07-07-2023

Edge Protection:
How Safe are Safety Bunds?

Intro - Jayden Ellis, Business Services Manager

STEVENSON

Presentation – Associate Professor Klaus Thoeni,
University of Newcastle, Australia

THE UNIVERSITY OF NEWCASTLE AUSTRALIA

Priority Research Centre
PRCGSE
Geotechnical Science & Engineering

Introduction

On the 10th of March 2020 an operator operating a CAT 740 articulated dump truck for a Stevenson subcontractor tragically lost his life in a workplace accident. The operators truck travelled over the bund and fell to rest at the road below.

In the wake of this tragedy, Stevenson Aggregates and Fulton Hogan have initiated a research project to look at the science behind bund design. We want to understand what happened and how we can do better to prevent similar accidents from happening in the future.

Kaipara along with Winstone Aggregates joined Stevenson and Fulton Hogan in support of the research project.

STEVENSON

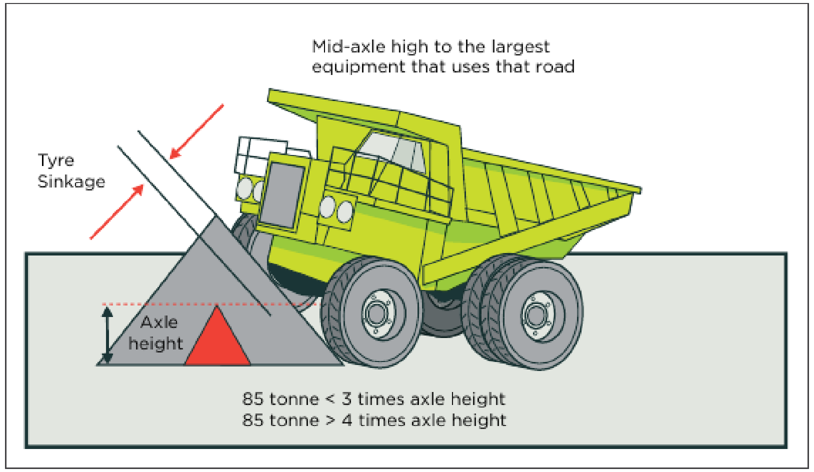
How safe are safety bunds?

MAQOHSC - SA (2009)

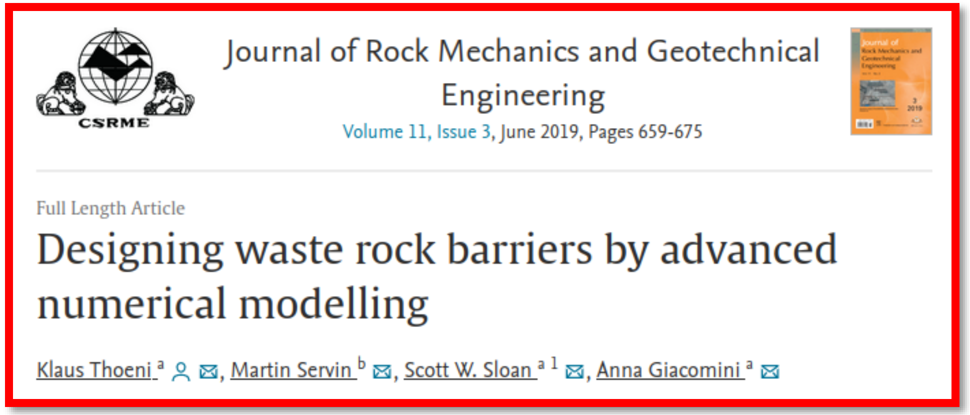
Problem statement

- Safety bunds (also called safety berms or windrows) are essential to any surface mining and quarry operations
- They are supposed to be an “effective” obstacle to reduce the risk of serious injury or death arising from errant mine and quarry vehicles
- Design is based on rules of thumb
- Incidents are reported on a regular basis
- Not clear how effective safety bunds are, especially for ADTs

Stecklein and Labra (1981)



WorkSafe New Zealand (2015)


CSRME
Journal of Rock Mechanics and Geotechnical Engineering
Volume 11, Issue 3, June 2019, Pages 659-675

Full Length Article

Designing waste rock barriers by advanced numerical modelling

Klaus Thoeni [a], Martin Servin [b], Scott W. Sloan [a 1], Anna Giacomini [a]

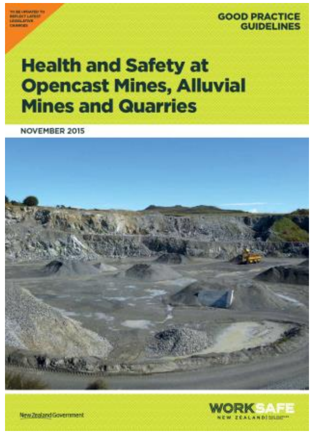
Thoeni et al. (2019)

➢ **Rigorous scientific-based approach is required to improve the understanding**

Methodology

Review

- current industry practice
- guidelines
- incident reports

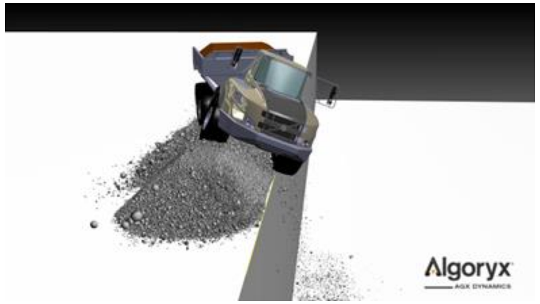


Experimental testing

- full-scale testing
- material characterisation

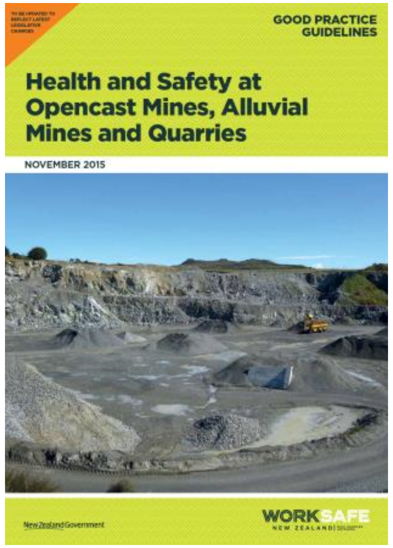
Numerical modelling

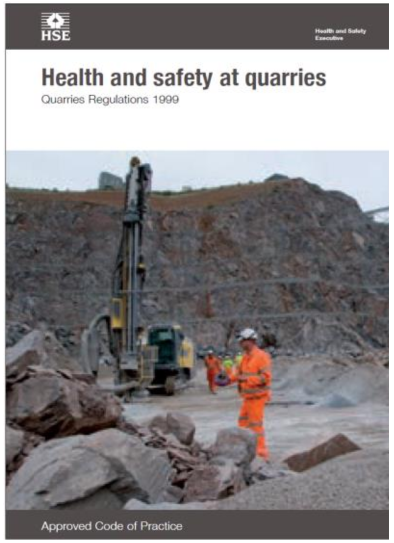
- advanced numerical model
- calibration and back analysis
- parametric study

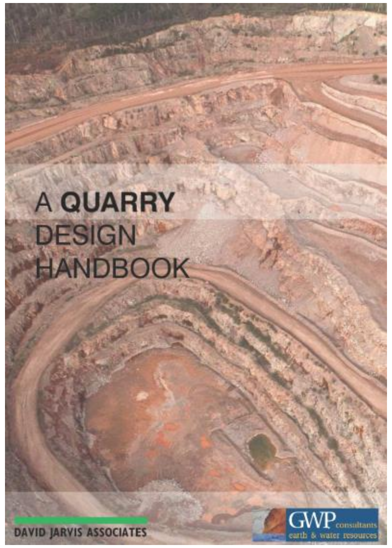


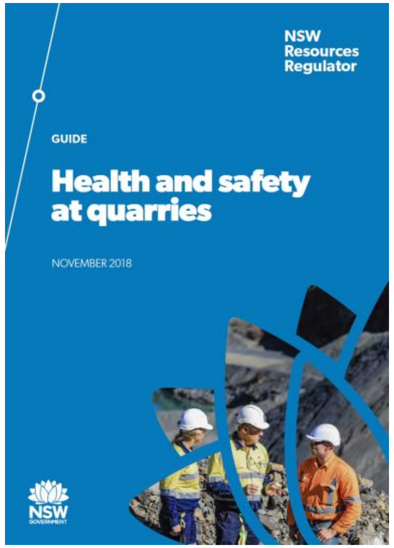
Outcome

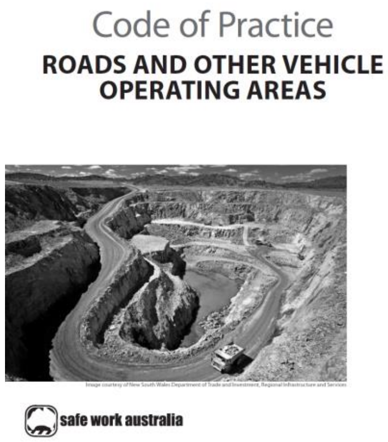
- Recommendations











Review of Current Practice

Review with particular focus on guidelines from:

- Australian states (NSW, QLD, WA)
- Safe Work Australia (AU)
- WorkSafe New Zealand “Good Practice Guidelines” (NZ)
- UK, US, Canada, …

Review of Current Practice: Bund Performance

According to several guidelines, inclusive *WorkSafe NZ (2015)*, bunds are designed to:

- give the driver a visual indication of the roadway edge
- provide a sense of contact to the driver if they contact the bund
- give the operator the opportunity to regain control and keep the vehicle from leaving the road
- keep a vehicle back from the edge.

Typical edge-of-road bunds should not be relied on, by themselves, to stop a <u>large</u> haul truck. At best, they will provide limited deflection and warning to the driver that the truck path needs correcting *(MSHA 1998; Thompson, 2010)*.

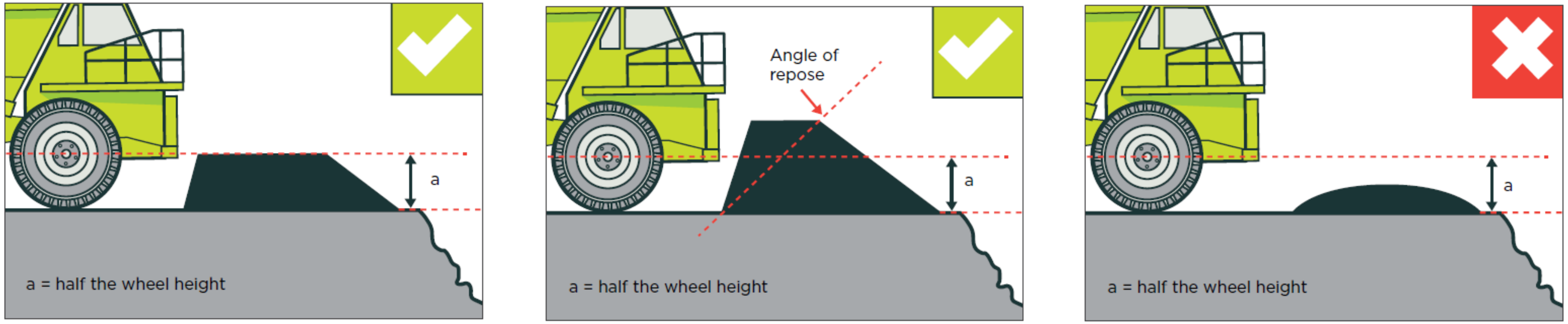
Poniewierski (2018)

Cerrejón/Colombia (2012)

Review of Current Practice: Bund Design

	Design parameter			
	Height	**Width**	**Slope**	**Vehicle**
NSW	At least 50% of the largest tyre diameter in use.	N/A	Roadside facing batter of the bund to be cut at 45° (1V:1H).	N/A
QLD	50% and 66% of the largest tyre diameter in use for trapezoidal and triangular respectively.	Indicated in table	Roadside facing batter angle of safety bunds to be 45° (1 Vertical to 1 Horizontal).	Y (RDT only)
WA	At least half (50-66%) of the largest tyre diameter in use.	N/A	N/A	N/A
SafeWork AU	At least 50% of the largest tyre diameter in use.	N/A	Roadside facing batter of the bund to be cut as vertical as possible.	N/A
WorkSafe NZ	50% of the largest tyre diameter in use.	N/A (angle of repose)	Roadside facing batter of the bund to be cut as close as possible to vertical >40°.	N/A
UK	1.5 m or half of the largest tyre diameter using the road – whichever is greater	N/A	As vertical as possible.	N/A

Review of Current Practice: Bund Design – cont'd

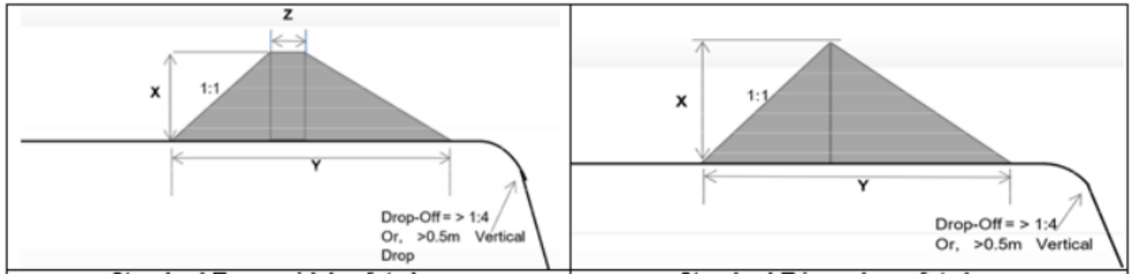


WorkSafe NZ (2015)

Support installation and construction of windrows by robust design calculations determined by a competent person.

