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Review of Global Mining Machine Braking Standards and Development of the CSA M424.3 Braking Standard.

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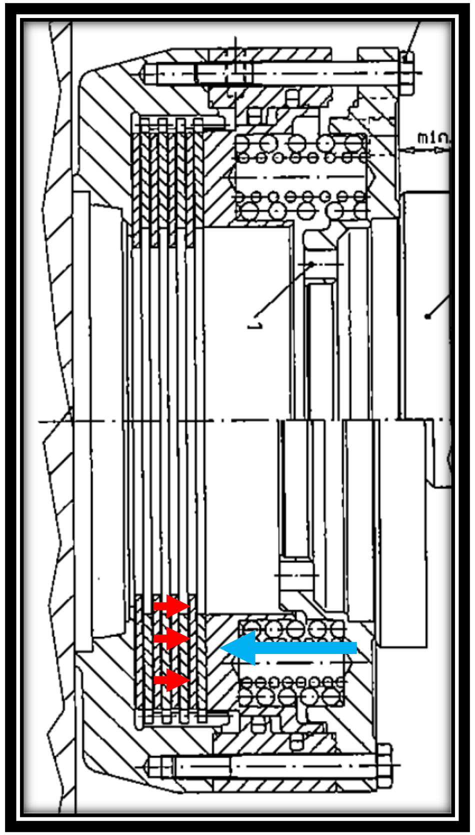
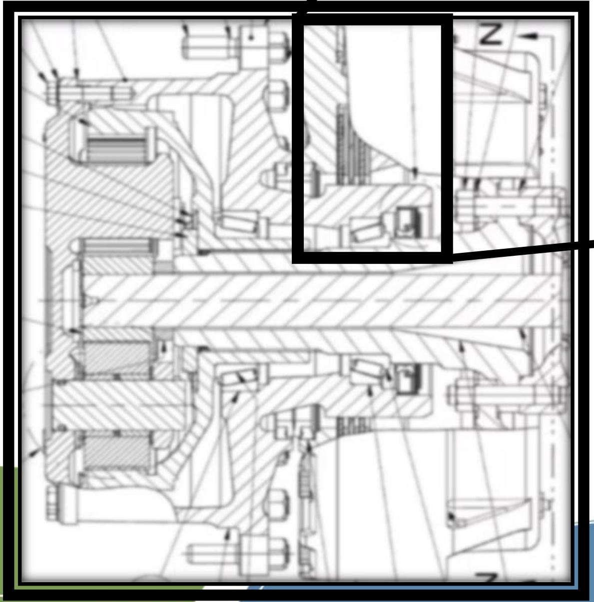
Canada

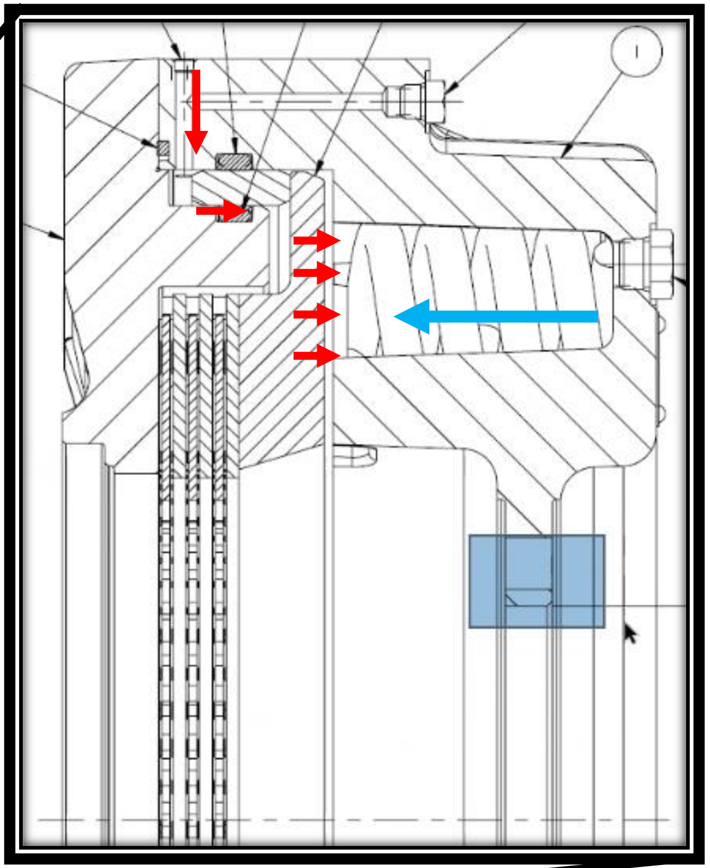
Brakes in U/G Mining Vehicles

- Perform 3 Brake functions Service Braking, Emergency / Secondary braking and Park Brake. Spring Applied Hydraulic Brakes. Fail safe Brakes.
- Test methods for Service brakes and Secondary brakes are different.



