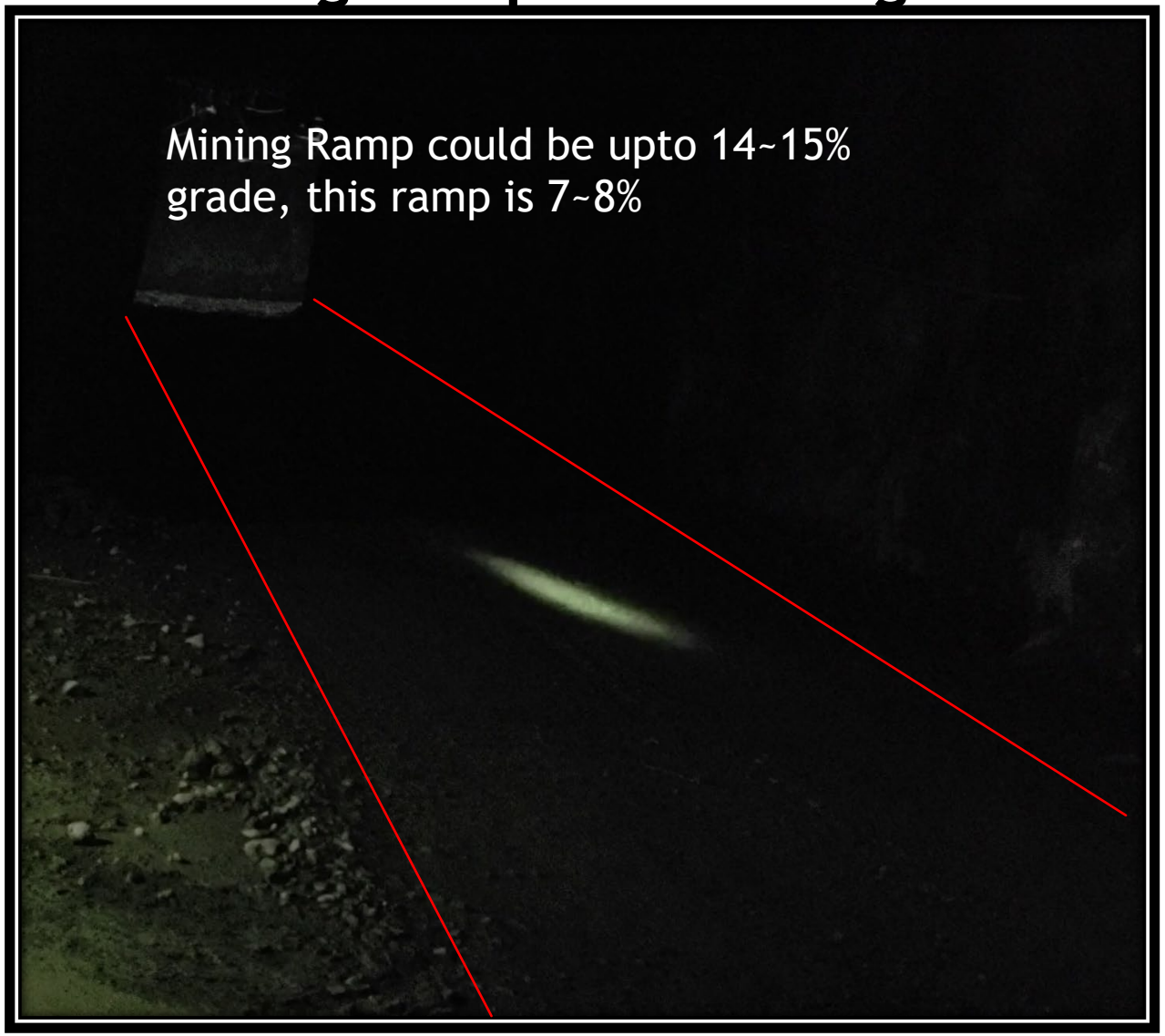
Rubber-tired, self-propelled **underground mining machines.** **CSA TSC Updates**

- Gaurav Mahajan, CanmetMINING

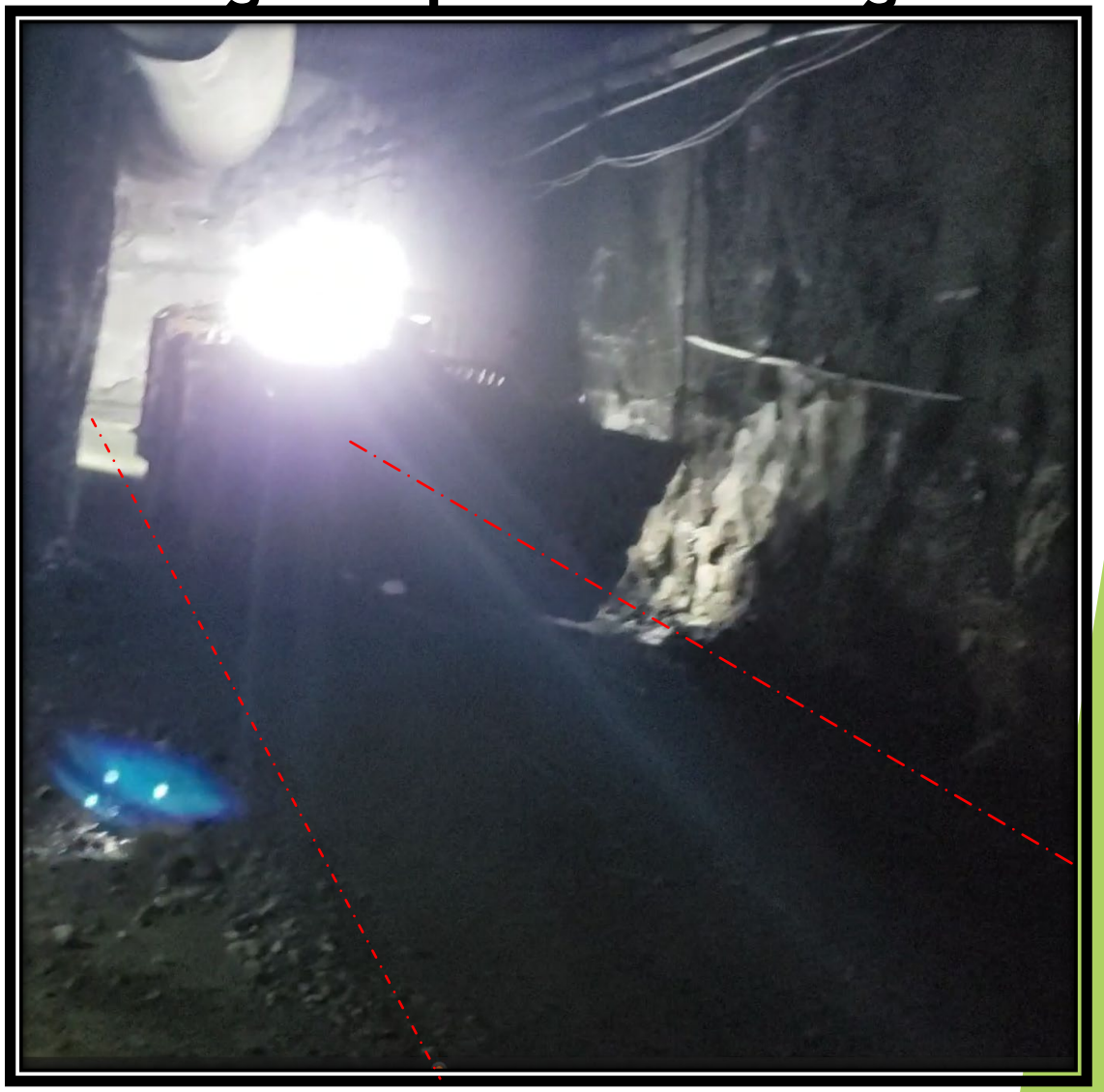
Committee Chairs: Cynthia Matikainen, Jason Flanagan

Brakes on UG Mining Equipment

Mining Ramp without lights



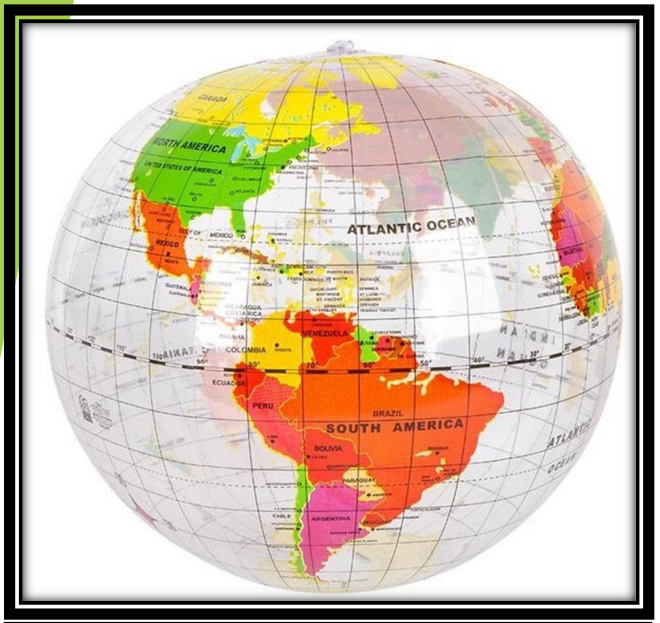
Mining Ramp with LHD lights



Current Standard:
M424.3 -22 Braking Performance - Rubber-Tired, Self-Propelled Underground Mining Machines

- Legislative requirement in Ontario, Nova Scotia, British Columbia, Alberta, New Brunswick, Newfoundland and Labrador and others.
- Prior to use in an underground mine the brake systems of a rubber-tired motor vehicle shall meet the requirements of CSA M424.3
- Over the years, CSA M424.3 has provided a consistent **framework for testing and validating** braking performance of mining equipment.

Why the **Technical Committee (TC)** initiated a review



To Align with Global International standards for U/G Braking.

Industry feedback

Mitigating risk involve in testing at 20% grade

Improve Safety

Making testing more accessible for End users and OEM's.