Vehicle	Standard tyre size	Inflated tyre diameter	Standard trapezoidal safety berm			Standard triangular safety berm	
			X	Y	Z	X	Y
MV / LV	Various	1.4m	0.7m	2.6m	1m	1m	2.3m
Cat 777	27.00R49	2.7m	1.4m	4.1m	1m	1.8m	4.2m
Cat 785	33.00R51	3.2m	1.6m	5.1m	1.4m	2.2m	5.1m
Cat 789	37.00R57	3.5m	1.8m	5.5m	1.4m	2.4m	5.6m
Cat 793	46.90R57	3.6m	1.8m	5.6m	1.4m	2.4m	5.6m
Kom 930E	53.80R63	3.8m	1.9m	6.0m	1.6m	2.6m	6.0m
Cat 797	59/80R63	4.0m	2.0m	6.3m	1.6m	2.7m	6.3m
<Insert/delete truck types as required>							

Note: Safety berm footprint width is based on a roadside facing batter angle of 45° and an outer side batter angle of 37°. Some dimensions have been adjusted for standardization.



Standard Trapezoidal safety berm (minimum height shall be 50% of the diameter of the largest vehicle tyre using the road)

Standard Triangular safety berm (minimum height shall be 66% of the diameter of the largest vehicle tyre using the road)

X = Safety Berm height; Y = Safety Berm footprint width; Z = Safety Berm crest width

QLD Department of Natural Resources (2019)

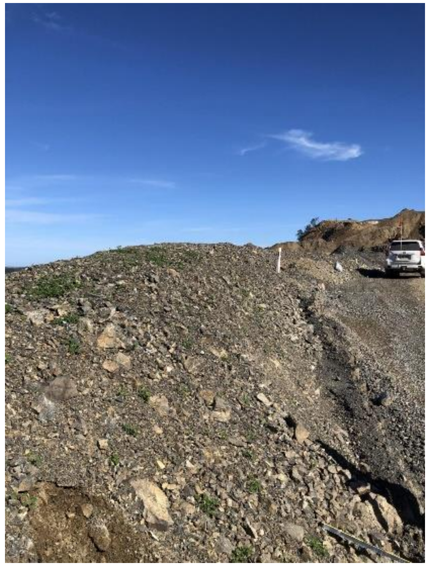
ADTs mentioned in *SME Mining Engineering Handbook (2011)*: "With 4x6- and 6x6-wheel drive ADTs, berm dimensions in excess of 66% wheel diameter are recommended, because of the truck's ability to climb smaller berms."

Review of Current Practice: High-risk Areas

	Design considerations for bunds in high-risk areas
NSW	Bund height to be increased in situations where: 1. Drop-off height is more than 5 m directly from the road edge. 2. Not enough well-graded material is available for bund construction. 3. The bunded edge protection changes from a deflection mechanism (straight road) to an impact absorption mechanism (the corners of the road).
QLD	Bund dimensions shall be increased to a height of greater than or equal to 3 m with a minimal footprint width of 7 m in areas that represent a higher level of risk, such as: 1. Drop-off heights greater than 5 m. 2. High travel speeds or higher approach speeds. 3. Only poorer quality material is available to construct the bunds.
WA	N/A
SafeWork AU	N/A
WorkSafe NZ	Use larger than typical bunds in areas where it is reasonable to expect more adverse conditions, such as where vehicles would have more speed or would contact the windrow head-on. An example would be where there is a curve at the bottom of a grade.
UK	Additional protections in high-risk areas, such as sharp bends or steep haul roads, where sand traps should also be considered. Increasing bund height well above the minimum should be considered in the vicinity of bends, corners and ramps.

Review of Current Practice: Construction Material

	Construction material
NSW	Bunds to be made of good quality well-graded material that will resist weathering and compact suitably. Boulder bunds are not recommended due to the risk of tyre damage or puncture.
QLD	Bunds to be made of good quality material that will resist weathering and compact suitably.
WA	N/A
SafeWork AU	Bunds to be made of material that provides sufficient drag on the vehicle but does not or limited damage to the underside of the vehicle.
WorkSafe NZ	Bunds to be made of firm material. Finer/softer material with less effort in compacting and shaping means a larger bund is required. The road that the bund is built upon needs to be firm and levelled.
UK	Quarried material, for example scalpings.



Review of Current Practice: Maintenance Requirements

	Bund Maintenance
NSW	Bunds shall be maintained regularly as the size and shape of the bund may change over time due to erosion, material settling and vehicle contact. Maintenance is required annually or whenever changes are made to the haul road such as routs, width or new roads, inspections are to be carried out.
QLD	As the size and shape of safety bunds may be altered by erosion, material settling, or by contact from mining equipment, safety bunds shall be regularly inspected and maintained to the required dimensions. Consideration is to be given to addressing potential material settlement over time, such as adding additional height.
WA	Bunds to be inspected and maintained in a good condition.
SafeWork AU	N/A
WorkSafe NZ	Bunds can deteriorate due to weathering and should be regularly inspected and maintained (at least weekly).
UK	N/A

WA, Aug-2019

WA, Dec-2015

Review of Incidents

UK QNJAC, 2018

NSW, Oct-2017

Review of incidents:

- ADT specific considerations
- Australia and New Zealand
- Contributing factors

Review of Incidents: Incident reports and bulletins

- *New Zealand Government, Work Safe NZ, Extractives Industry Quarterly Report 2019/2020 Q4 April to June*:

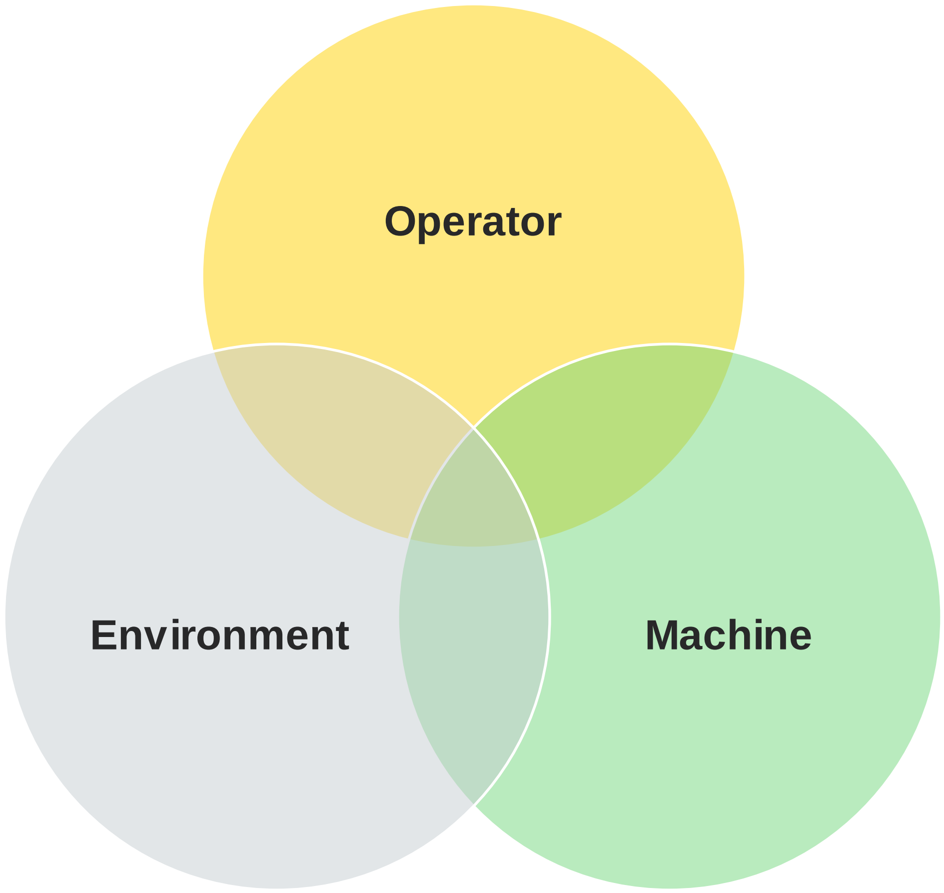
Since July 2019, 73 notifiable events have occurred in NZ quarries and alluvial mines. Of these 43% involved the collapse, overturning, failure or malfunction of, or damage to plant. Of which:

  - 28% involved overturning of mobile plant
  - 14% involved breach of safety bund

- *Queensland Government, Department of Natural Resources, Mines and Energy. Mines safety bulletin no. 170, 6 April 2018, Version 2*:

”The continuation of these rollover events at quarries and mines is evidence that the risk controls for operating ADTs are both inadequate and ineffective at an industry level”.

- Contributing factors




Full-scale Testing

- Truck fleet
- Materials
- Tipping test
- Bund preparation
- Reverse impact test

Full-scale Testing: Truck fleet

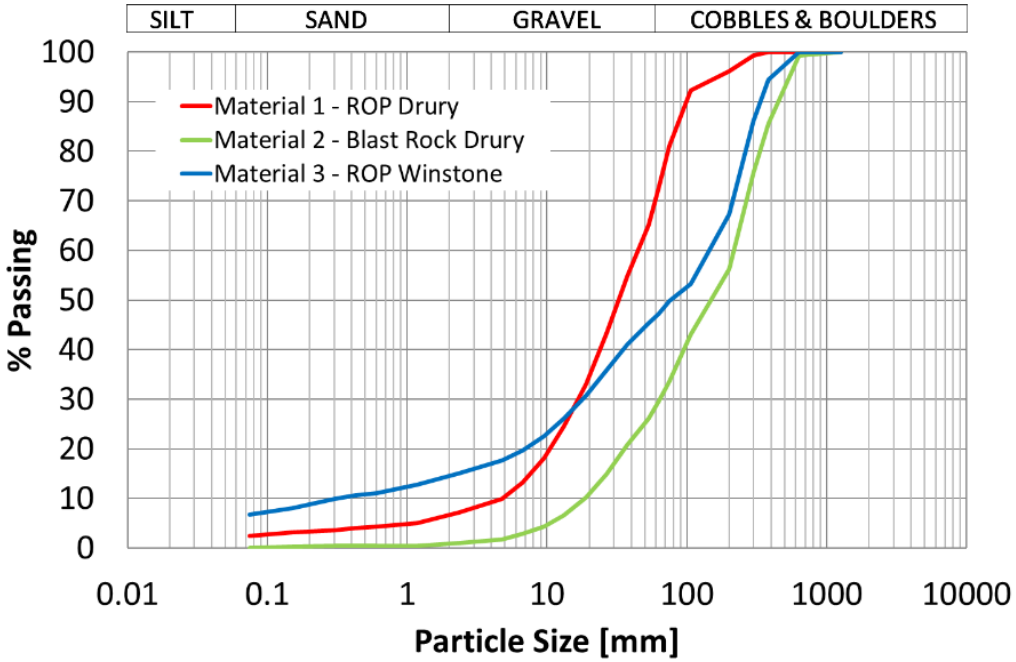
		Volvo A45G (ADT)	CAT 773B (RDT)
WEIGHTS	Gross Vehicle Weight (GVW) [t]	72.1	84.3
	Maximum Payload [t]	41	45.4
	Empty Weight [t]	31.1	38.9
	Front Axle (empty) [t]	53.10%	47%
	Rear Axle (empty) [t]	46.90%	53%
	Front Axle (loaded) [t]	29%	33%
	Rear Axle (loaded) [t]	71%	67%
OPERATING SPECS	Top Speed (loaded) [km/h]	57	61
	Top Speed Reverse (loaded) [km/h]	18	14
	Standard Tire	29.5R25	21.00-35
	Tire Overall Diameter (OD) [m]	1.89	2.05
	Tire Overall Width (OW) [m]	0.77	0.58
DIMENSIONS	Wheelbase [m]	6.46	4.19
	Centreline Front Tire Width [m]	2.64	3.18
	Overall Rear Tire Width [m]	3.40	4.05
	Overall Length [m]	11.26	9.27
	Overall Height [m]	3.60	4.23