Mining axle Wheel Hub



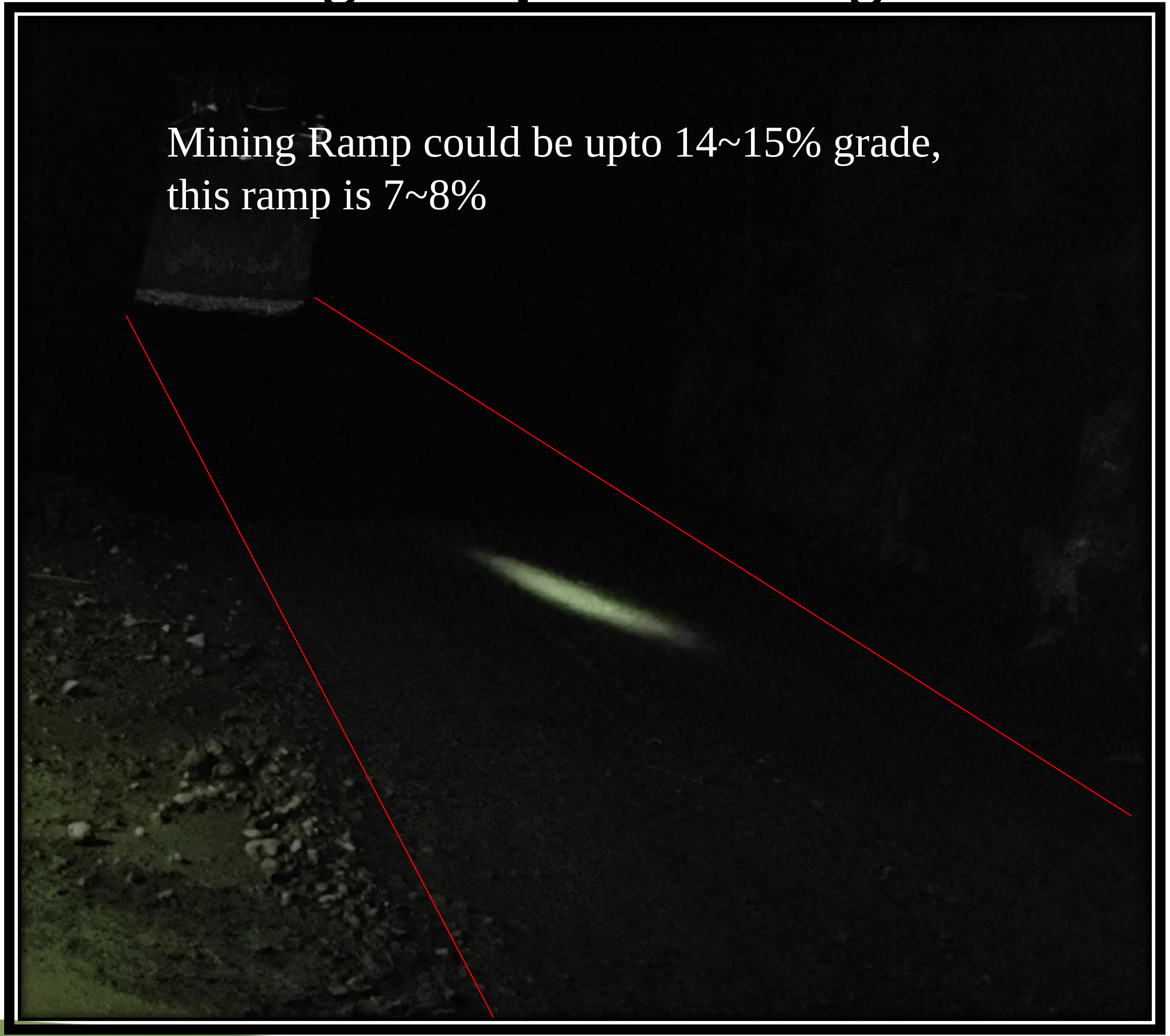


Detailed Cross Section

Test ramp site with 20% Grade in SUDBURY compliant to CSA grade requirement

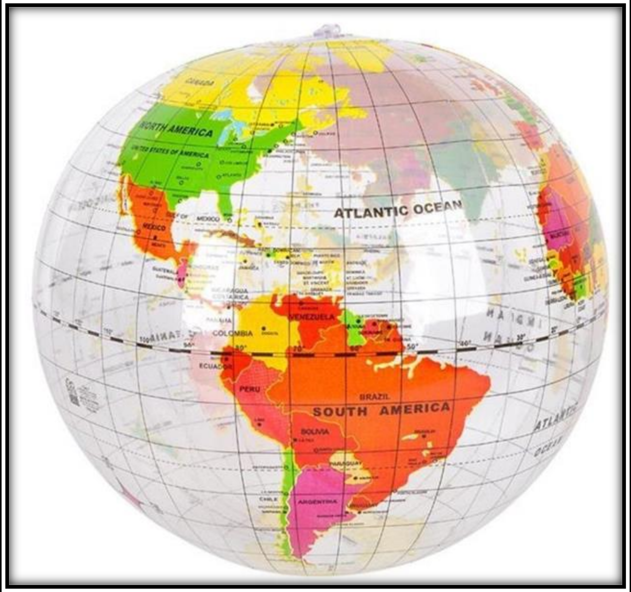
Courtesy of Equipment North

Mining Ramp without lights



Mining Ramp with LHD lights

Why are we doing this Study



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

Mitigating risk involve in testing at 20% grade

Reduce Dependence on the Special test Ramps.

Cost saving Maintaining Test Ramps

Propose developing an equivalent method by testing on flat ground 0% Grade.

This Canmet MINING work is sponsored under a R&D Grant by CSA

CSA GROUP™

Scope of this study

- Environmental scan of Canadian and Global Braking Standard and Regulations.
- Develop calculations and **brake performance models** for alternative brake testing on flat ground 0% grade.
- **Devise a test plan to validate** the models to ensure machines brakes performance tested with new approach at 0% grade is effective as 20% grade.
- Build confidence on flat ground testing **by ensuring the stability of machine** during braking on downhill 20% grade and flat ground.