Improve Accessability

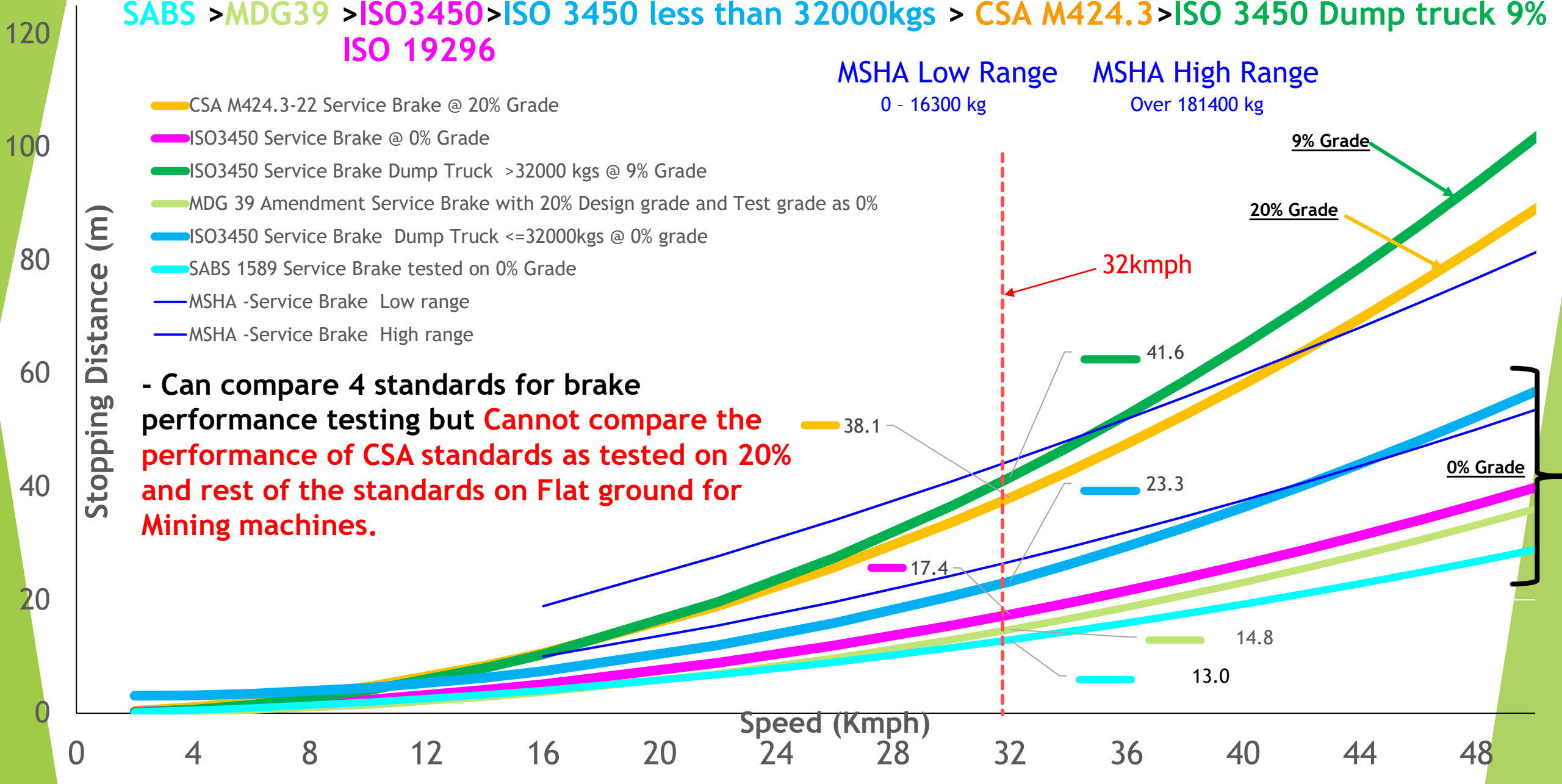
Cost saving Maintaining Test Ramps

Improve Accessability

Technological advancements in vehicle braking systems.
Mining machines are stopping with in 28~49% of the required CSA stopping limits. Based on CSA braking data of 100 machines.

CanmetMINING study -- Key findings

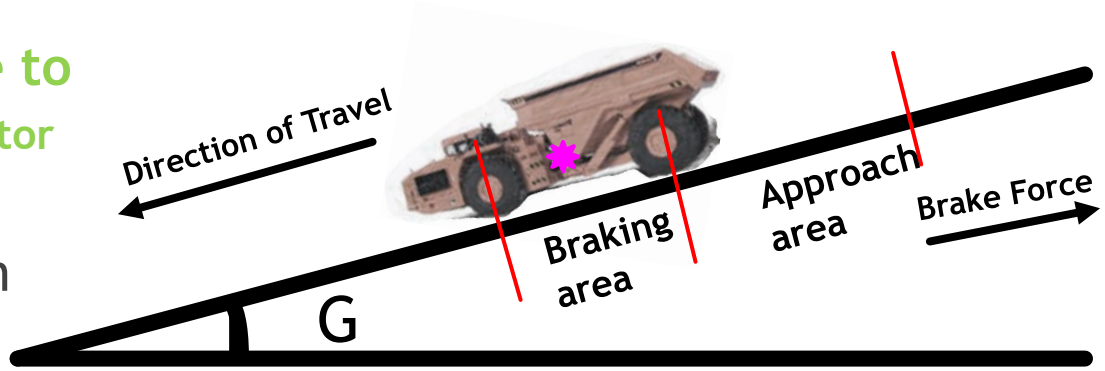
SABS >MDG39 >ISO3450>ISO 3450 less than 32000kgs > CSA M424.3>ISO 3450 Dump truck 9% ISO 19296



- Can compare 4 standards for brake performance testing but Cannot compare the performance of CSA standards as tested on 20% and rest of the standards on Flat ground for Mining machines.

Proposed universal formula (Grade Independent)

Stopping distance (TOTAL) = Stopping Distance Due to Deceleration + Stopping Distance due to system and operator response time.

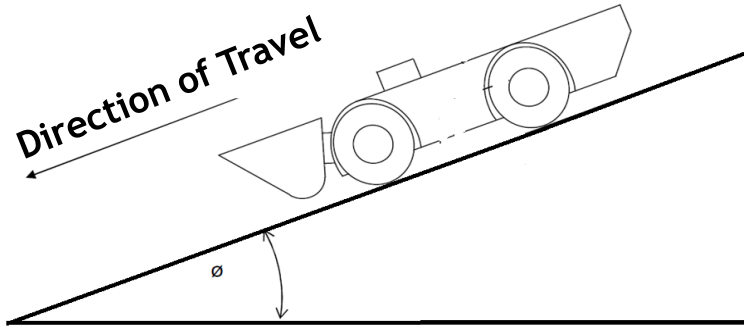


- Considering the grade - the effective deceleration acting against the vehicle's travelling on grade is given by: Effective Deceleration rate = $a \pm g * G$,
  Depending upon direction of travel

Stopping Distance Due to Deceleration

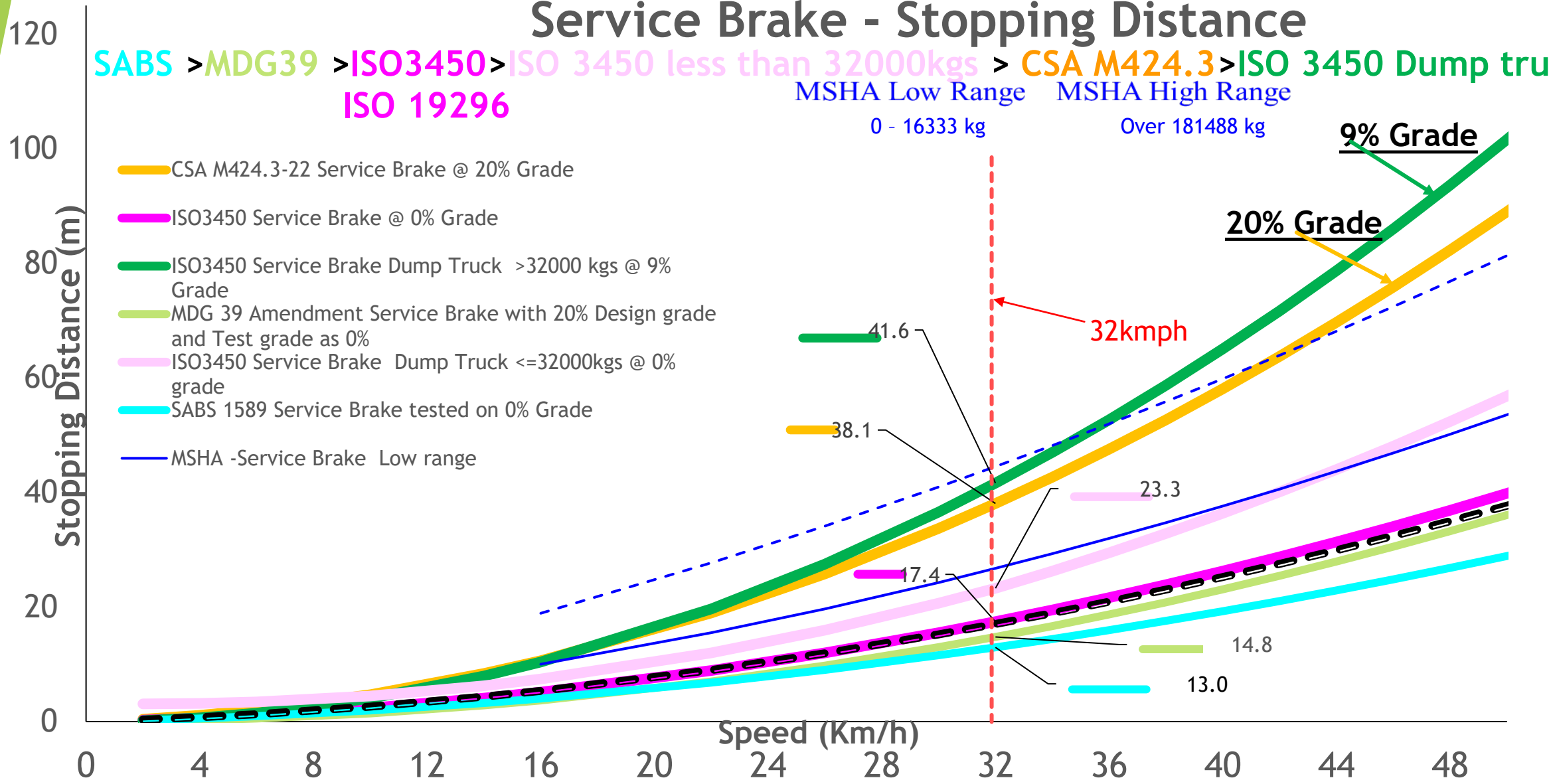
$$d = \frac{V^2}{2g\left(\frac{a}{g} \pm G\right)} + V\,t$$

Stopping Distance due to system and operator response time.