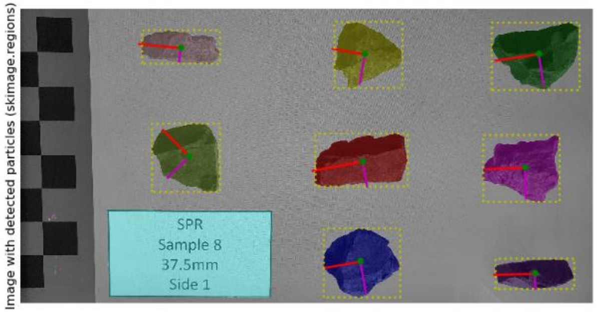
Full-scale Testing: Material characterisation

Material 1: ROP Drury

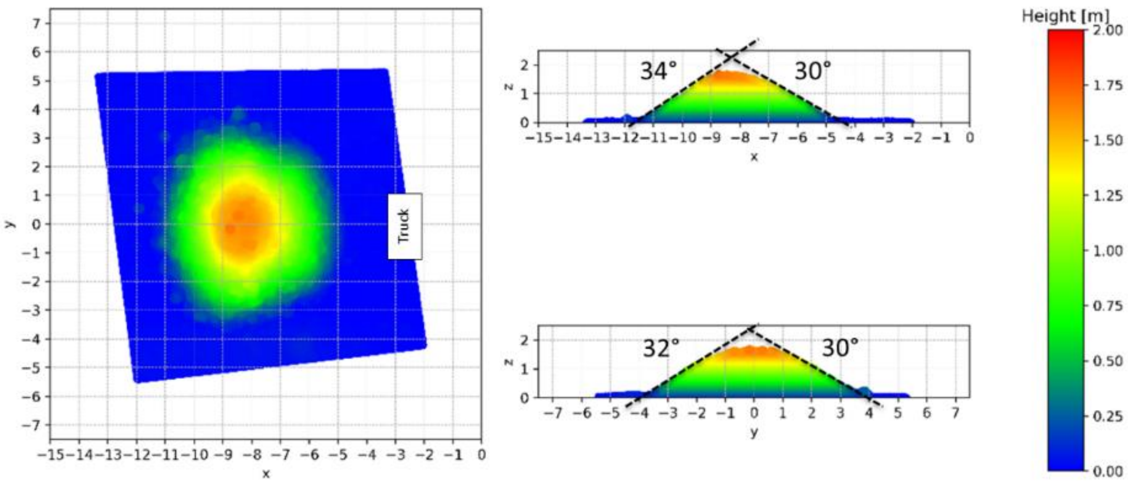
Material 2: Blast rock

Material 3: ROP Winstone





Material 1 (ROP Drury)

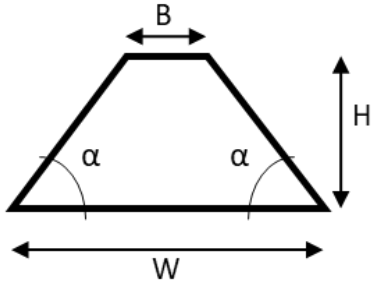


Full-scale Testing: Bund preparation

Material 1

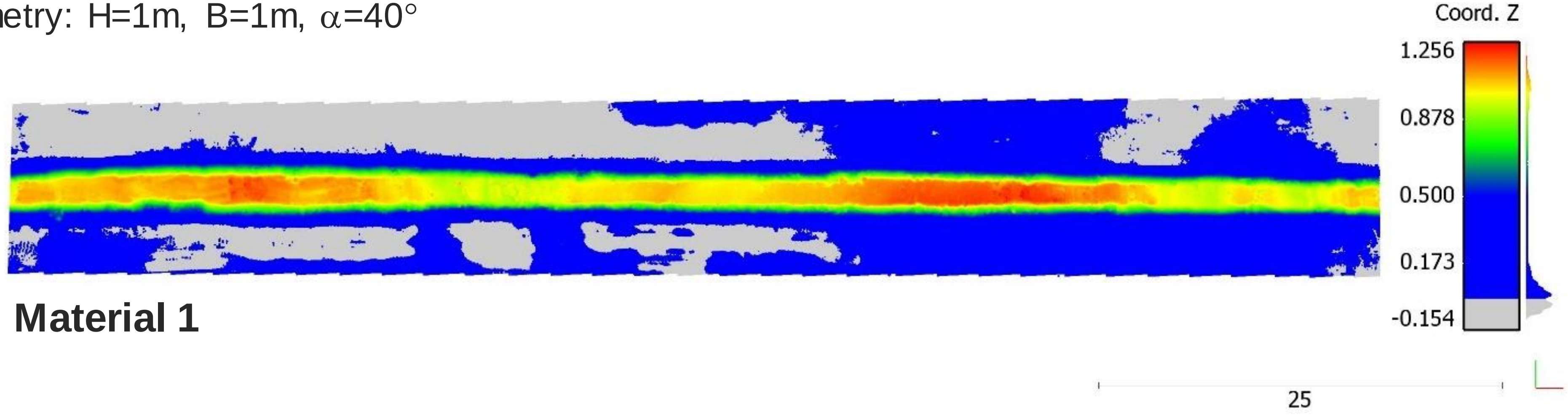
Material 2

Material 3



Material	Description	Bund height H [m]	Top width B [m]	Base width W [m]	Roadside facing batter [°]
1	ROP Drury	1.1 (1.0-1.3)	1.3 (1.1-1.5)	3.9 (3.6-4.3)	41 (39-41)
2	Blast rock Drury	1.1 (1.0-1.3)	1.4 (1.1-1.9)	3.9 (3.6-4.1)	43 (37-48)
3	ROP Winstone	1.3 (1.2-1.4)	0.8 (0.4-1.1)	3.4 (3.0-3.8)	45 (42-45)

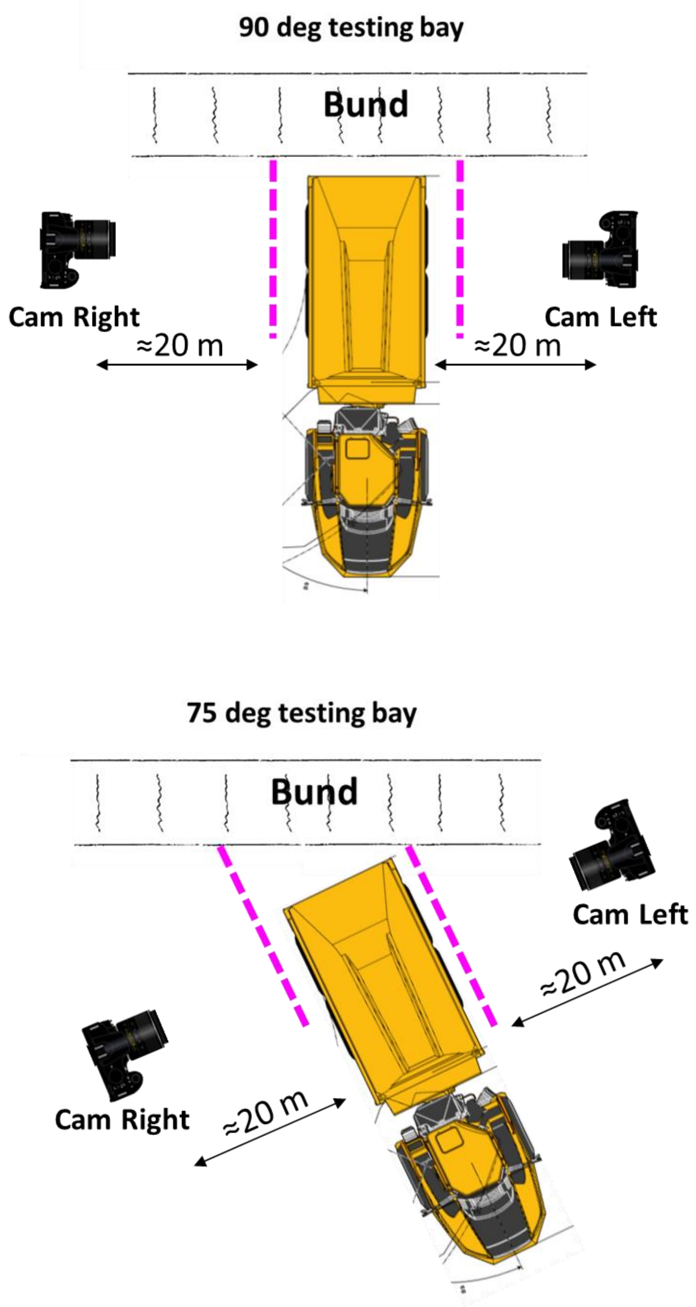
Aimed geometry: H=1m, B=1m, α=40°



Material 1

Full-scale Testing: Reverse impact test

- Trucks (fully loaded):
  - RDT: CAT 773B
  - ADT: Volvo A45G
- Materials:
  - Material 1 (ROP - Run of Pit - Drury)
  - Material 2 (Blasted Rock - Drury)
  - Material 3 (ROP - Winstone)
- Bund shape:
  - trapezoidal according to current practice
- Tests conducted at different approach angles
  - reversing at 90 deg
  - reversing at 75 deg
- Each tests was carried out 3 times (repeatability)

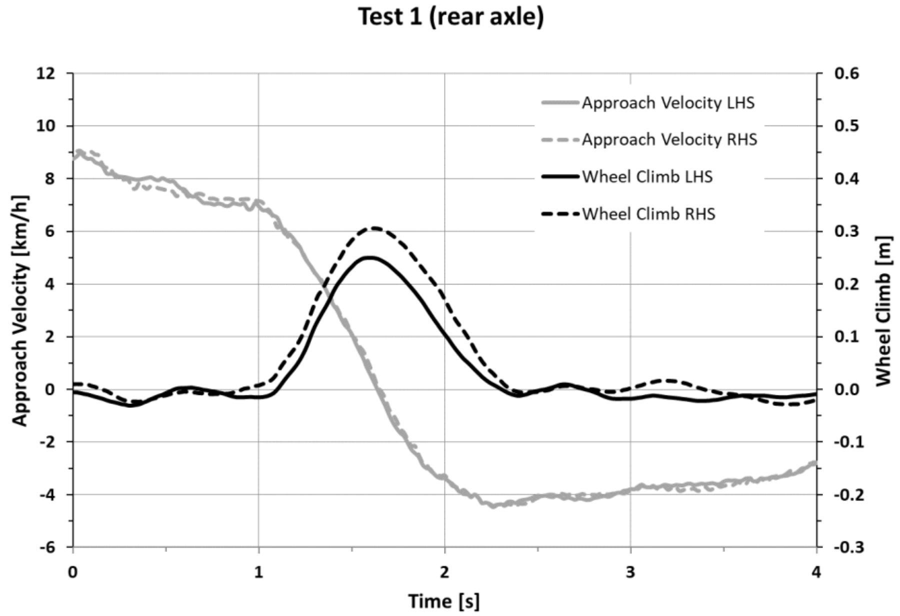


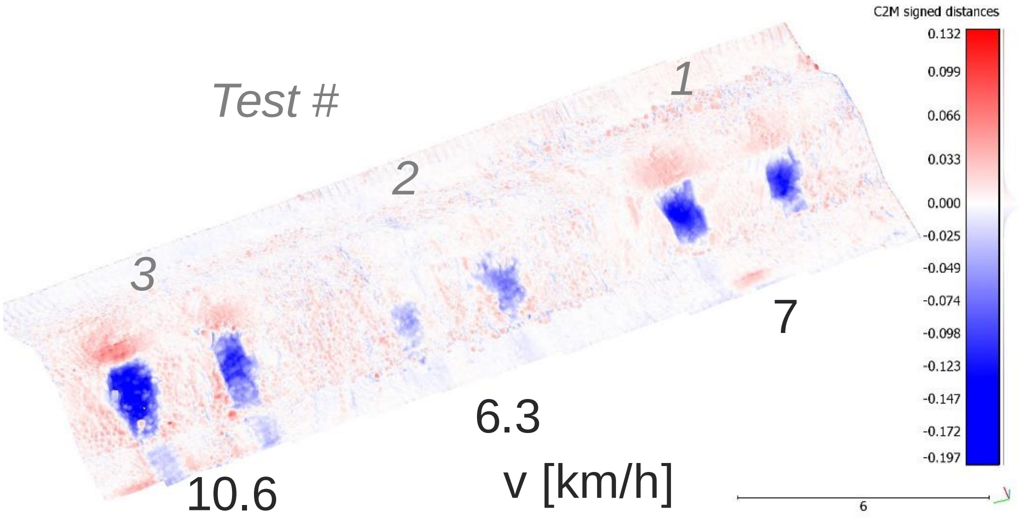
Full-scale Testing: Testing Program

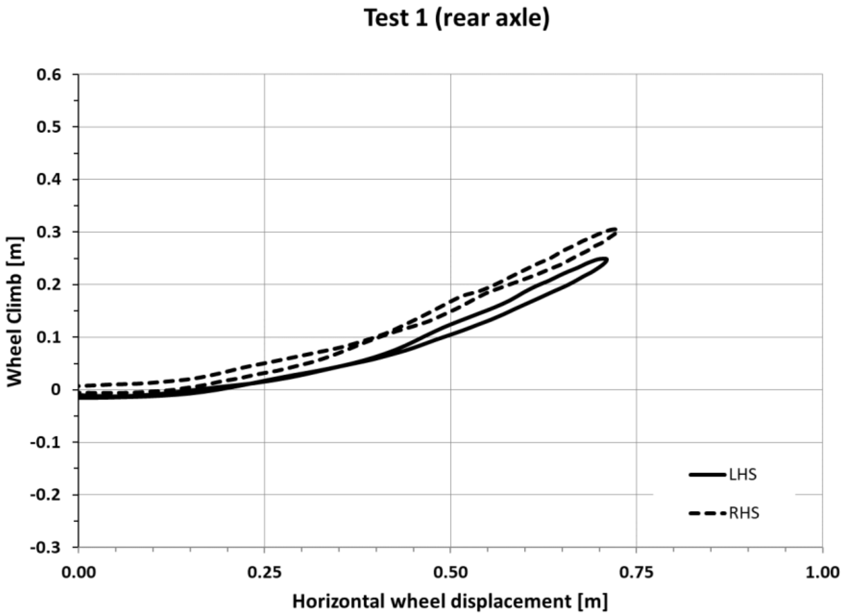
# Tests	Truck	Material	Approach	Approach angle [deg]
1-3	Volvo A45G	1	reversing	90
2-6	Volvo A45G	1	reversing	75
7-9	CAT 773B	1	reversing	90
10-12	CAT 773B	1	reversing	75
13-15	Volvo A45G	2	reversing	90
16-18	Volvo A45G	2	reversing	75
19-21	CAT 773B	2	reversing	90
22-24	CAT 773B	2	reversing	75
25-27	Volvo A45G	3	reversing	90
28-30	Volvo A45G	3	reversing	75