- Evaluate the results of CSA brake evaluation for100 U/G Mining Machines.

U/G Mining standards reviewed

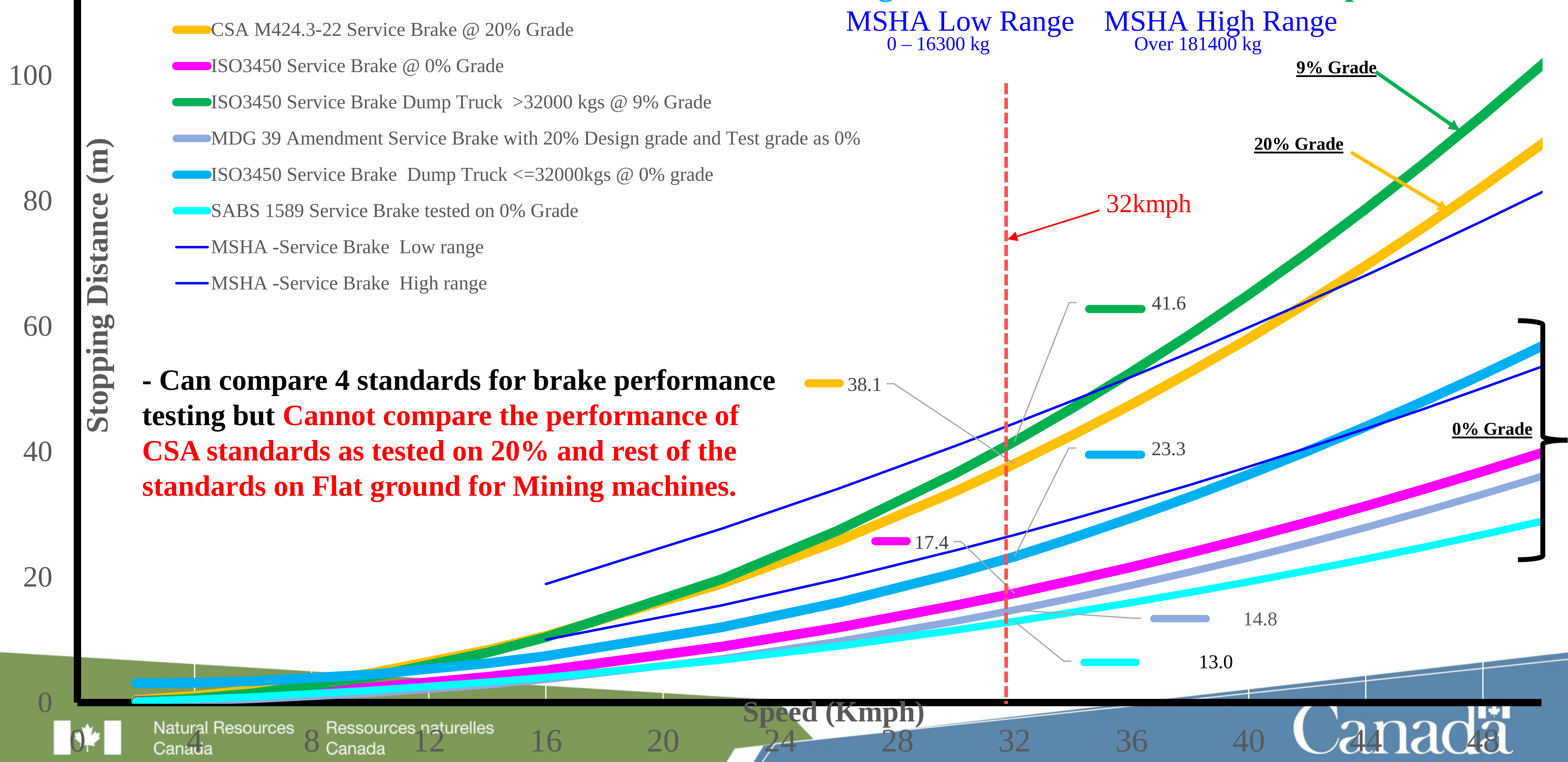
CAN/CSA M424.3:22	MSHA Guidelines	ISO 3450:2011 – Annex A	SANS 1589-1	MDG 39 - Mining Design Guideline	ISO 19296:2018
• Braking Performance - Rubber-Tired, Self-Propelled Underground Mining Machines. • Applicable in **Canadian** Jurisdiction	• Mining and earthmoving machinery — Mobile machines working — Machine Safety. • Applicable in **USA** • 30 CFR 56.14101 and 57.14101 / 30 CFR 77.1605(b)	• Brakes for purpose-built underground mining machines • Used GLOBALY for **construction equipment** but Annexure A is stipulating requirements for U/G Mining machines.	• The braking performance of trackless underground mining machines — Load haul dumpers and dump trucks. • Applicable in South African	• **Handbook for Approval Assessment of Transport Braking Systems on Free-Steered Vehicles in Underground coal Mines.** • Australian	• Mining — Mobile machines working underground — **Machine safety** Section – 4.10 Braking ~ Same requirement as *ISO 3450:2011 Annex A*