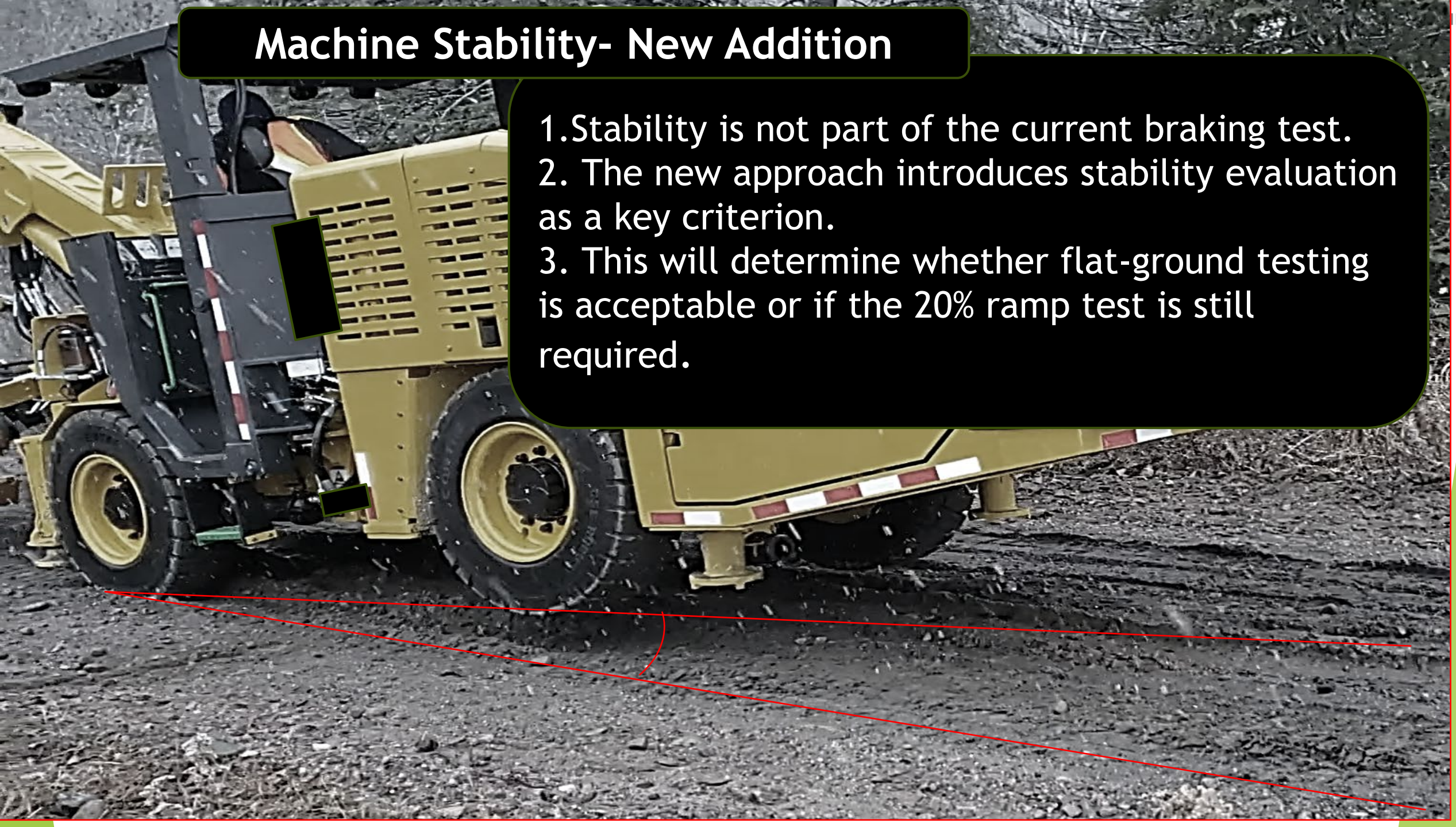
- Using the above formula, deceleration rate for CSA testing on flat ground is calculated. 3.14m/s2
- Formulas been verified the formula to validate the stopping distances in ISO 3450, SABS 1589 for flat ground and ISO at 9% for dump trucks and CSA at 20% as well as 0% Grade.

CanmetMINING study findings

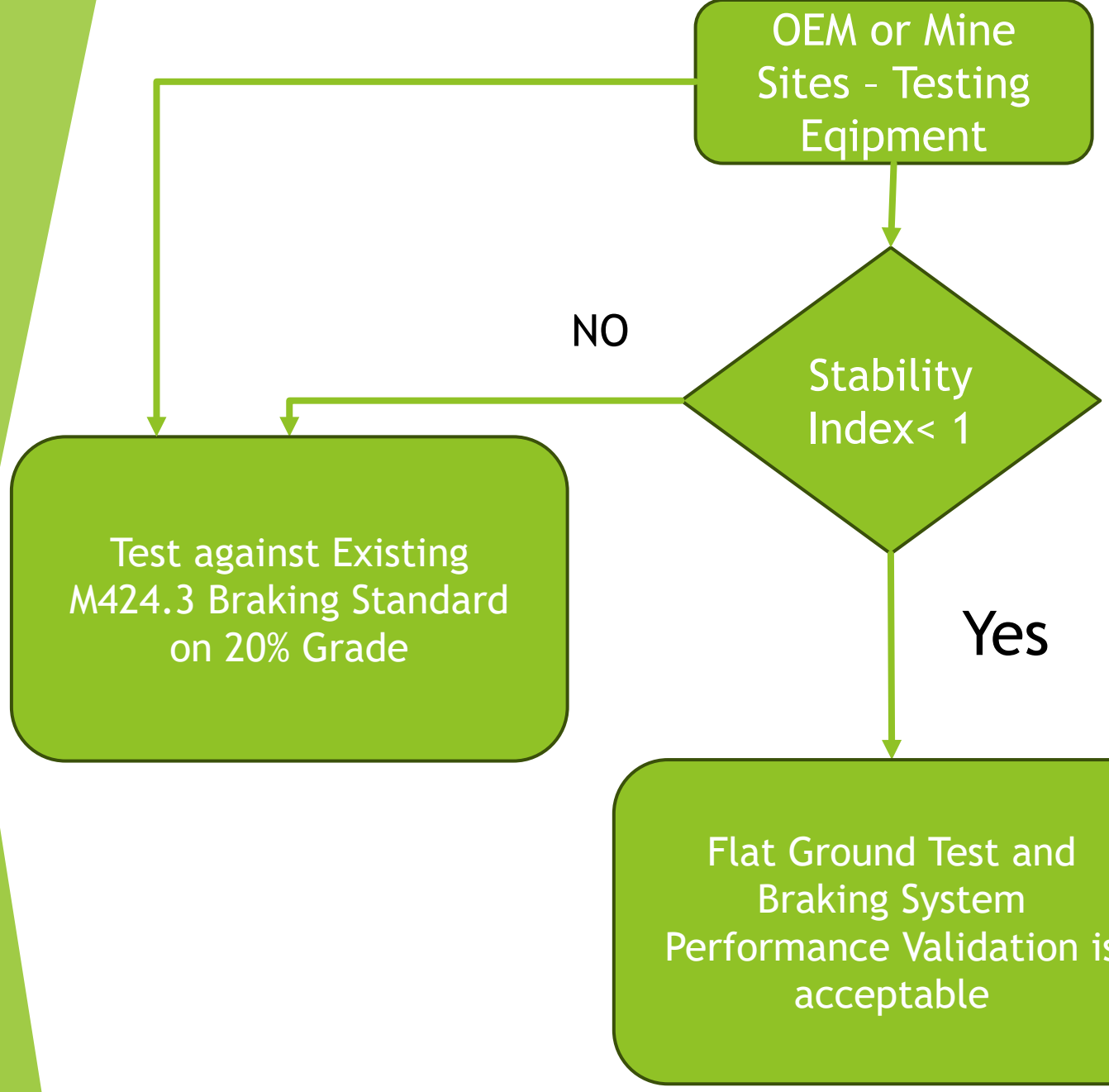


Machine Stability- New Addition

1.Stability is not part of the current braking test.
2. The new approach introduces stability evaluation as a key criterion.
3. This will determine whether flat-ground testing is acceptable or if the 20% ramp test is still required.



Proposed path forward



This provides a path for OEMs to qualify the brake performance on Flat ground if they demonstrate conformance to stability Index calculation provided in the Annex of M424.0-25

What is considered for **Longitudinal Stability during braking** on slope

$$\text{Stability Index} = \frac{\text{Actual Machine CG height}}{\text{Critical CG height}}$$

Critical CG height (h') is the Height of the Centre of Gravity(CG) of vehicle , when Rear axle reaction is less than ZERO due to dynamic weight shift from slope/grade machine is negotiating, braking deceleration rate and machine weight distribution.

- **Index ≥ 1** → Risk of rear lift-off
- **Index < 1** → Stable under given conditions

Critical CG height formula used is based on below.