12 (Material 1) + 12 (Material 2) + 6 (Material 3) = 30 Tests

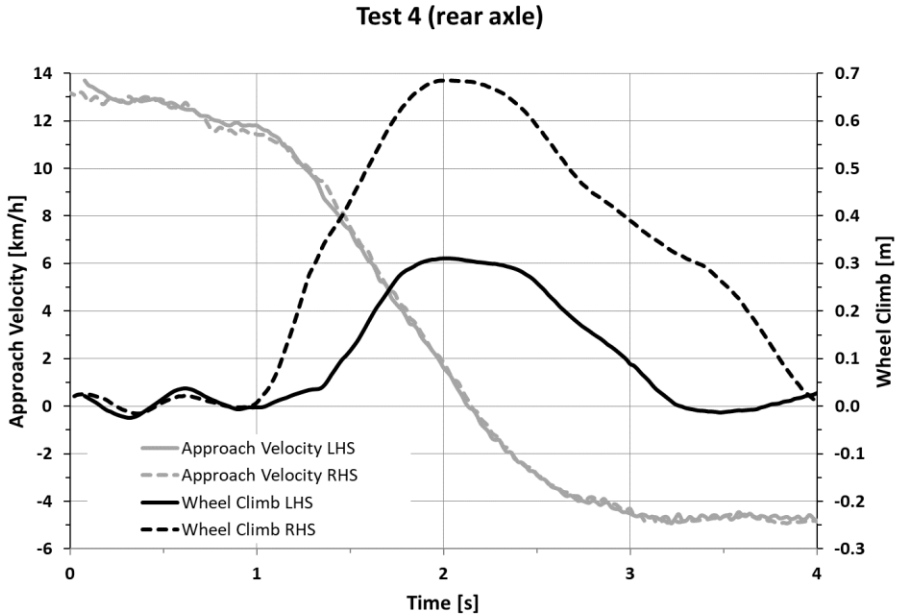
Full-scale Testing: Test 1-3 (ADT, Material 1, 90°)

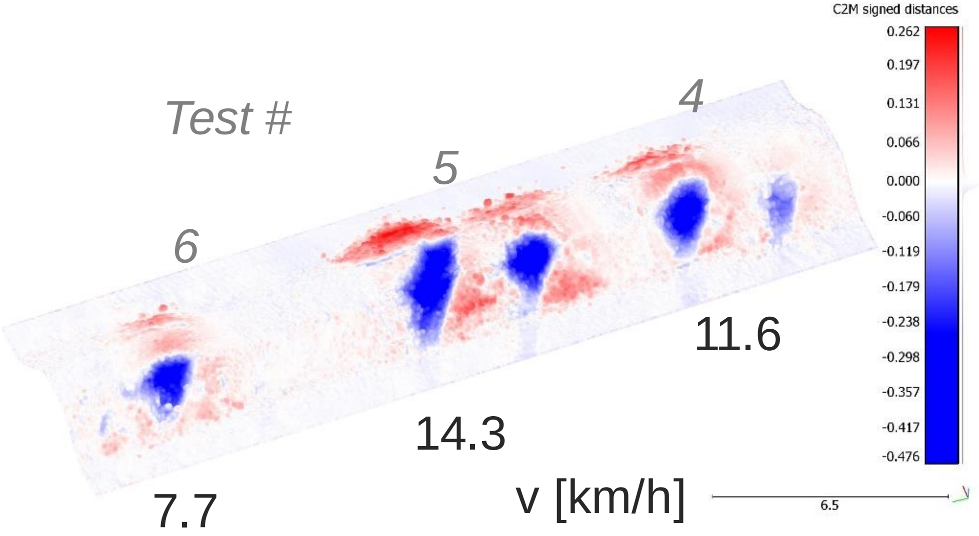


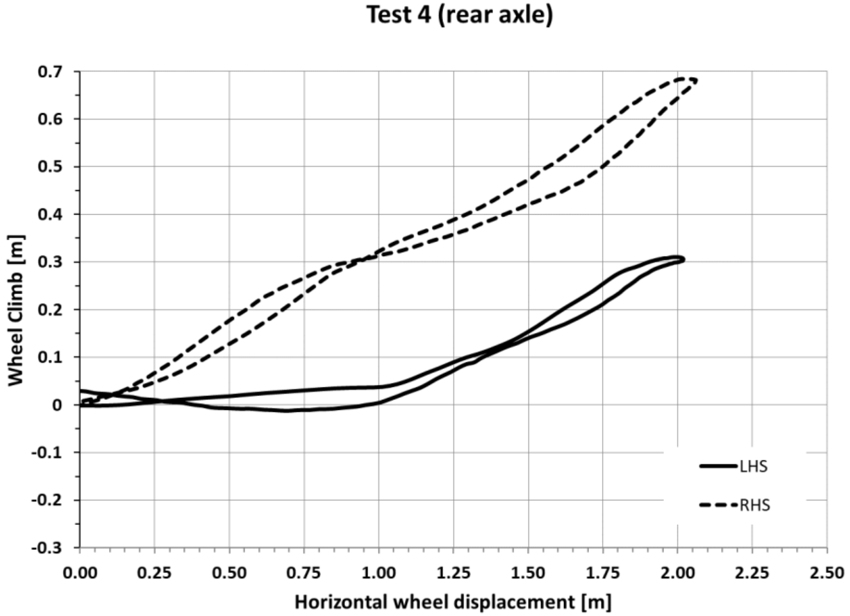




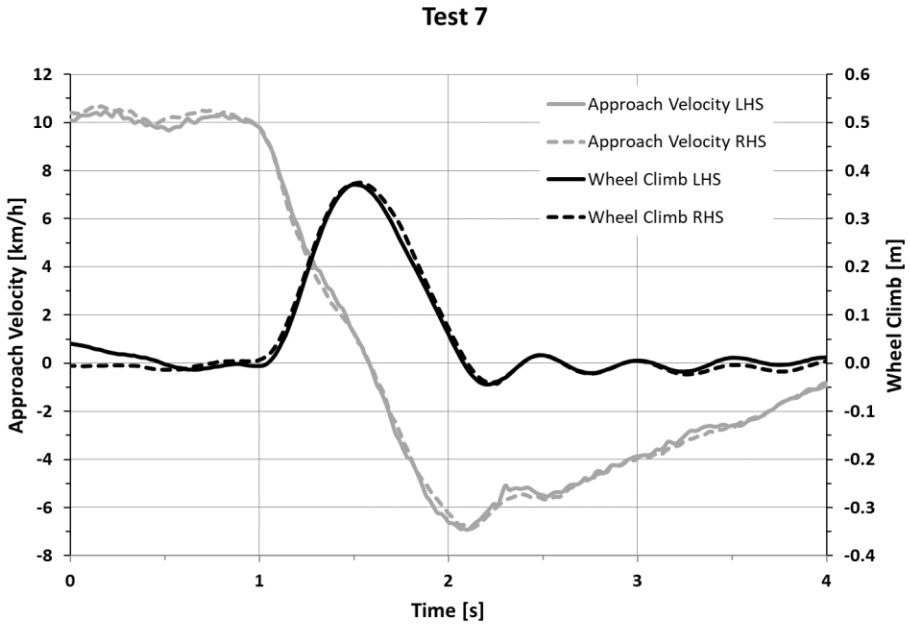
Full-scale Testing: Test 4-6 (ADT, Material 1, 75°)

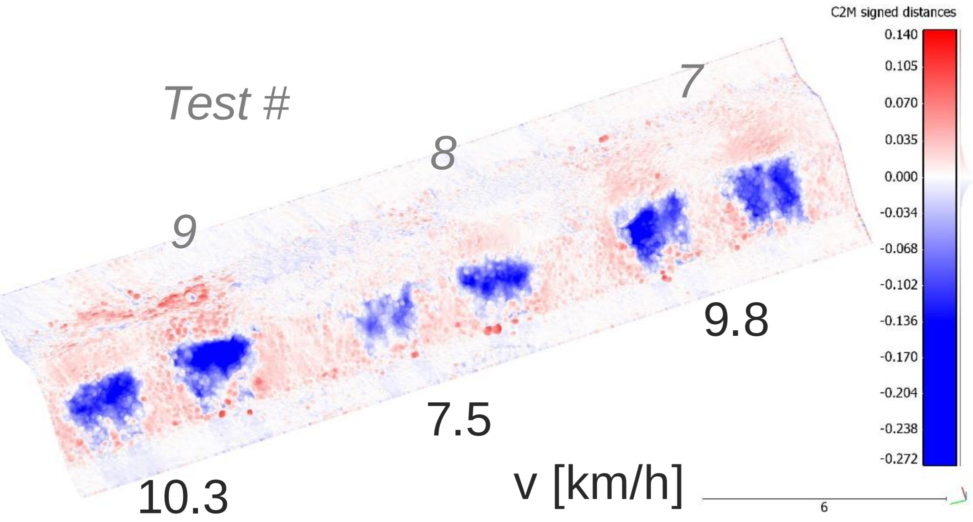


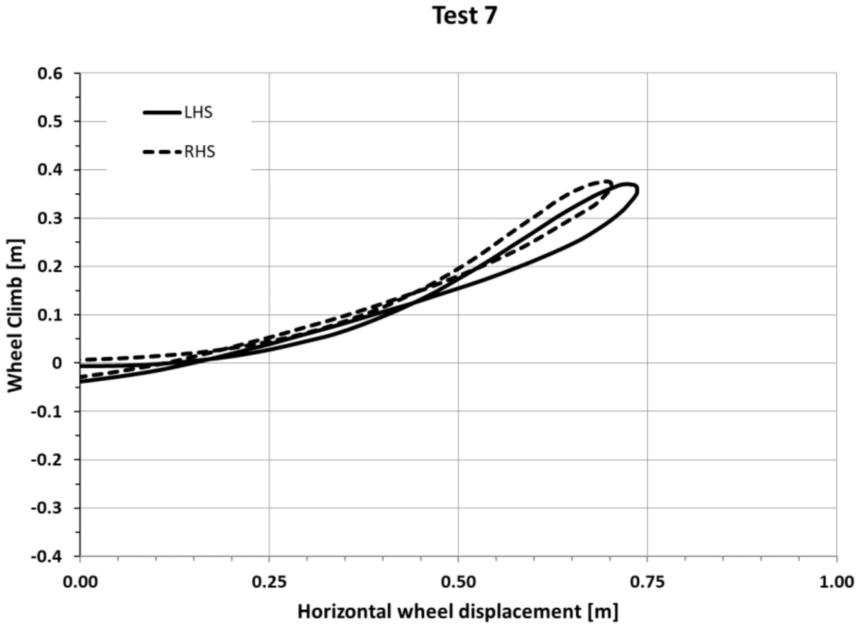




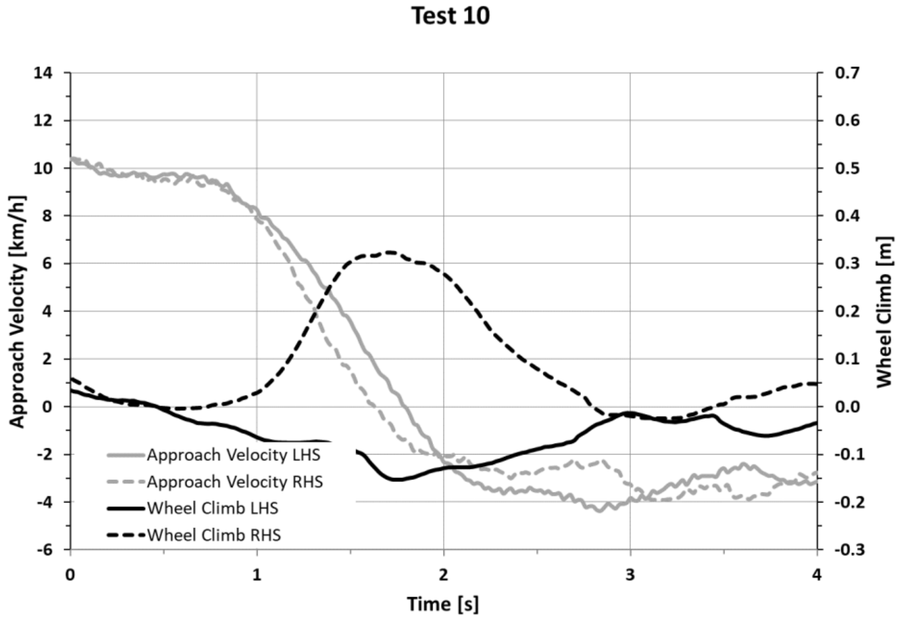
Full-scale Testing: Test 7-9 (RDT, Material 1, 90°)