Key Differences in Braking Standards

- ISO 3450, ISO 19296, MSHA and SABS 1589 standards **consider response time** for stopping distance formulas but other standards like MDG 39 and CSA M424.3-22 don't.
- ISO 3450, ISO 19296, MSHA and SABS 1589 standards have defined values of **minimum deceleration rates**.
- All except ISO 3450 and 19296 standards have **different stopping distance formulas**.
- ISO 3450, MSHA and MDG 39 guidelines have **different formulas for different weight class of machines** for examples weight greater than 32000kgs and less than 32000kgs. But NO separate classification suggestion in ISO3450 Annex.
- Different Standards **tests brakes on different grades**.
  - CSA demands testing on 20% Grade.
  - ISO 3450, ISO 19296, MDG39 , SABS1589 demands brake testing on flat ground. (0% grade)
  - ISO 3450 for dump truck with weight greater than 32000kgs demands brake testing on flat ground. (9% grade)
- MDG 39 guidelines are unique in its approach has criterion of the **brake performance test via stopping distance using the design grade factor and test grade factor** in formula.
- MSHA –Stopping distances are computed using a **constant deceleration of 9.66 FPS2 / 2.94 m/s2** and **system response times** of .5.1, 1.5, 2, 2.25 and 2.5 seconds for each increasing weight category respectively. Stopping distance values include a **one-second operator response time**.