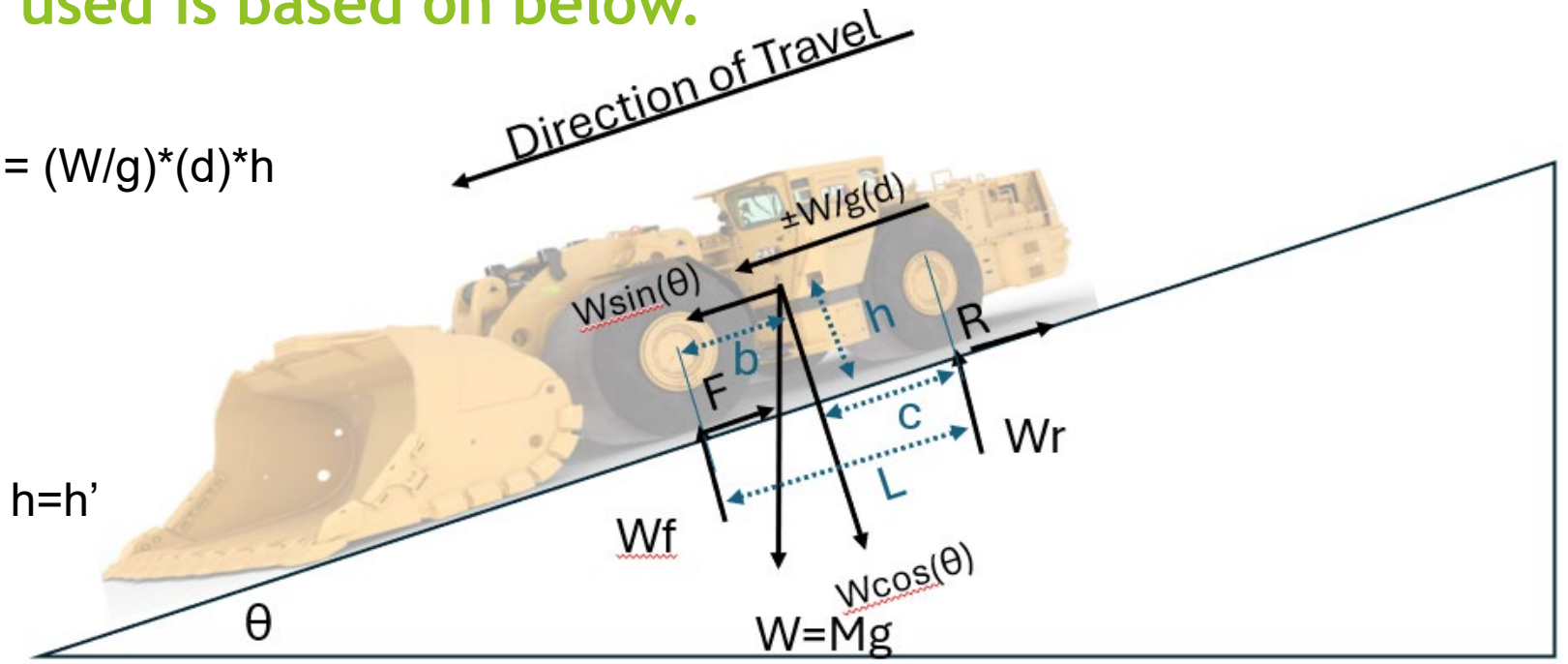
Taking Moment on Front axle (F)
Dynamic weight transfer due to braking is = (W/g)*(d)*h
Weight transfer due to slope = W *sin(θ)
Static load share = W*cos (θ)

Wr= W/L * (b*cosθ - h* sinθ - h*d/g)

When Rear tire lift off the ground; Wr = 0 , h=h'

Solving for h'

$$\text{Critical CG Height } h' = \frac{b.\cos\theta}{(\sin\theta + (d/9.81))}$$



Free body diagram of forces acting on machine during downhill ramp braking.

Rear tire lift occurs if h≥h' for the given slope θ and deceleration rate d.

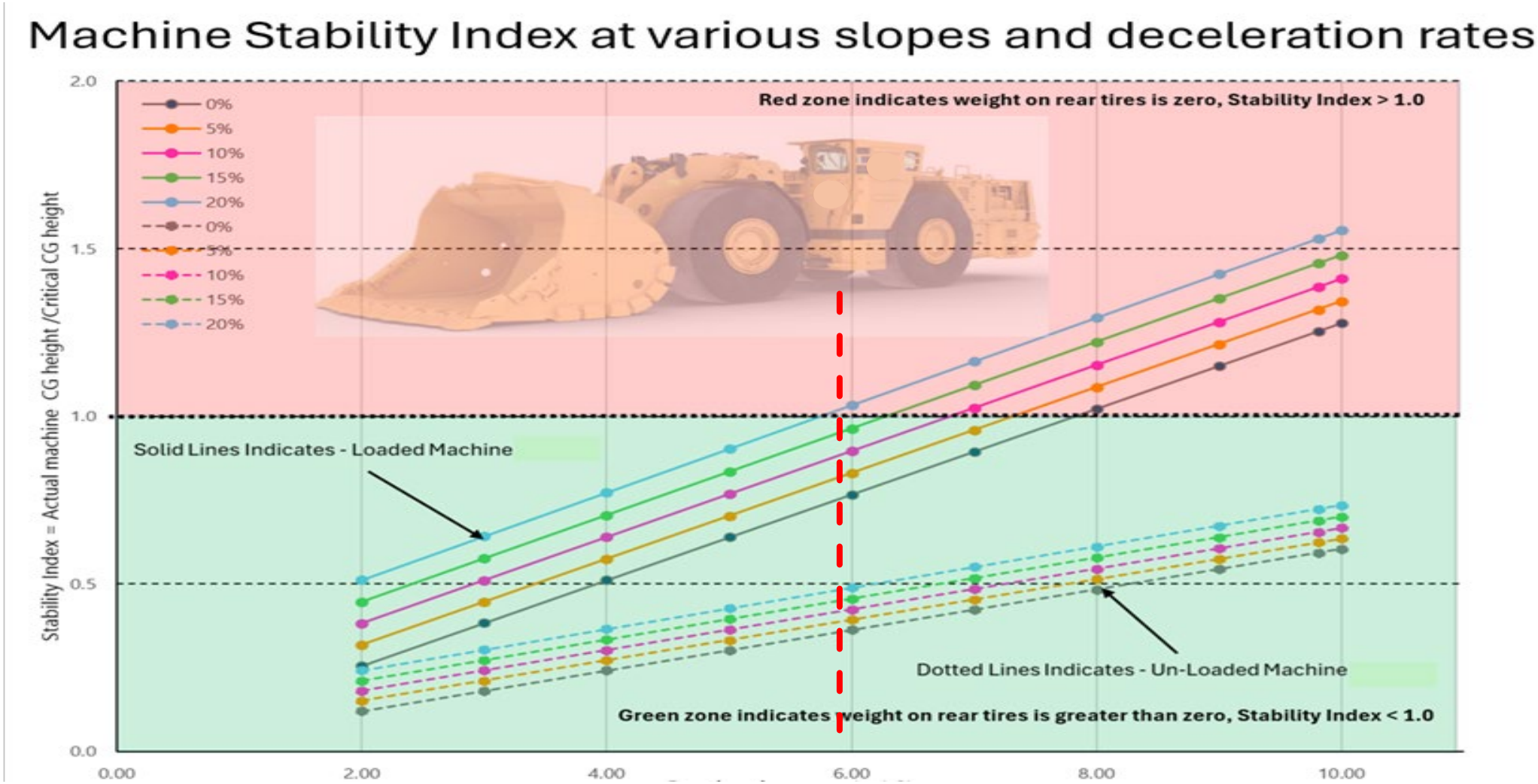
Parallelly, **taking moment on Rear axle (R)** ,

Wf can be obtained as
Wf = W/L * (b*cosθ + h* sinθ + h*d/g)

W = weight of truck (Mg)
g = gravitational acceleration (9.81 m/s^2)
d = braking deceleration (m/s^2)
L = wheelbase
h = height of center of gravity (CG)
h' = critical CG height
θ = slope angle downhill
Wf = Front normal reaction
Wr = Rear normal reaction

Graph for better data visualization

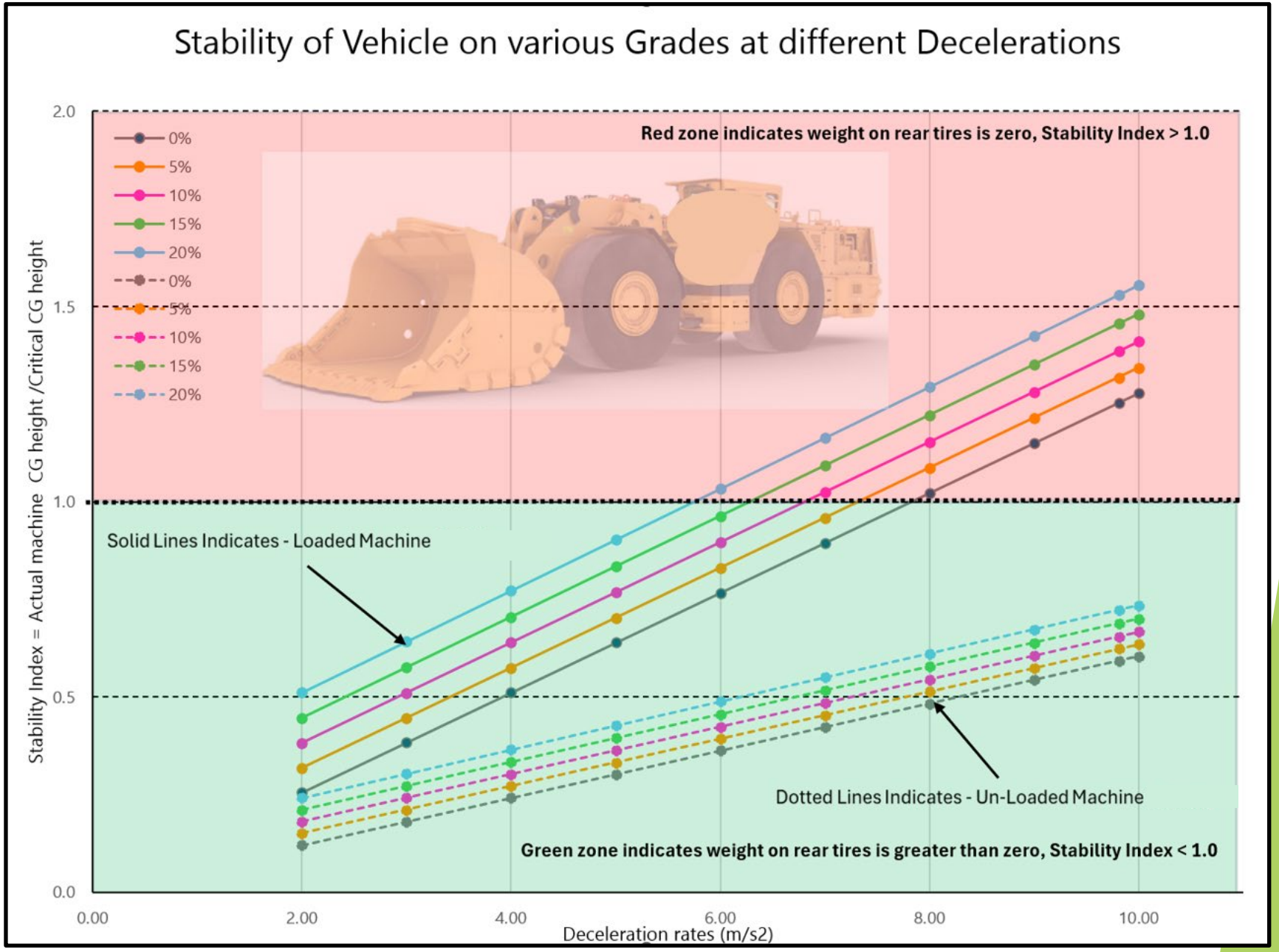
- For better visualization, Stability index is plotted against deceleration rates
  - Red zone **Index ≥ 1** → Risk of rear lift-off during braking
  - Green zone **Index < 1** → Stable during braking