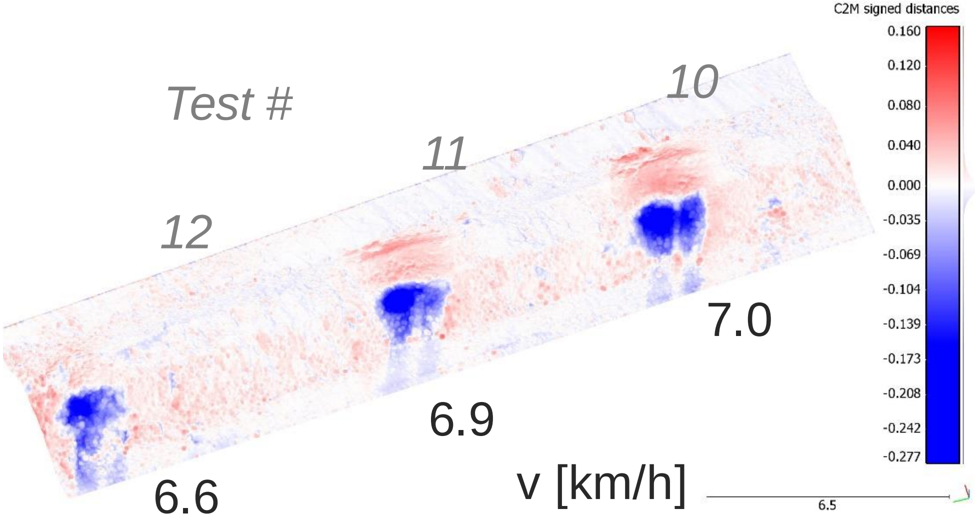


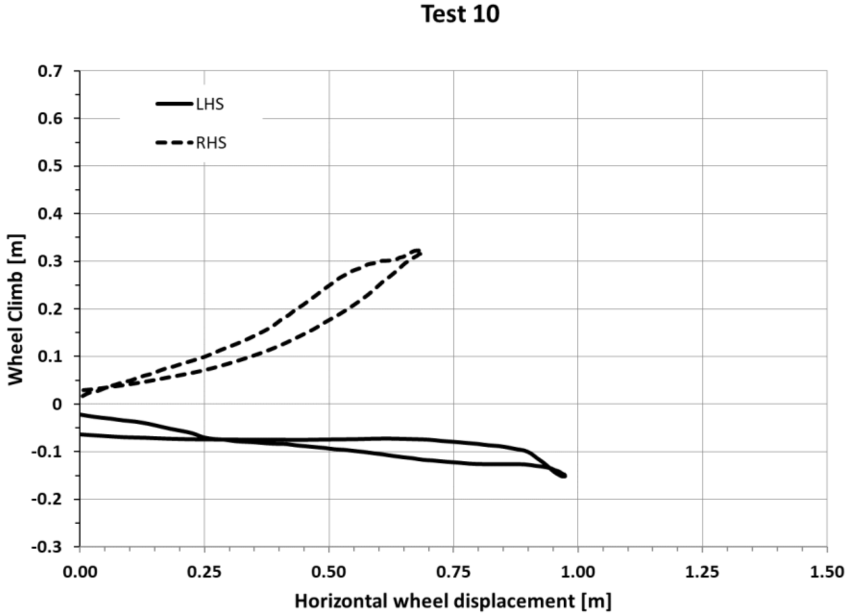




Full-scale Testing: Test 10-12 (RDT, Material 1, 75°)

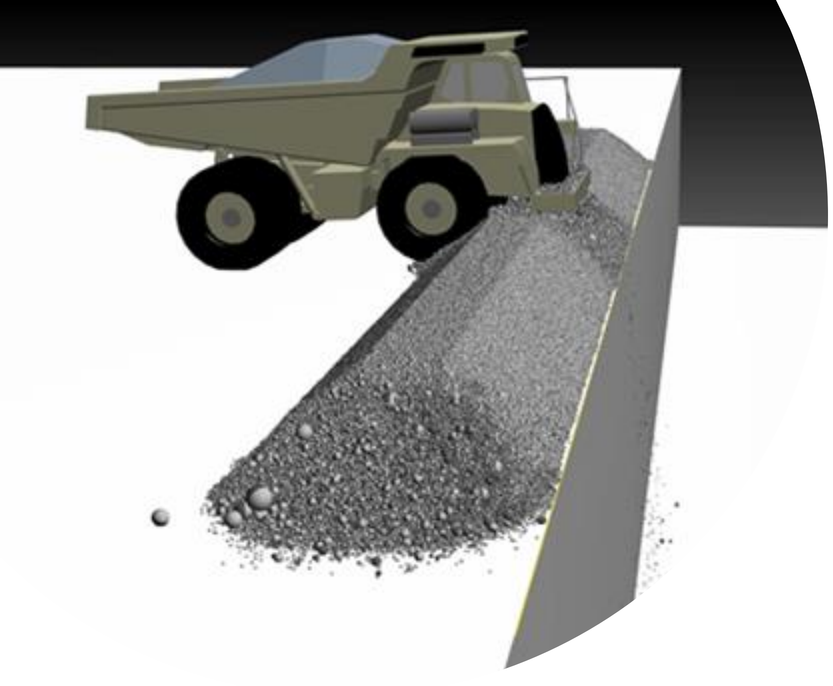


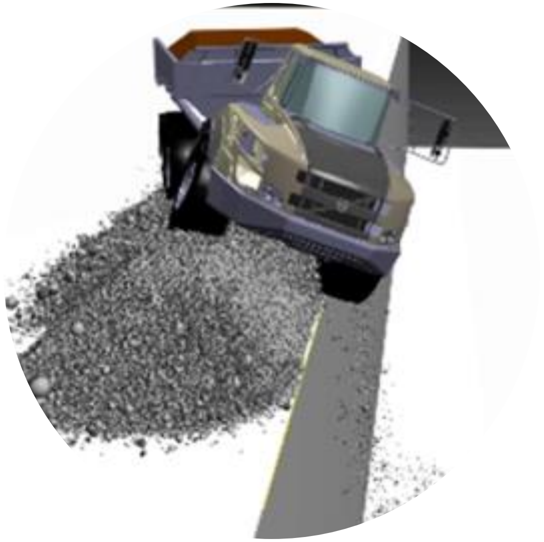


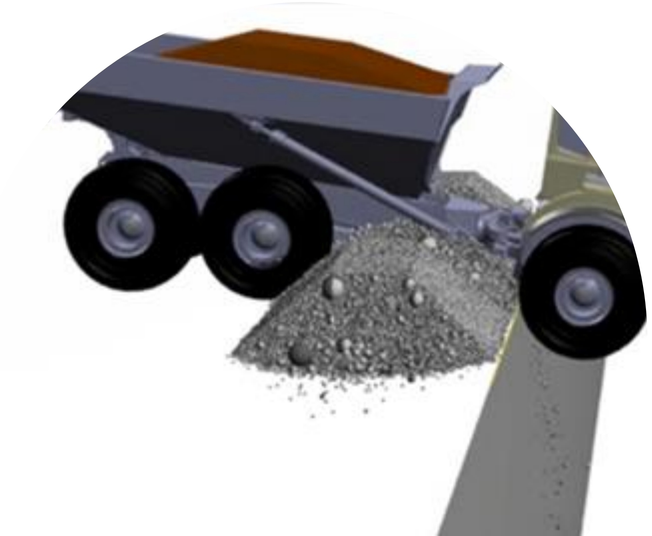


Full-scale Testing: Summary

- The reverse impact tests clearly indicate that there is a difference between the behaviour of an ADT compared to an RDT when running into a bund:
  - ADT tended to climb the bund without giving the driver a warning whereas the RDT shook considerably at first contact with the bund
  - RDT reacts based on material whereas ADT generally tends to climb independently of the material used
  - The truck driver also reported that the 90 and 75° impacts felt almost identical for the ADT whereas there was a clear difference for the RDT.
- Overall the three materials performed very similar during the reverse impact tests





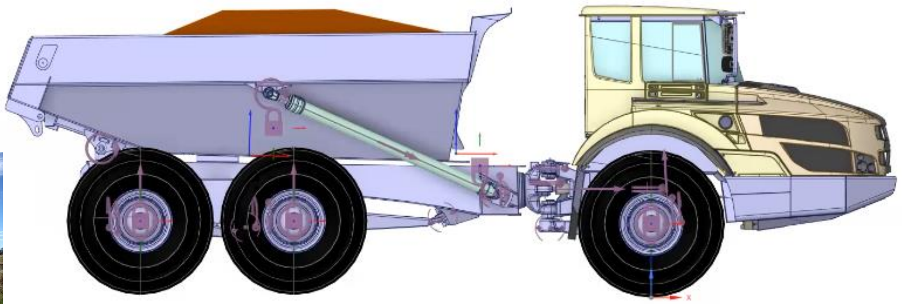


Numerical Modelling

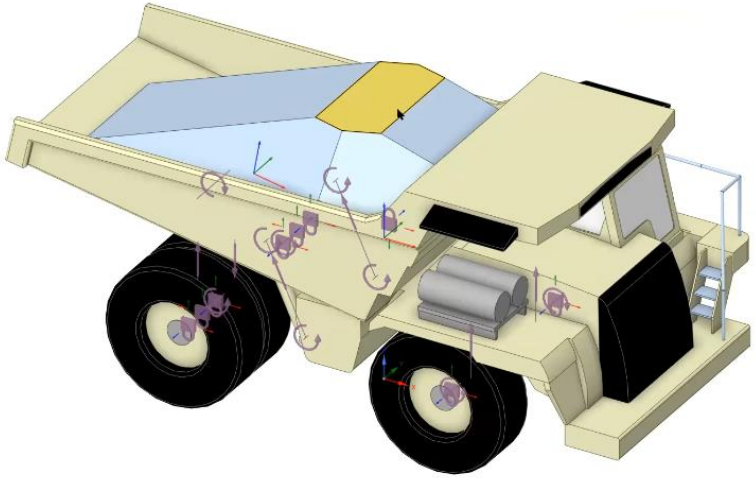
- Numerical model of trucks
- Numerical model of granular material
- Calibration using full-scale tipping and reverse impact tests
- Back analysis
- Parametric study and results

Numerical Modelling: Model of trucks and granular material

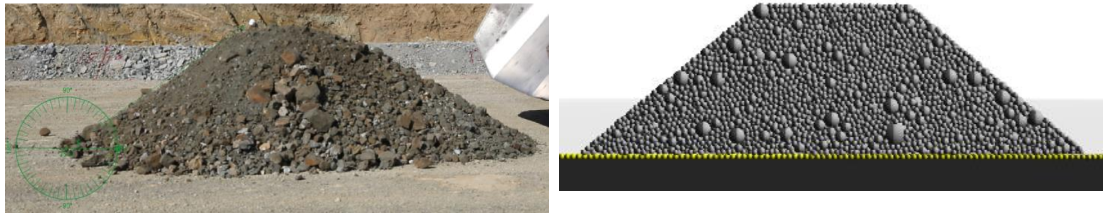
- Volvo A45G (CAD file provided by Volvo):