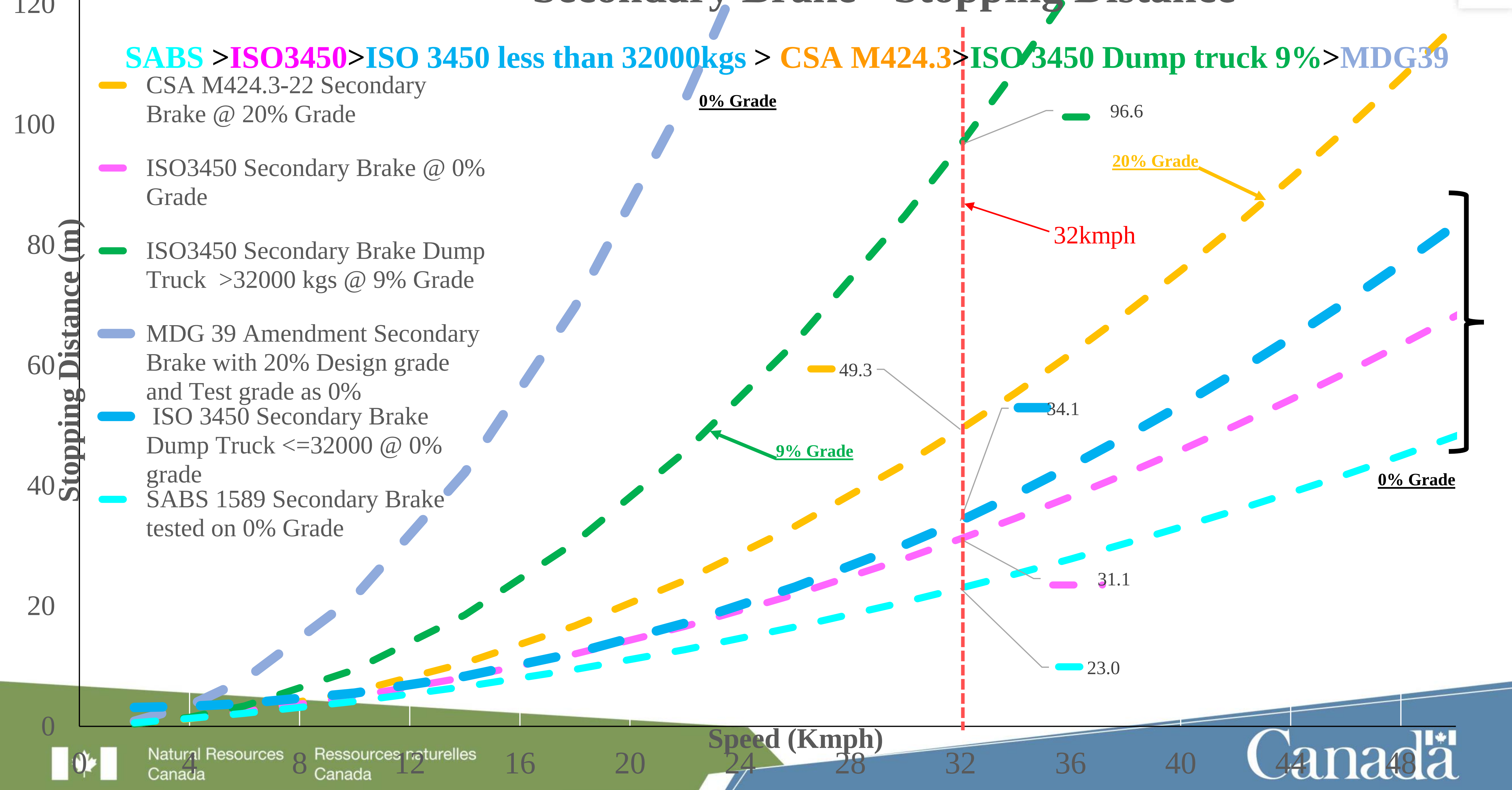
Service Brake - Stopping Distance

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



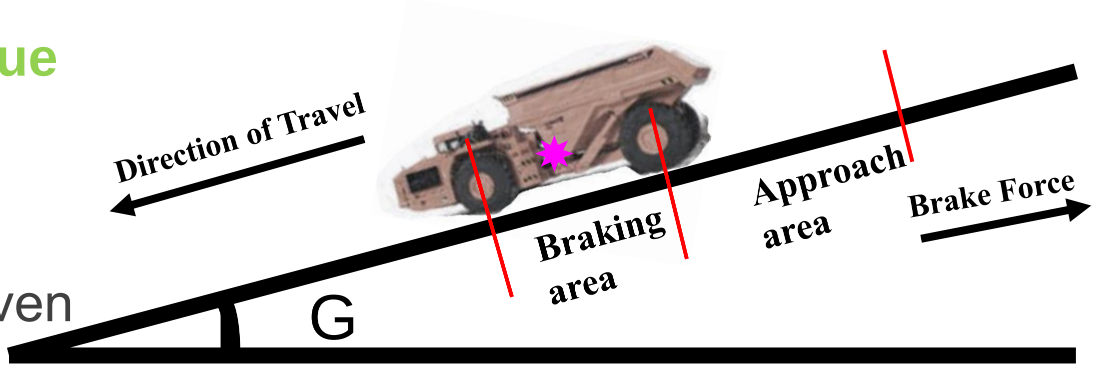
- Can compare 4 standards for brake performance testing but Cannot compare the performance of CSA standards as tested on 20% and rest of the standards on Flat ground for Mining machines.

Secondary Brake - Stopping Distance



Proposed universal formula (Grade Independent)

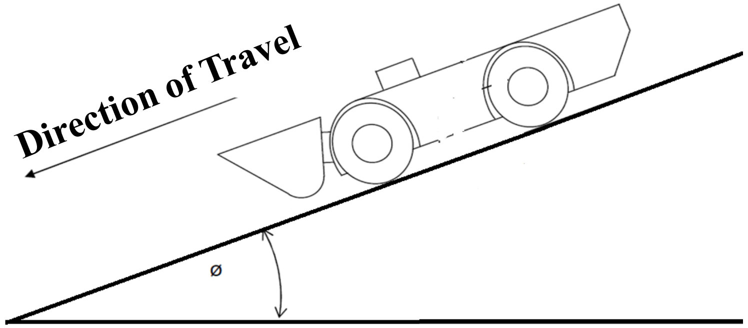
Stopping distance (TOTAL) = Stopping Distance Due to Deceleration + Stopping Distance due to system and operator response time.