Example of Load Haul Dump (LHD)

		Loaded
Machine weight	Kg	82350
Condition		Loaded
Weight Distribution to FA	%	74.0%
Front Axle (FA) Static Load	Kg	60939
Rear Axle (RA) Static Load	Kg	21411
Wheel Base	m	3.78
Centre of Gravity (CG) Height	m	1.232
CG distance from FACL	m	1.0
CG from RACL	m	2.8
Wheel Track Front Axle	m	2.15
Wheel Track Rear Axle	m	2.15
Deceleration(-ve)/ Accerlation(+) recorded during testing	m/s2	5.95

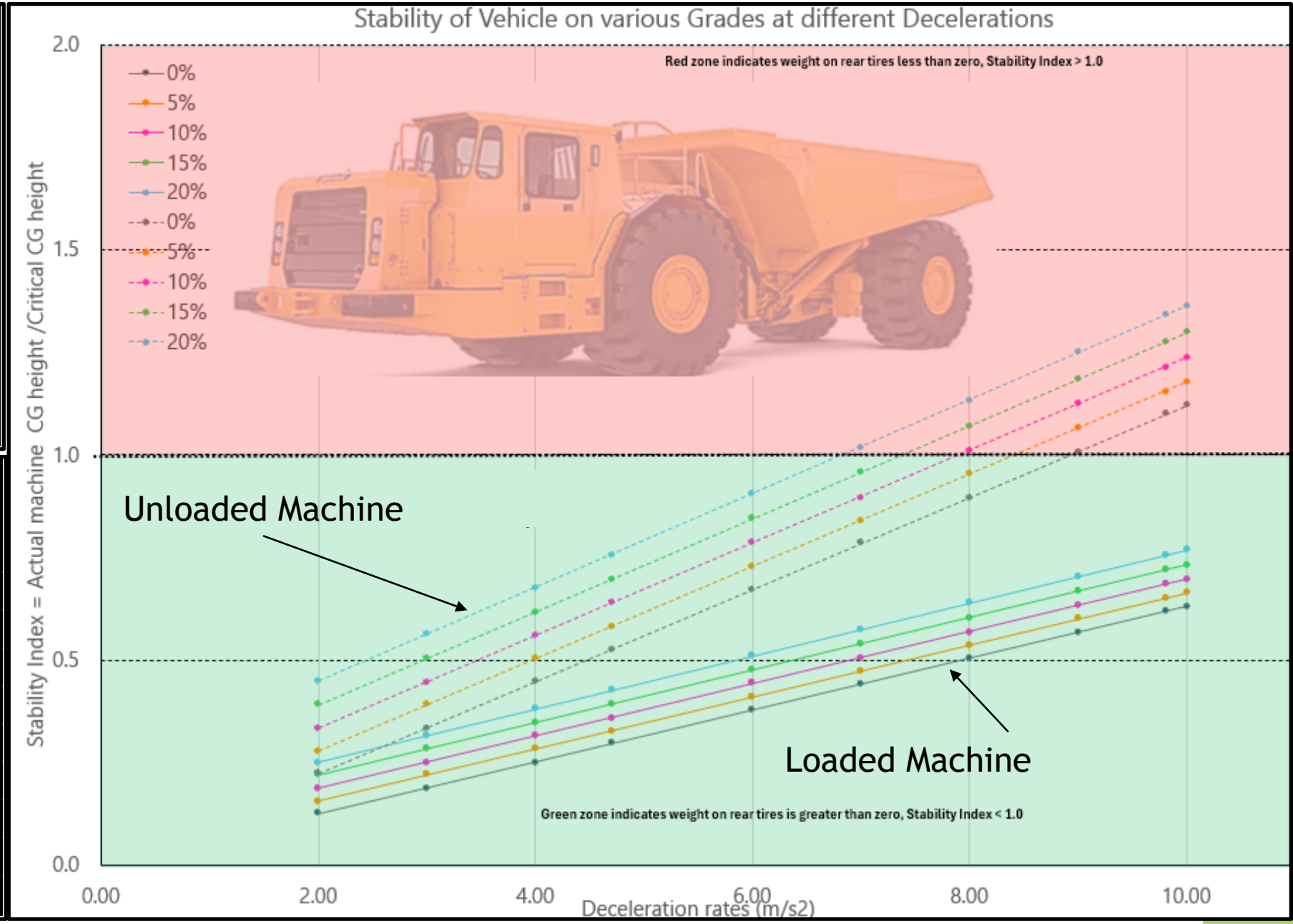
		Unloaded
Machine weight	Kg	63850
Condition		Unloaded
Weight Distribution to FA	%	45.0%
Front Axle (FA) Static Load	Kg	28733
Rear Axle (RA) Static Load	Kg	35118
Wheel Base	m	3.78
Centre of Gravity (CG) Height	m	1.232
CG distance from FACL	m	2.1
CG from RACL	m	1.7



Example of UG Mining Truck

Mining Truck		Loaded
Machine weight	Kg	100010
Condition		Loaded
Weight Distribution to FA	%	46.8%
Front Axle (FA) Static Load	Kg	46805
Rear Axle (RA) Static Load	Kg	53205
Wheel Base	m	5.57
Centre of Gravity (CG) Height	m	1.8381
CG distance from FACL	m	3.0
CG from RACL	m	2.6
Deceleration(-ve)/ Accerlation(+) recorded during testing	m/s2	4.7

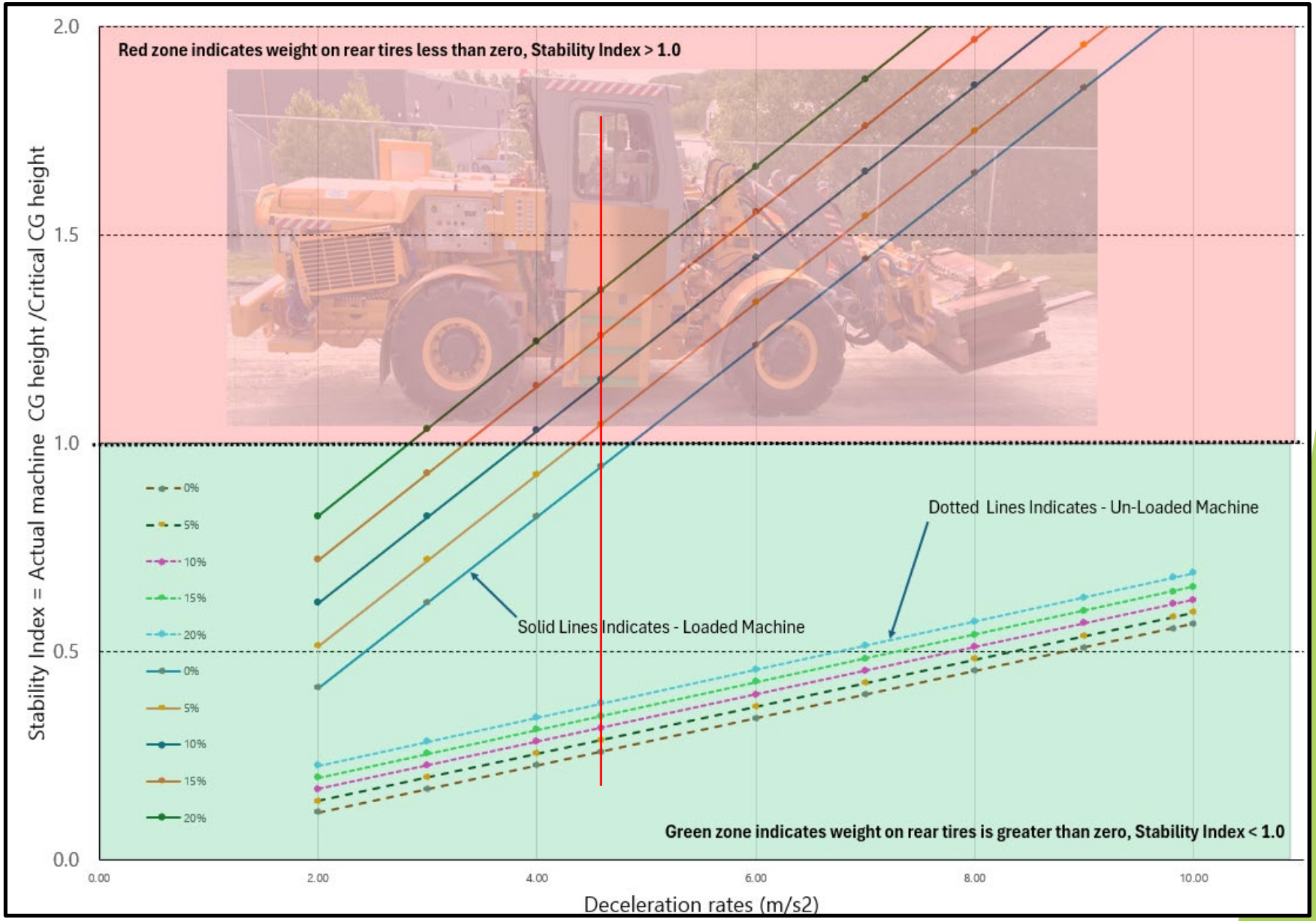
Mining Truck		Unloaded
Machine weight	Kg	55010
Condition		Unloaded
Weight Distribution to FA	%	70.0%
Front Axle (FA) Static Load	Kg	38507
Rear Axle (RA) Static Load	Kg	16503
Wheel Base	m	5.57
Centre of Gravity (CG) Height	m	1.8381
CG distance from FACL	m	1.7
CG from RACL	m	3.9
Decelration on flat ground		4.7