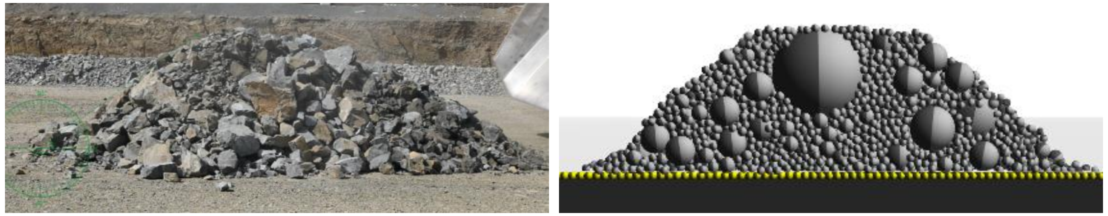
- CAT 773B (simplified CAD file):



- Representation of granular material:

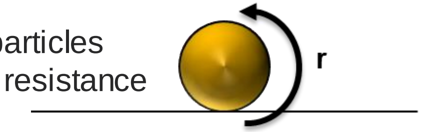


Material 1

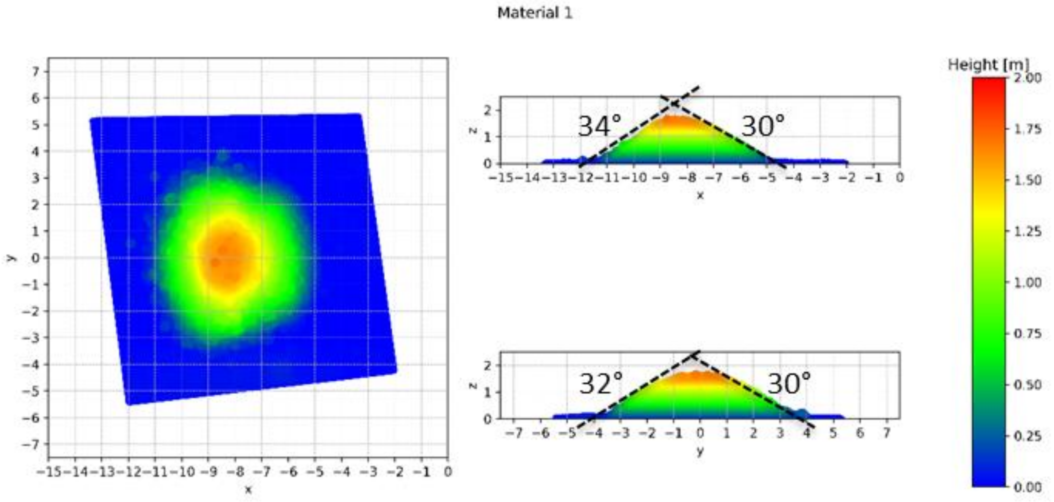


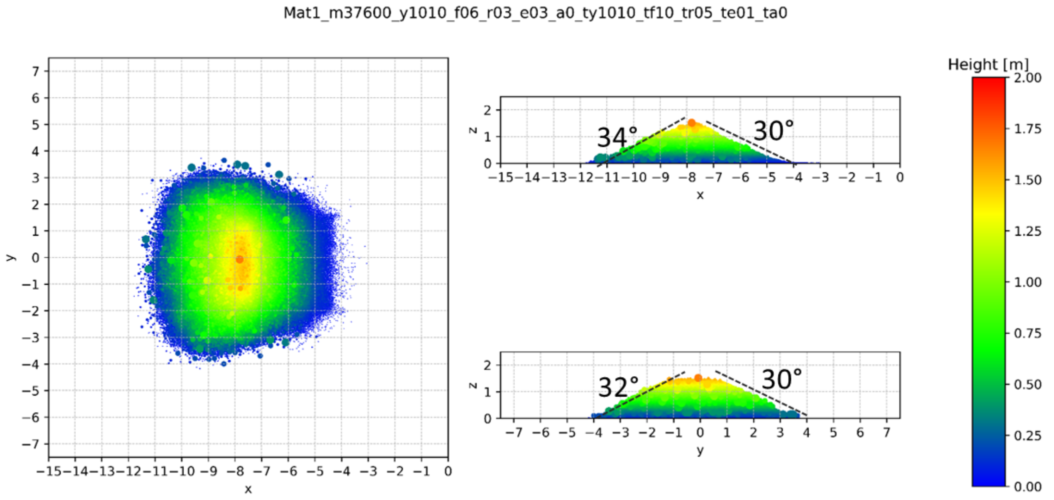
Material 2

Material 3



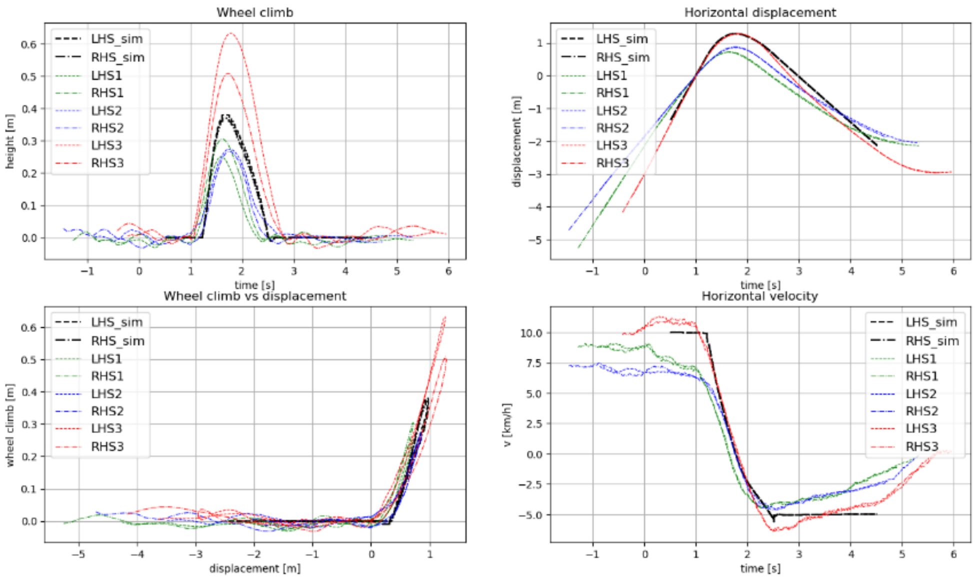
Numerical Modelling: Calibration, tipping test



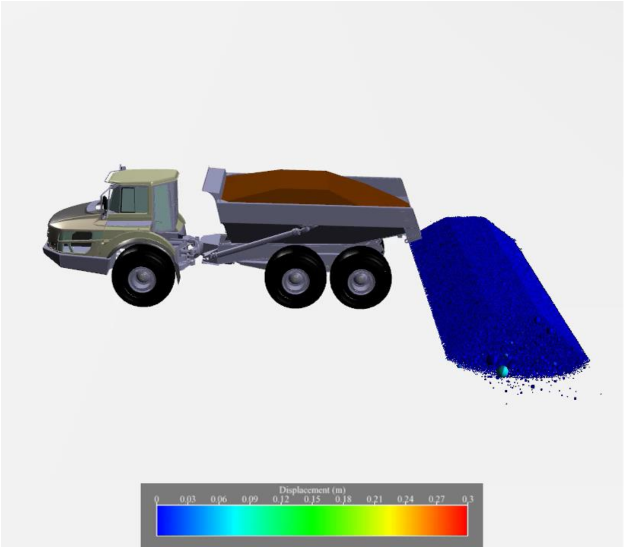


Numerical Modelling: Calibration, Reverse Impact, ADT 90°, Material 1

- Truck speed at impact:
  - Full-scale test: 6.3-10.6 km/h
  - Simulation: 10 km/h
- Wheel climb (top left):
  - Full-scale test: 0.3-0.6 m
  - Simulation: 0.4 m *(<u>captured well</u>)*
- Horizontal displacement (bottom left):
  - Full-scale test: 0.7-1.3 m
  - Simulation: 0.9 m *(<u>captured well</u>)*

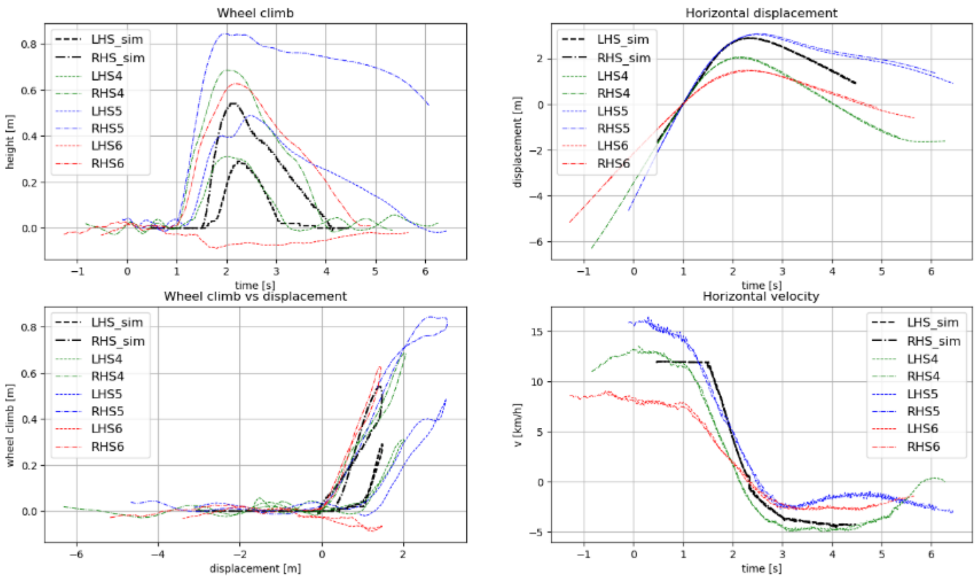


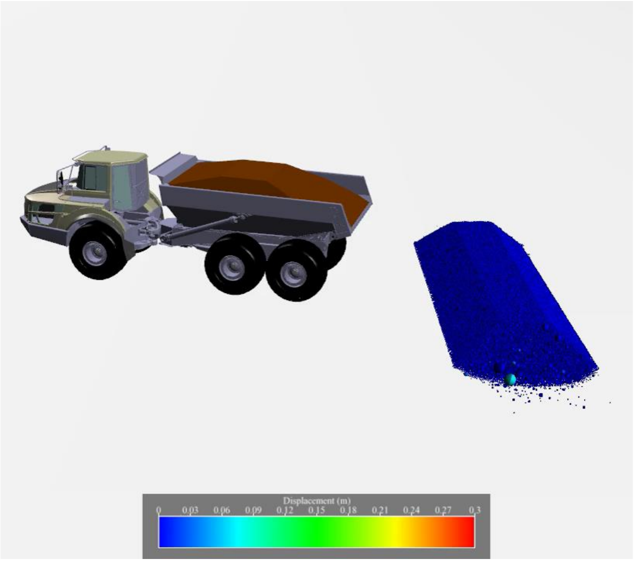
LHS2



Numerical Modelling: Calibration, Reverse Impact, ADT 75°, Material 1

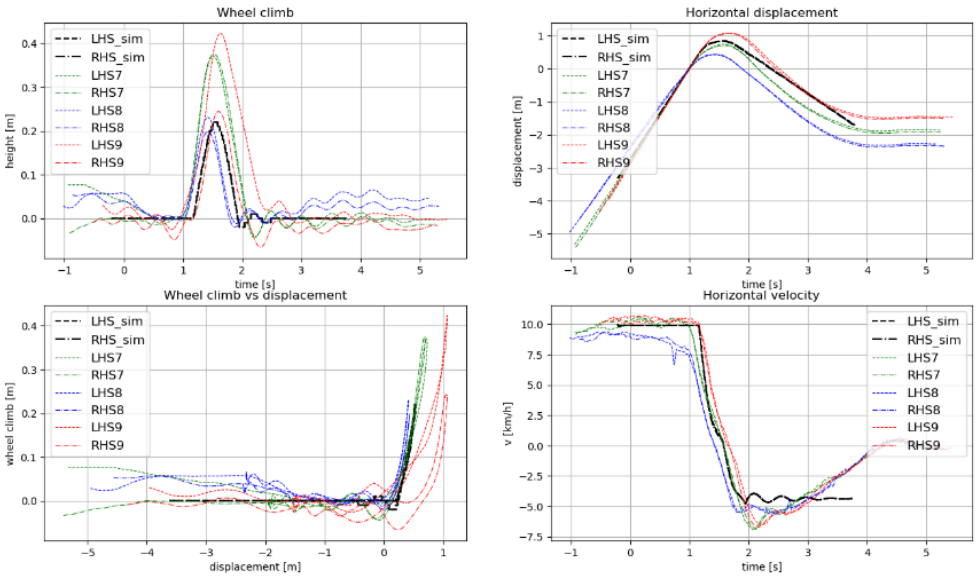
- Truck speed at impact:
  - Full-scale test: 7.7-14.3 km/h
  - Simulation: 12 km/h
- Wheel climb RHS (top left):
  - Full-scale test: 0.6-0.8 m
  - Simulation: 0.5 m *(<u>slightly underestimated</u>)*
- Horizontal displacement RHS (bottom left):
  - Full-scale test: 1.5-3.1 m
  - Simulation: 1.9 m *(<u>captured well</u>)*