- 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*

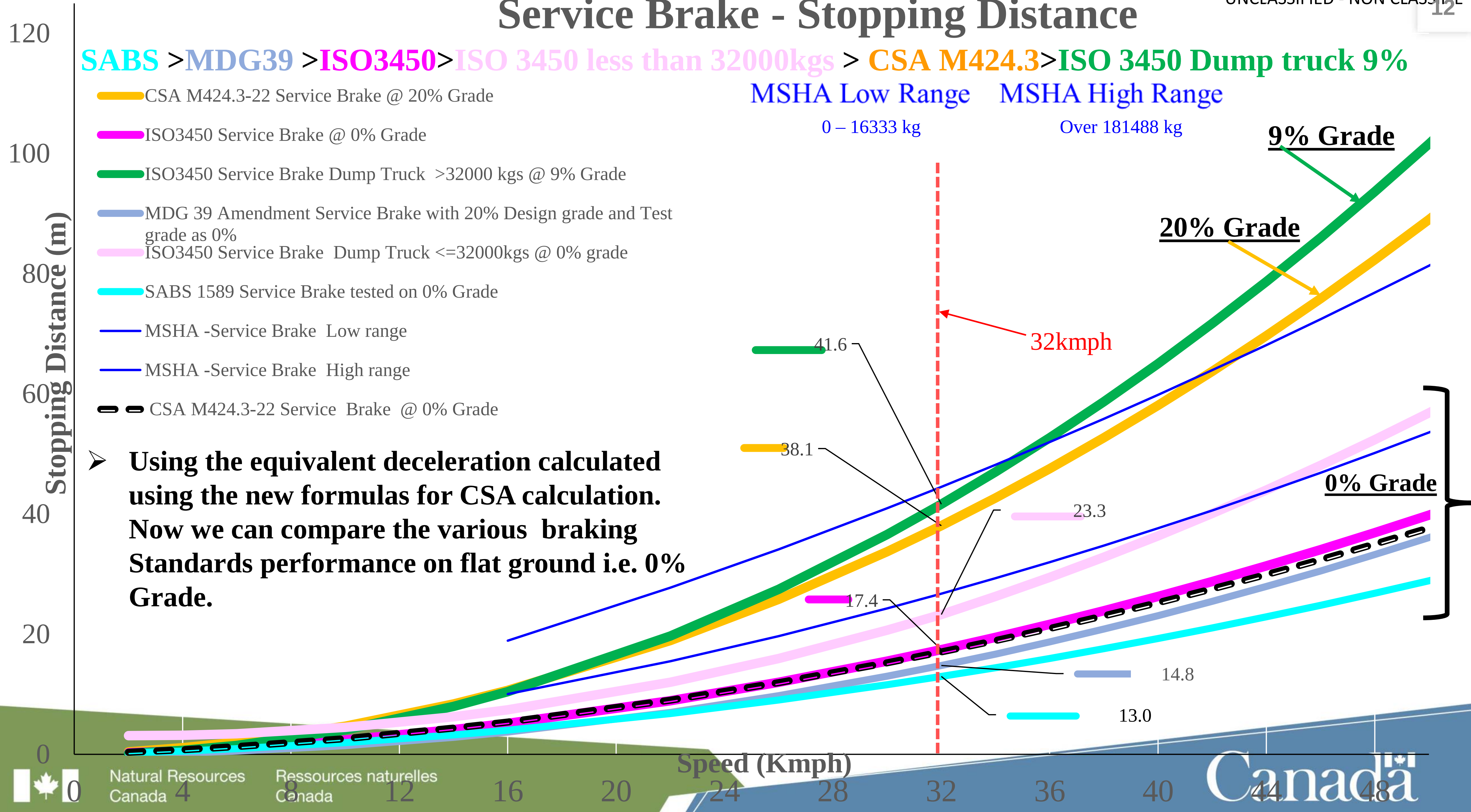
Stopping Distance Due to Deceleration

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.