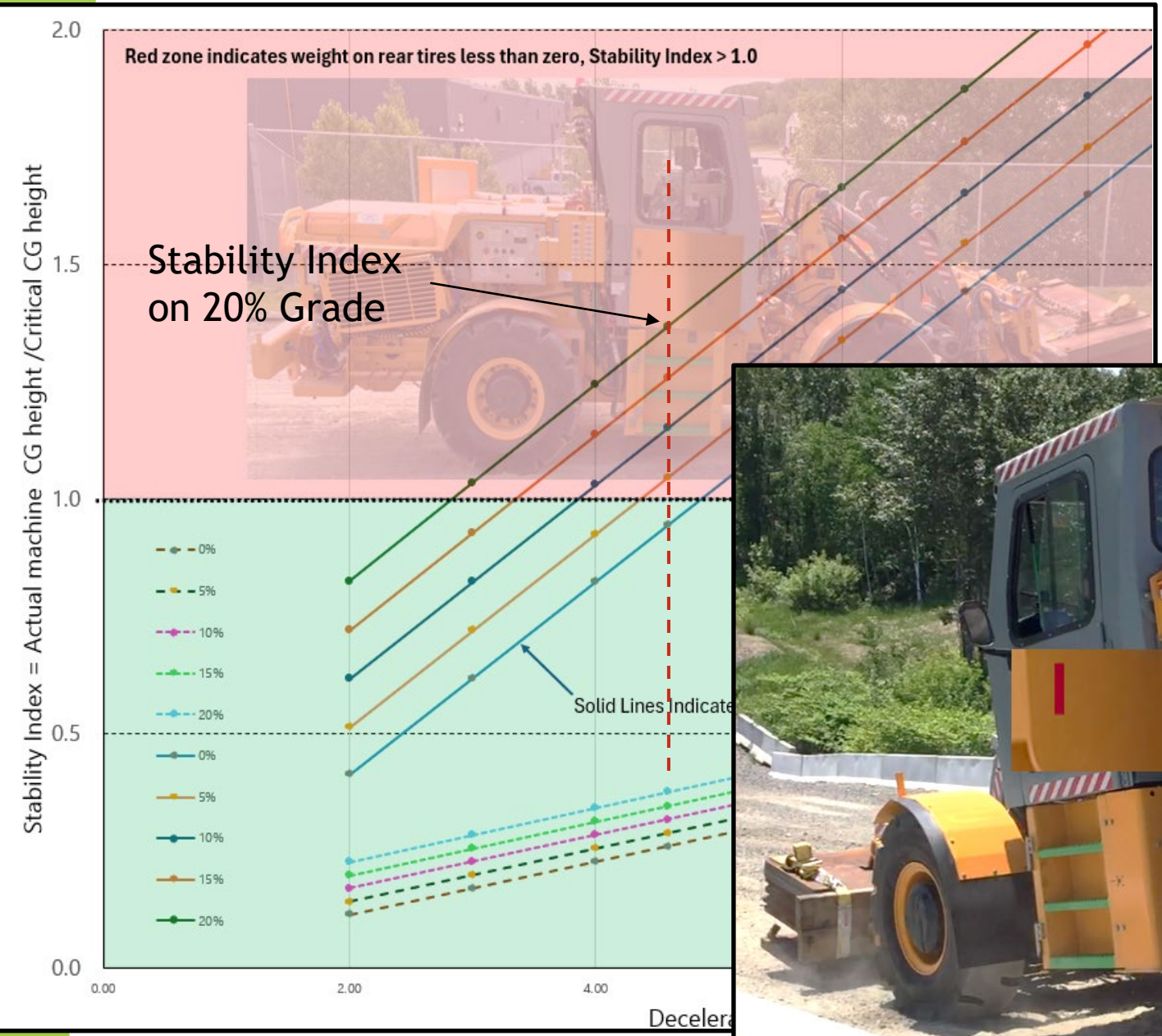
Example of Forklift

		Loaded
Machine weight	Kg	22661
Condition		NA
Weight Distribution to FA	%	84.7%
Front Axle (FA) Static Load	Kg	19187
Rear Axle (RA) Static Load	Kg	3475
Wheel Base	m	3.04
Centre of Gravity (CG) Heigh	m	0.943
CG distance from FACL	m	0.5
CG from RACL	m	2.6
Decelration on flat ground		4.59

		Unloaded
Machine weight	Kg	16021
Condition		NA
Weight Distribution to FA	%	44.2%
Front Axle (FA) Static Load	Kg	7076
Rear Axle (RA) Static Load	Kg	8945
Wheel Base	m	3.04
Centre of Gravity (CG) Height	m	0.943
CG distance from FA CL	m	1.7
CG from RA CL	m	1.3
Decelration on flat ground	m/s2	4.59



Example of Forklift – Actual Ramp test



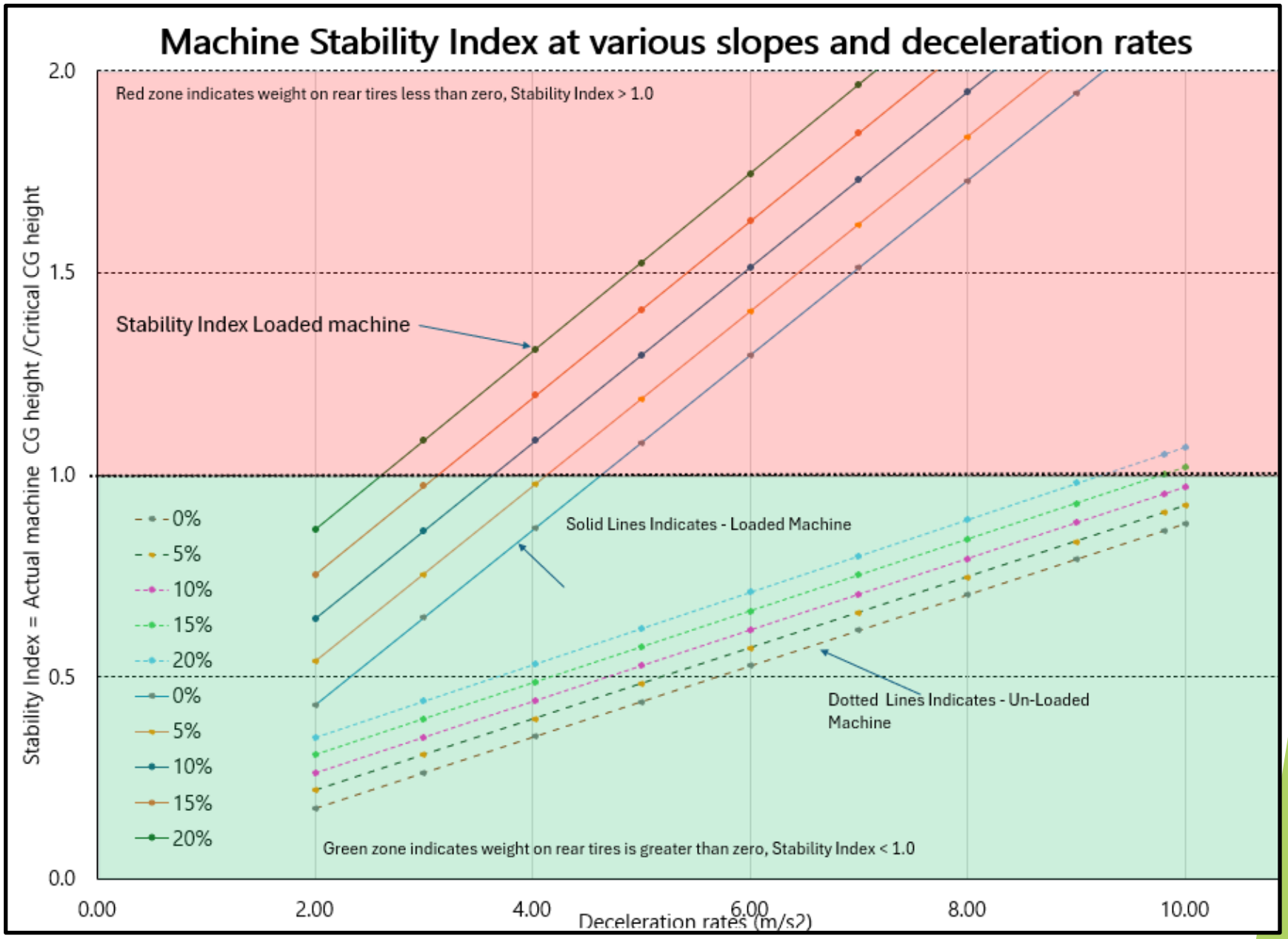
	Critical Heigh Factor Down Hill Travel				
Deceleration rate (m/s2)	0%	5%	10%	15%	20%
2.00	0.4	0.5	0.6	0.7	0.8
3.00	0.6	0.7	0.8	0.9	1.0
4.00	0.8	0.9	1.0	1.1	1.2
4.59	0.9	1.0	1.2	1.3	1.4
6.00	1.2	1.3	1.4	1.6	1.7
7.00	1.4	1.5	1.7	1.8	1.9
8.00	1.6	1.8	1.9	2.0	2.1