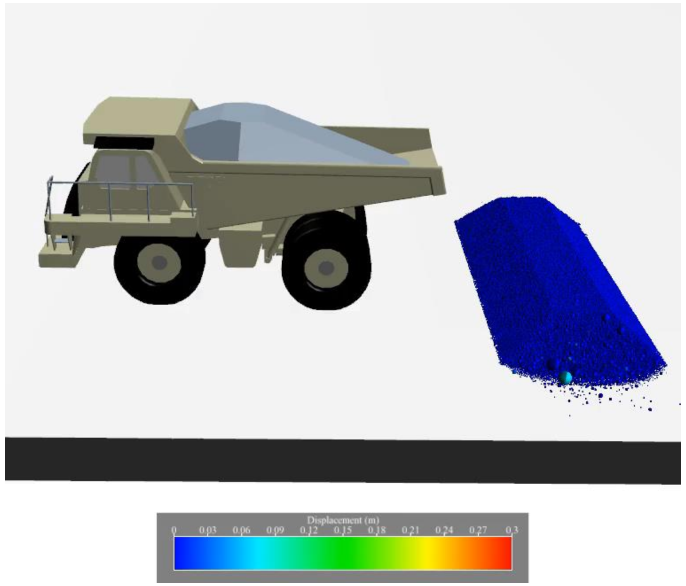




Numerical Modelling: Calibration, Reverse Impact, RDT 90°, Material 1

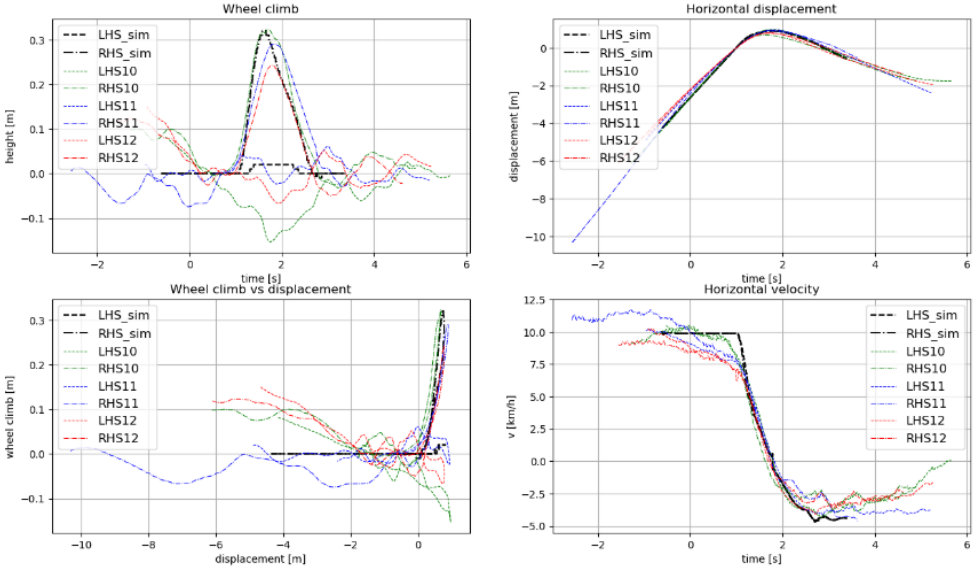
- Truck speed at impact:
  - Full-scale test: 7.5-10.3 km/h
  - Simulation: 10 km/h
- Wheel climb (top left):
  - Full-scale test: 0.2-0.4 m
  - Simulation: 0.2 m (*captured well*)
- Horizontal displacement (bottom left):
  - Full-scale test: 0.4-1.1 m
  - Simulation: 0.4 m (*captured well*)



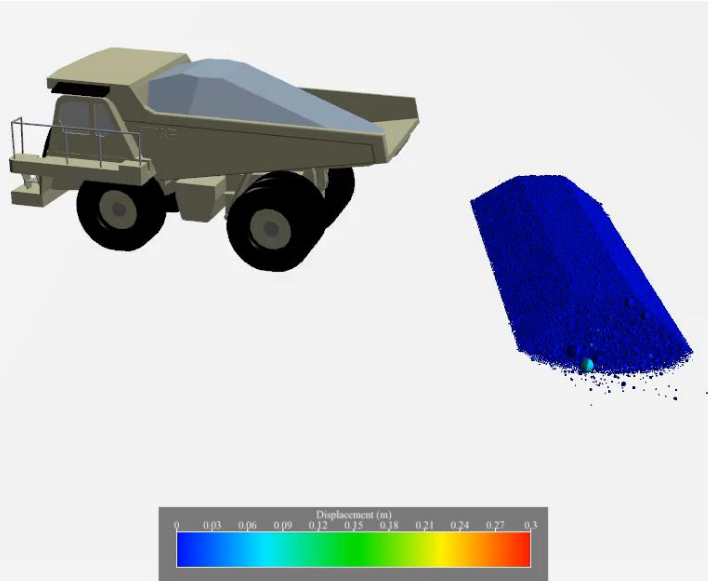


Numerical Modelling: Calibration, Reverse Impact, RDT 75°, Material 1

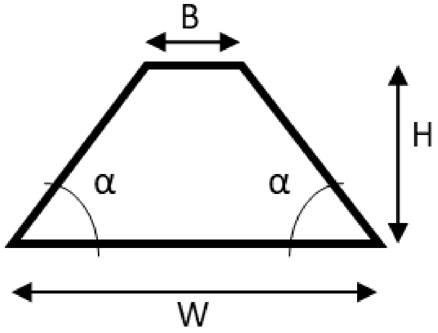
- Truck speed at impact:
  - Full-scale test: 6.6-8.1 km/h
  - Simulation: 10 km/h
- Wheel climb RHS (top left):
  - Full-scale test: 0.2-0.3 m
  - Simulation: 0.3 m (*<u>captured well</u>*)
- Horizontal displacement RHS (bottom left):
  - Full-scale test: 0.7-0.9 m
  - Simulation: 0.8 m (*<u>captured well</u>*)



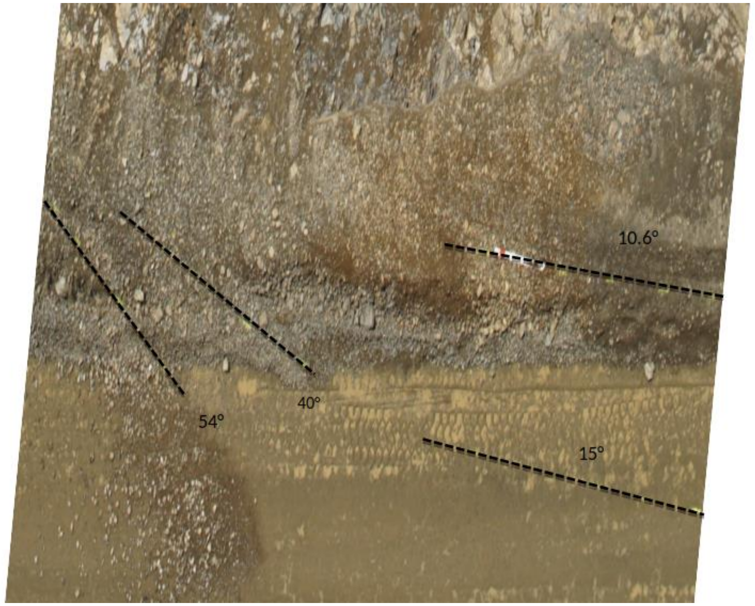
LHS10



Numerical Modelling: Back analysis Drury accident

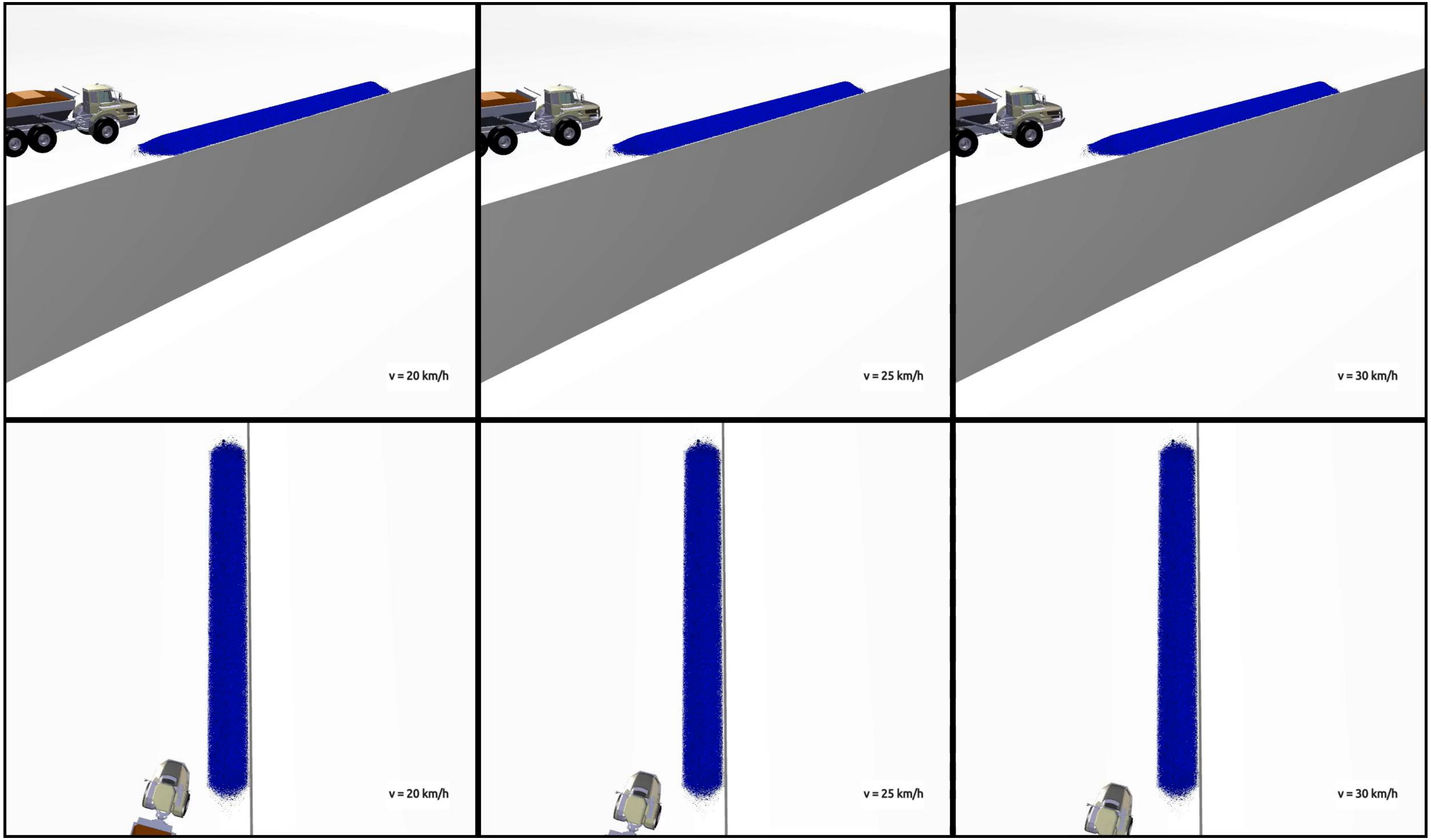


- Bund geometry: Height H = 0.9 m, top width B = 0.4 m, bund angle α = 30°
- Material: Material 1
- Assumption: Forward motion with shallow approach angle of 15°
- Truck: Volvo A45G (similar specs to CAT 740B EJ ADT), fully loaded
- Simulations with velocities of 20, 25 and 30 km/h



Numerical Modelling: Back analysis Drury accident – cont’d

v=20 km/h | v=25 km/h | v=30 km/h

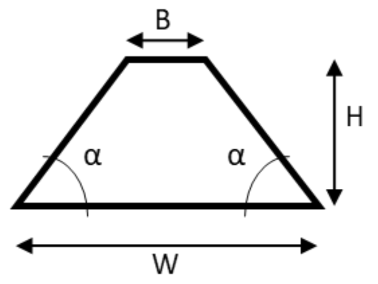


Numerical Modelling: Parametric study

- Investigated geometries

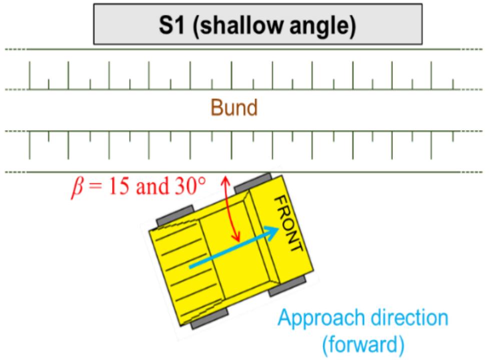
Geometry	Height H [m]	Top width B [m]	Batter angle α [°]	Base width W [m]	Cross-sectional area [m^2]
1*	1.0	1.0	40	3.4	2.2 (1)
2	1.3	1.0	40	4.1	3.3 (1.5)
3	1.5	0.5	40	4.1	3.4 (1.6)
4	1.5	1.0	40	4.6	4.2 (1.9)