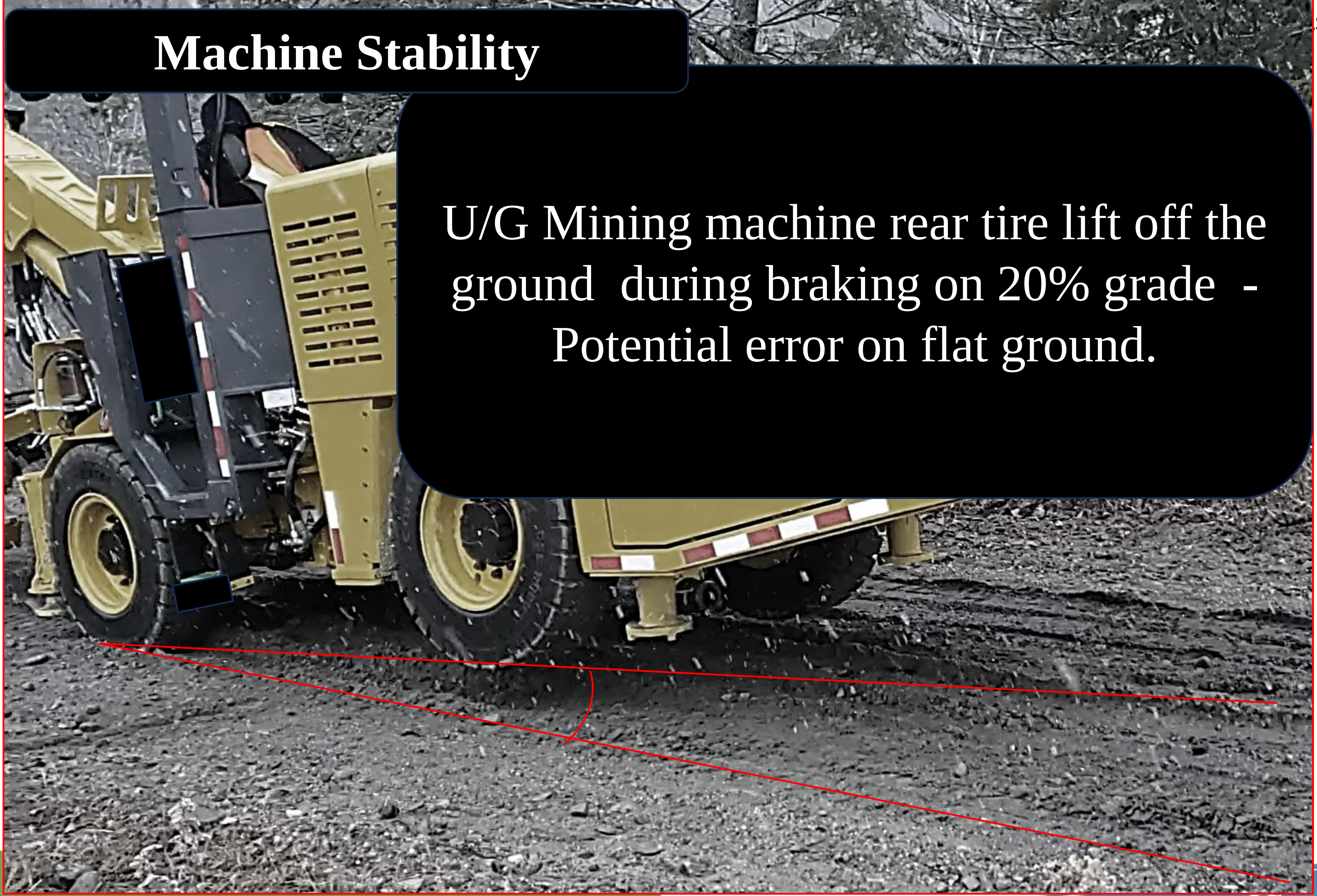
Service Brake - Stopping Distance



- Using the equivalent deceleration calculated using the new formulas for CSA calculation. Now we can compare the various braking Standards performance on flat ground i.e. 0% Grade.

Machine Stability

U/G Mining machine rear tire lift off the ground during braking on 20% grade - Potential error on flat ground.



Braking Stability Calculator

Calculator - Impact of Grades and Deceleration force during braking on Axle Loading

Machine weight	Kg	28300									
Weight Distribution to FA	%	62.5%		Fd		No drag as slow moving		0	N		
Front Axle (FA)	Kg	17688		Fo		No trailer in this machine		0	N		
Rear Axle (RA)	Kg	10613									
Wheel Base	m	4									
Centre of Gravity (CG) Height	m	1.4	0.35								
CG distance from FA	m	1.5									
CG from RA	m	2.5									
Deceleration(-ve)/ Accerlation(+) recorded during testing	m/s2	-13				CSA Grade					Flat Ground
Test Grade in %	%	-45%	-40%	-35%	-30%	-25%	-20%	-15%	-10%	-5%	0%
Test Grade in Degrees	Deg	-24.2	-21.8	-19.3	-16.7	-14.0	-11.3	-8.5	-5.7	-2.9	0.0
Front Axle weight downhill travel	Kg	33320.2	33226.9	33092.5	32913.6	32687.6	32412.4	32087.0	31711.2	31286.0	30813.4
Rear Axle weight downhill travel(-ve means up in air)	Kg	-7512.8	-6951.1	-6381.3	-5807.1	-5232.6	-4662.0	-4100.1	-3551.6	-3021.3	-2513.4
Change in front axle weight (+ve means increase)	Kg	15632.7	15539.4	15405.0	15226.1	15000.1	14724.9	14399.5	14023.7	13598.5	13125.9
% increase in front axle weight (+ve means increase	%	88%	88%	87%	86%	85%	83%	81%	79%	77%	74%
Change in Rear axle weight (-ve means Decrease	Kg	-18125.3	-17563.6	-16993.8	-16419.6	-15845.1	-15274.5	-14712.6	-14164.1	-13633.8	-13125.9
% increase in Rear axle weight (+ve means increase	%	-171%	-165%	-160%	-155%	-149%	-144%	-139%	-133%	-128%	-124%
Cross Checking	Kg	25807.4	26275.9	26711.2	27106.5	27455.0	27750.4	27986.9	28159.6	28264.7	28300.0