Tested Deceleration value is 4.58m/s^2

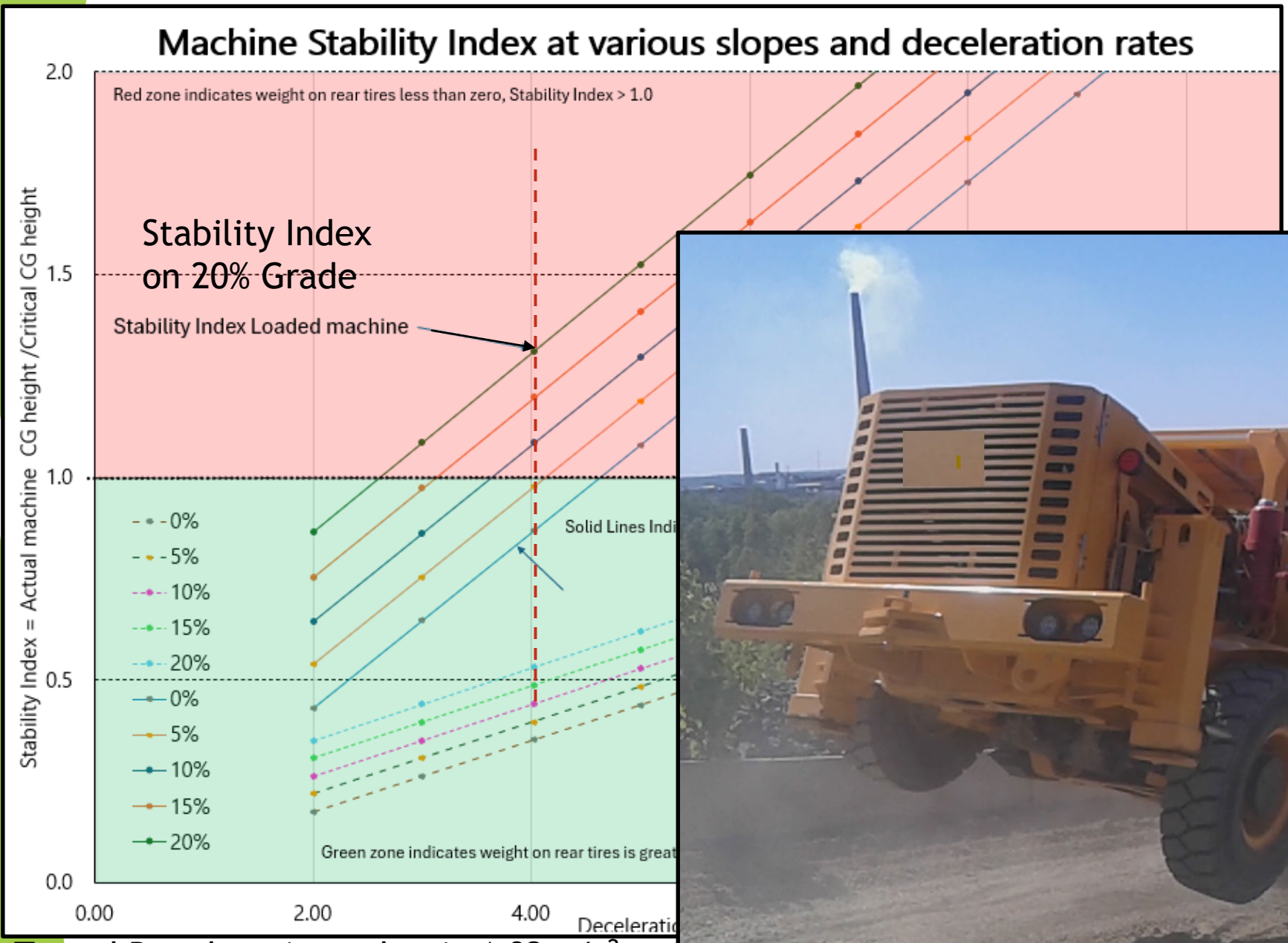
Example of Utility Vehicle

		Loaded
Machine weight	Kg	24408
Condition		NA
Weight Distribution to FA	%	84.4%
Front Axle (FA) Static Load	Kg	20608
Rear Axle (RA) Static Load	Kg	3800
Wheel Base	m	4.67
Centre of Gravity (CG) Height	m	1.5411
CG distance from FACL	m	0.7
CG from RACL	m	3.9
Decelration on flat ground	m/s2	4.02

		Unloaded
Machine weight	Kg	19042
Condition		NA
Weight Distribution to FA	%	61.7%
Front Axle (FA) Static Load	Kg	11757
Rear Axle (RA) Static Load	Kg	7285
Wheel Base	m	4.67
Centre of Gravity (CG) Height	m	1.5411
CG distance from FACL	m	1.8
CG from RACL	m	2.9
Decelration on flat ground	m/s2	4.02



Example of Utility Vehicle – Actual test image on 20% Ramp- Validating



	Critical Heigh Factor Down Hill Travel				
Deceleration rate (m/s2)	0%	5%	10%	15%	20%
2.00	0.4	0.5	0.6	0.8	0.9
3.00	0.6	0.8	0.9	1.0	1.1
4.02	0.9	1.0	1.1	1.2	1.3
5.00	1.1	1.2	1.3	1.4	1.5
6.00	1.3	1.4	1.5	1.6	1.7

Tested Deceleration value is 4.02m/s^2

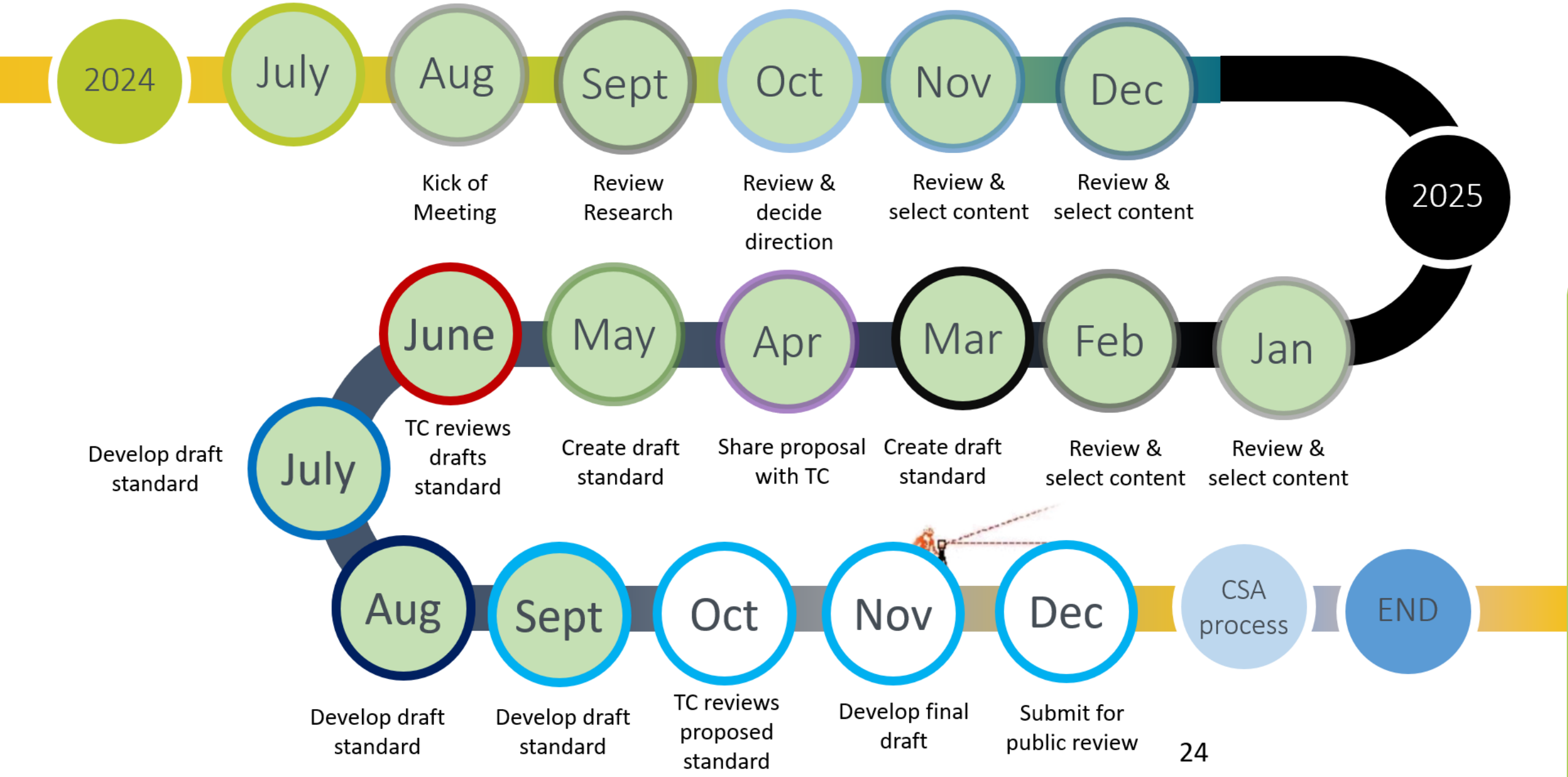
Key Outcomes

- Ramp test still accepted and applicable under CSA M424.3
- New Update on M424.0 will provide OEMs to qualify the brake performance on Flat ground if they demonstrate conformance to stability Index calculation provided in the Annex of M424.0-25
- Alignment with ISO 19296 Annex A for flat ground testing – If stability index is less than 1

Validation effort has been ongoing with support of the OEM's and Mines

- Special thanks to **CSA, CAT, Maclean, Kovatera, Epiroc team** and **VALE** for the support on validation efforts and standard proposal development.

M424.3 :25 Schedule



M424.0 :25 Annex C Stability Index calculation

Critical CG height is the Height of the Centre of Gravity of the vehicle , when the Rear tires are unweighted due to dynamic weight shift when braking on a slope.

Deceleration rate can be determined by measurement or calculated by the manufacturer.

M424.3 :25 Proposal

Adopt ISO 19296 Annex A within M424.0, with Canadian deviations

Proposed clause CSA M424.0:

4.10 Braking

4.10.1 General requirements

If the stability index is less than 1.0 (see M424.0 annex C), the test may be performed according to ISO 19296 Annex A with Canadian deviations.

If the stability index is greater than 1.0 the brakes on rubber-tyred wheeled machines shall fulfil the requirements of CSA M424.3.

Revisions to CSA M424.3:

4.1 General

The general requirements for braking, test conditions and performance tests of M424.0 apply except as specified in this standard.

The following applies to machines that have a Stability Index of greater than 1.0, see M424.0 Annex C.

For machines that have a stability index less than 1.0

The test facility and method remains the same for tests performed on a 20% grade.

Questions?

Canadian Provincial regulation referencing CSA Braking Standard.

- *Braking Performance — Rubber-Tired, Self-Propelled Underground Mining Machines*, CSA M424.3, Canadian Standards Association, Toronto, ON, Canada, 2022. [Online]. Available: https://www.csagroup.org/store/product/2700258/
- Government of Ontario, 1990. *Mines and Mining Plants, R.R.O. 1990, Reg. 854, s.119*. [Online]. Available: https://www.ontario.ca/laws/regulation/900854
- Government of Nova Scotia, 2008. *Underground Mining Regulations, N.S. Reg. 296/2008, pt. 9*. [Online]. Available: https://novascotia.ca/just/regulations/regs/ohsmine.htm
- Government of British Columbia, "Trackless diesel powered equipment," in *Health, Safety and Reclamation Code for Mines in British Columbia*, Ministry of Energy, Mines, and Low Carbon Innovation, Victoria, BC, Canada, p. 4-24, 2024. [Online]. Available: https://www2.gov.bc.ca/gov/content/industry/mineral-exploration-mining/health-safety/health-safety-and-reclamation-code-for-mines-in-british-columbia
- Government of Alberta, 2021. *Occupational Health and Safety Code, Alta. Reg. 191/2021, s. 574*. [Online]. Available: https://search-ohs-laws.alberta.ca/legislation/occupational-health-and-safety-code/part-36-mining/#:~:text=574(1),Self%2DPropelled%20Underground%20Mining%20Machines
- Government of New Brunswick, 1996. *Underground Mine Regulation, N.B. Reg. 96-105*. [Online]. Available: https://laws.gnb.ca/en/showfulldoc/cr/96-105/20160821
- Government of Newfoundland and Labrador, 2012. *Occupational Health and Safety Regulations, N.L. Reg. 5/12, s. 533-534*. [Online]. Available: https://www.assembly.nl.ca/legislation/sr/annualregs/2012/nr120005.htm

BACK UP

Presentation plan

- Braking system of UG Mining machines Primary/Secondary Brakes/ Emergency
  Safety in UG Mining Braking system
  Why- TC is doing the project, TSC constitutes Engineers /Industry Experts / OEMs regulatory experts/ Provincial Regulators /End users/ Mine fleet managers

  What's the Benefit
  Approach Agreed by Technical Sub Committee

CSA M424.0:22
Underground mining mobile equipment — General requirements (Adopted ISO 19296:2018, first edition, 2018-11, with Canadian deviations)

CSA M424.1:22

Flameproof non-rail-bound diesel-powered machines for use in gassy underground coal mines

CSA M424.3:22

Braking performance — Rubber-tired, self-propelled underground mining machines

CSA M424.4:22

Self-propelled, electrically driven, non-rail-bound mobile machines for use in non-gassy underground mines

CSA M424.2:22

Diesel-powered machines for use in non-gassy underground mines

Key area focused

1. **Background** on Braking system in UG Mining.
2. **Current Regulation requirement.**
3. Why **CSA TC Open's** standard for review
4. **Finding of CanmetMINING Braking standards Comparison study.**
5. **Proposed approach** and **additional safety considerations** – Stability Index Proposed.
6. **Ongoing Validation and Verification** of the proposal.
7. Consolidated Recap.

Why this revision

- Numerous OEM and Mining companies are facing challenges with limited numbers of ramps.
- OEM's design machine fixed one global braking performance i.e. designed brake torque is good to meet or exceed the global braking standards. CSA , ISO , SANS, MDG39 , MSHA etc.
- Representatives from mobile equipment manufacturers and mining companies have requested a test on level ground because it would save money and time without compromising on safety of the miners.
- Ramps must be maintained in acceptable condition for testing requiring audits of the parameters.

- Canmet Mining performed a braking standards study under grant from CSA.
  - Finding revealed the CSA braking requirement once transcended on flat ground are very much same as ISO 3450 (Canmet Mining Graph)
- Safety – additional safety using Stability Index
- Ongoing validation effort on stability index. (15 machines evaluated)
  - Support from OEM's and Mining sites to share data.
- Proposal for future standard changes at TSC – Flow Chart OEM's Technical regulators and End Users. ……. Industry expert….
  - Allow OEM and end users to check brake performance on flat grounds.
  - Make it safe for the operators and
  -

M424.3 :25 Proposal

Adopt ISO 19296 Annex A within M424.0, with Canadian deviations

Proposed clause CSA M424.0:

4.10 Braking

4.10.1 General requirements

If the stability index is less than 1.0 (see M424.0 annex C), the test may be performed according to ISO 19296 Annex A with Canadian deviations.

If the stability index is greater than 1.0 the brakes on rubber-tyred wheeled machines shall fulfil the requirements of CSA M424.3.

Revisions to CSA M424.3:

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For machines that have a stability index less than 1.0

The test facility and method remains the same for tests performed on a 20% grade.

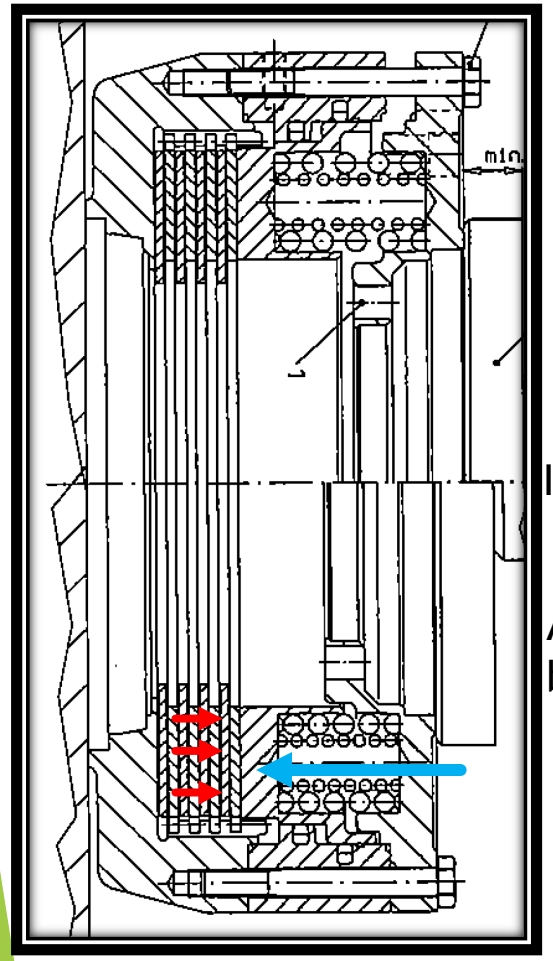
Why CSA TC initiated a review

The **Technical Committee (TC)** initiated a review to address

- **Industry feedback – alignment with global standards.**
- **Technological advancements** in vehicle braking systems.
- **Mining machines are stopping with in 28~49% of the required CSA stopping limits.**
- To improve **testing safety, repeatability, and accessibility** across different regions and facilities.

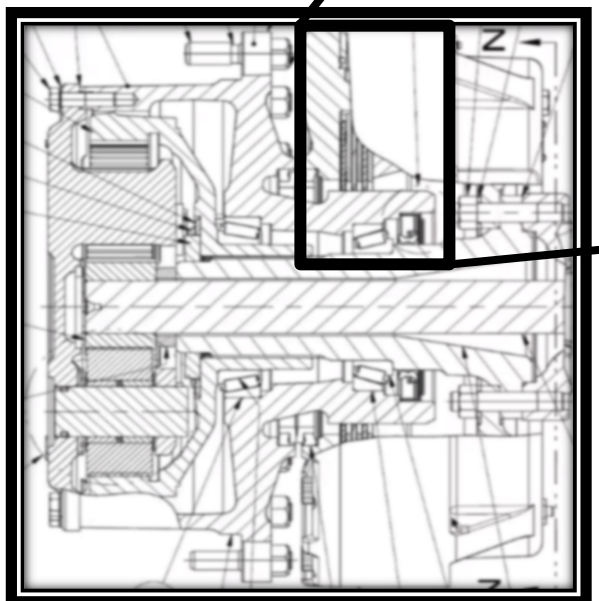
Brakes in U/G Mining Vehicles

- Service Brake / Primary brakes.
- Emergency Brakes / Secondary Brakes.
- Park Brake – to hold vehicle stationary

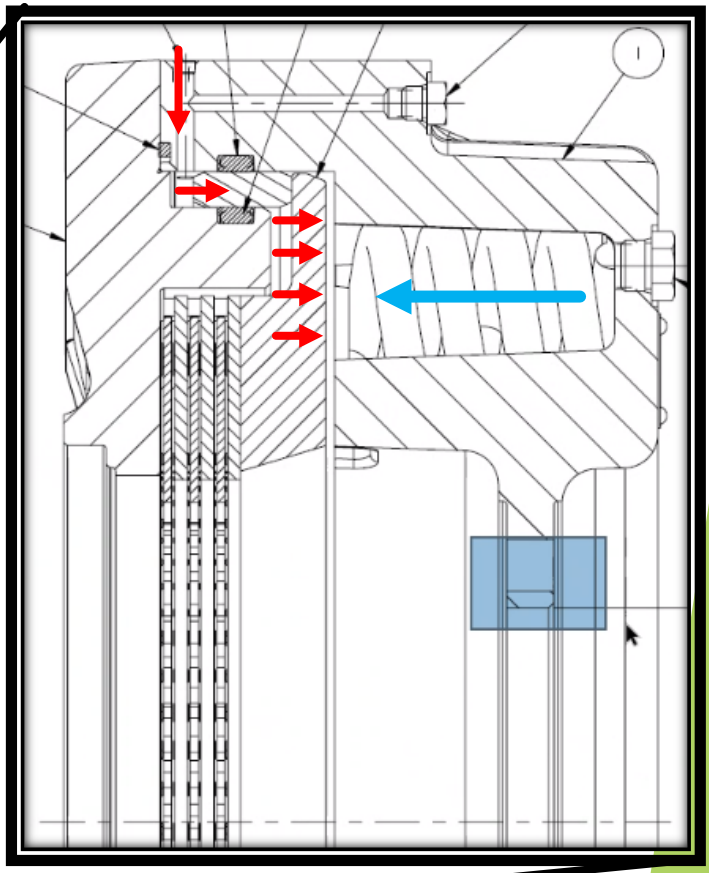


Internal Wet Brakes

Application based brake cooling.



Spring Applied Hydraulic Release



Fail Safe Brakes

M424.0 :25 Annex C Stability Index calculation

Critical CG height is the Height of the Centre of Gravity of the vehicle , when the Rear tires are unweighted due to dynamic weight shift when braking on a slope.

Deceleration rate can be determined by measurement or calculated by the manufacturer.

M424.3 :25 Proposal

Adopt ISO 19296 Annex A within M424.0, with Canadian deviations

Proposed clause CSA M424.0:

4.10 Braking

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