Note - Input the Values in the Cell in Yellow

Values in Red Indicates the Rear axle reaction is ZERO

The above calculator has formulas built to capture the Air Drag (Fd) and Trailer load (Fo) on theweight transfer on axles. In the above shown Example - As mining vehicles are slow moving vehicles, operating at speed less than 30kmph I have neglected the Air Drag to Zero. Also trailer load can be added if known to the above sheet for calculation of axle loads impact.

Braking Stability Calculator

Calculator - Impact of Grades and Deceleration force during braking on Axle Loading

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Wheel Base	m	4									
Centre of Gravity (CG) Height	m	1.4	0.35								
CG distance from FA	m	1.5									
CG from RA	m	2.5									
Deceleration(-ve)/ Accerlation(+) recorded during testing	m/s2	-8					CSA Grade				Flat Ground
Test Grade in %	%	-45%	-40%	-35%	-30%	-25%	-20%	-15%	-10%	-5%	0%
Test Grade in Degrees	Deg	-24.2	-21.8	-19.3	-16.7	-14.0	-11.3	-8.5	-5.7	-2.9	0.0
Front Axle weight downhill travel	Kg	30233.5	29847.5	29441.0	29015.0	28571.2	28111.4	27638.2	27154.4	26663.5	26168.8
Rear Axle weight downhill travel(-ve means up in air)	Kg	-1933.5	-1547.5	-1141.0	-715.0	-271.2	188.6	661.8	1145.6	1636.5	2131.2
Change in front axle weight (+ve means increase)	Kg	12546.0	12160.0	11753.5	11327.5	10883.7	10423.9	9950.7	9466.9	8976.0	8481.3
% increase in front axle weight (+ve means increase	%	71%	69%	66%	64%	62%	59%	56%	54%	51%	48%
Change in Rear axle weight (-ve means Decrease	Kg	-12546.0	-12160.0	-11753.5	-11327.5	-10883.7	-10423.9	-9950.7	-9466.9	-8976.0	-8481.3
% increase in Rear axle weight (+ve means increase	%	-118%	-115%	-111%	-107%	-103%	-98%	-94%	-89%	-85%	-80%
Cross Checking	Kg	28300.0	28300.0	28300.0	28300.0	28300.0	28300.0	28300.0	28300.0	28300.0	28300.0

Note - Input the Values in the Cell in Yellow

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U/G Mining Machines - Brakes performance

100 Underground Mining machines stopping distances compared against CSA standard allowable limits

- First gear –Stopping distances (SD) is on avg. about ***49% of the allowable CSA limit.***
- Second Gear – SD is on avg. about ***37% of the allowable CSA limit***
- Third Gear – SD is on avg. about ***28% of the allowable CSA limit.***
- Fourth Gear – SD is on avg. about ***37 % of the allowable CSA limit.***

Indicates the CSA standard limits are not STRICT - Todays Mining machines are stopping with in 28~49% of the required limits.

BOLTER // LHD // TRUCKS // PERSONNEL CARRIERS // JUMBOS

Future action plan

- Collaborations with Industry partners – Validating (testing, measuring, recording and dissection data for analysis) the braking performance using the proposed formulas on different types and classes of underground mining machines.
- Testing and validating the calculator for stability checks and how it can be integrated to brake performance checks to give more confidence on testing on flat ground.
- Plan is to re-open the CSA M424.3 Technical committee to review potential changes to Brake Standard.
- The finding will help us to improve the next version of the CSA M424.3 Braking standard.

Thank You for your time!

References

- Technical reference guidelines | NSW Resources Regulator
- Brakes - 30 CFR 56.14101 and 57.14101 / 30 CFR 77.1605(b) (msha.gov)
- eCFR :: 30 CFR Part 56 -- Safety and Health Standards—Surface Metal and Nonmetal Mines
- R.R.O. 1990, Reg. 854: MINES AND MINING PLANTS (ontario.ca)