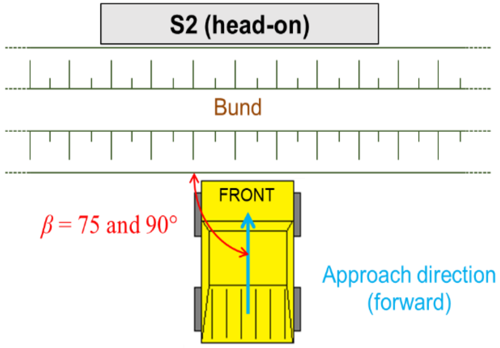
*Dimensions suggested by *WorkSafe NZ (2015)*



- Scenarios with different velocities

Scenario	Approach angle β [°]	Approach velocity v [km/h]	Material	Geometry	Truck
S1	15, 30	5 to 60 in increments of 5	1, 2, 3	1, 2, 3, 4	ADT, RDT, both loaded and unloaded
S2	75, 90				

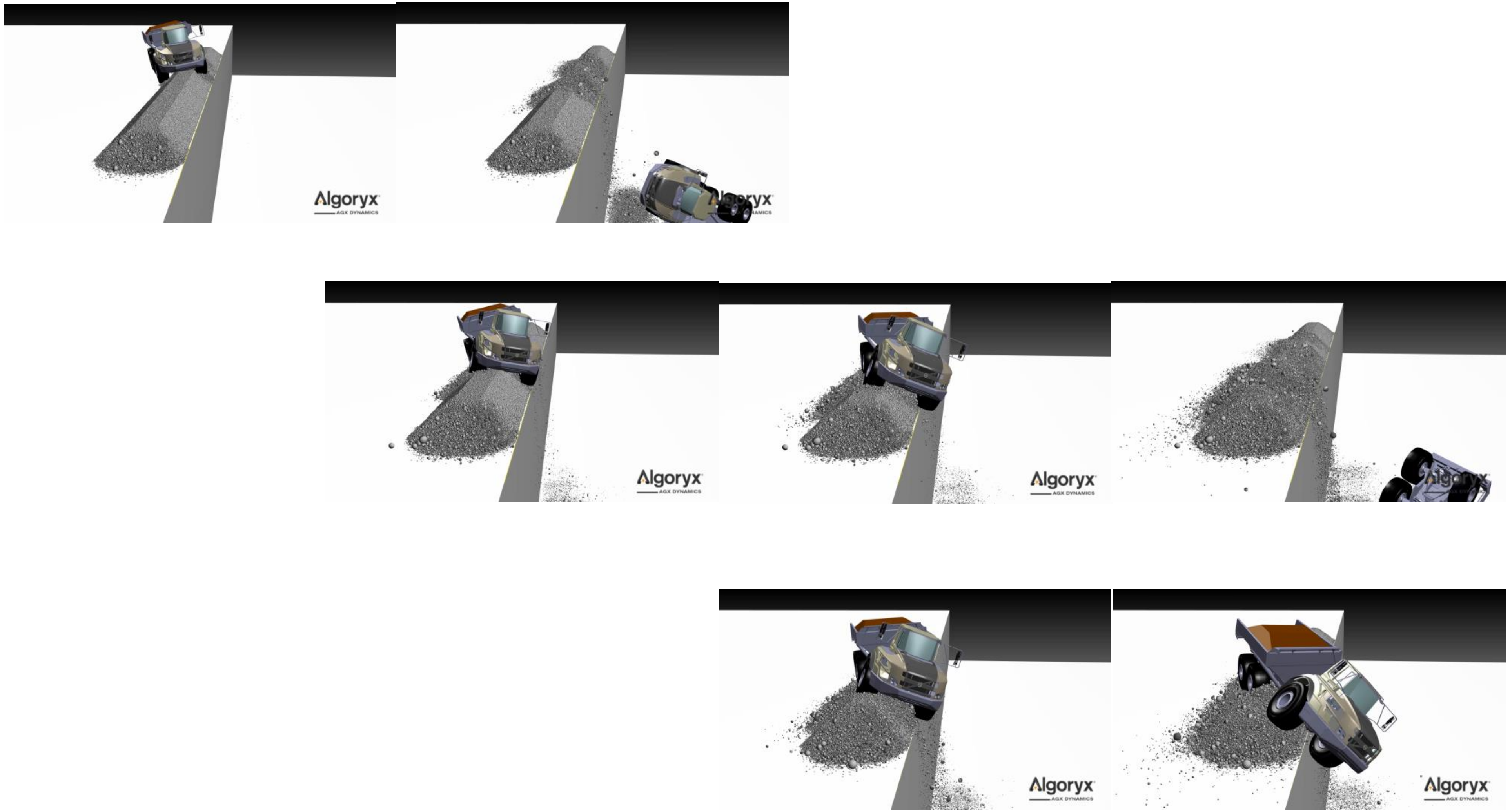




about 3,000 Simulations

Numerical Modelling: ADT loaded, Material 1, 15°

v=25 v=30 v=35 v=40km/h



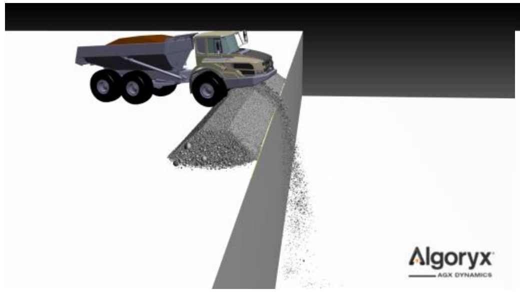
H=1.0
(B=1.0)

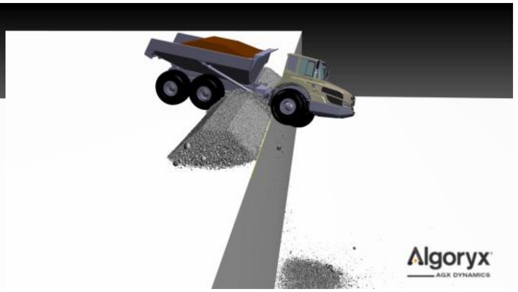
H=1.3
(B=1.0)

H=1.5
(B=0.5)

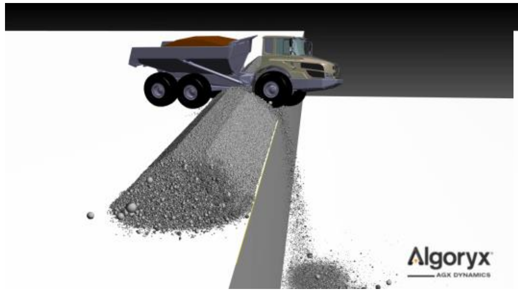
Numerical Modelling: ADT loaded, Material 1, 75°

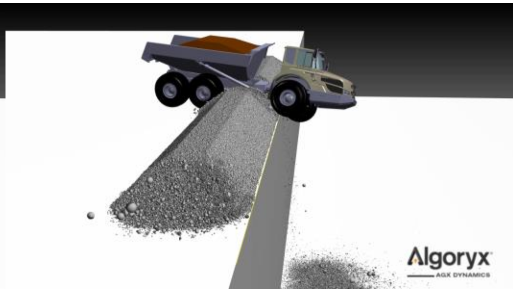
v=10 | v=15 | v=20km/h





H=1.0
(B=1.0)



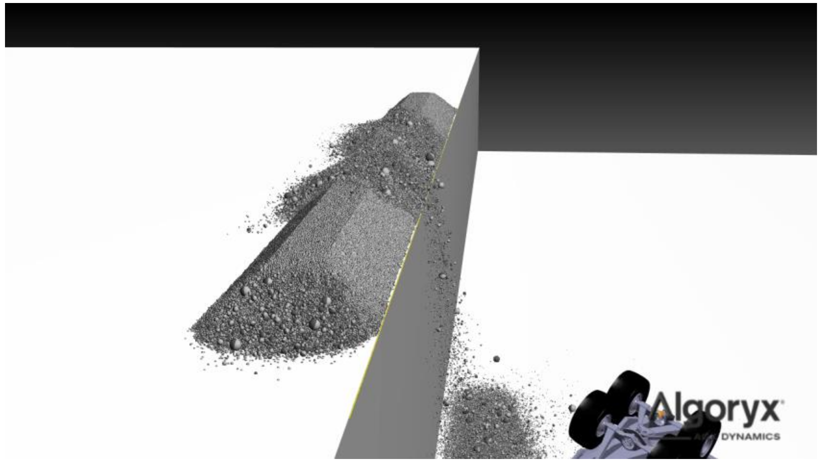


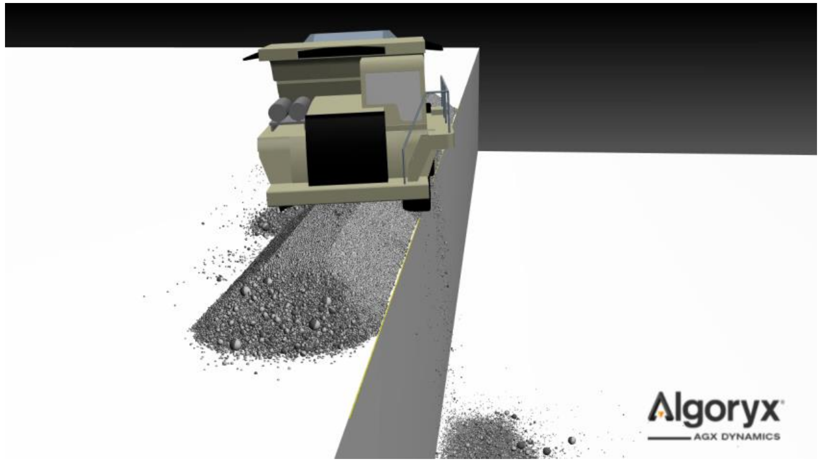
H=1.3
(B=1.0)

H=1.5
(B=0.5)

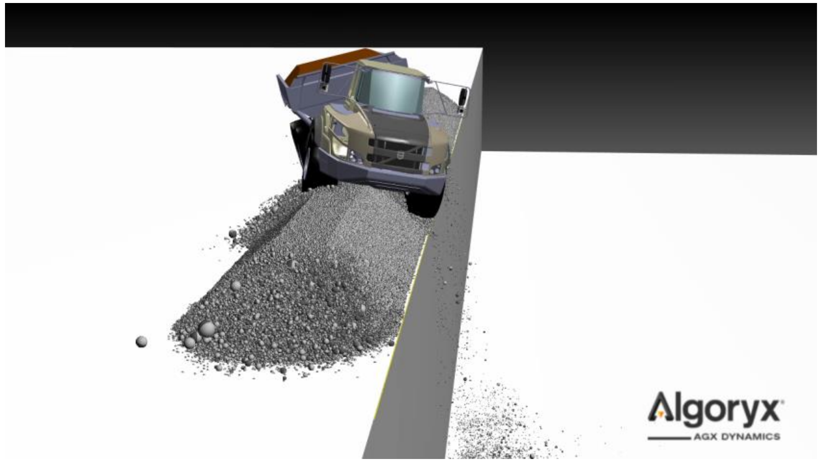
Numerical Modelling: ADT vs. RDT, Material 1, 15°, loaded, v=30km/h

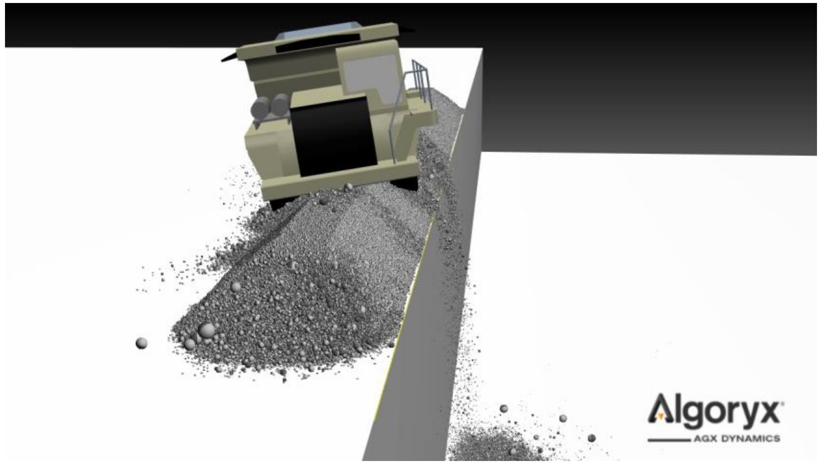
H=1.0, B=1.0





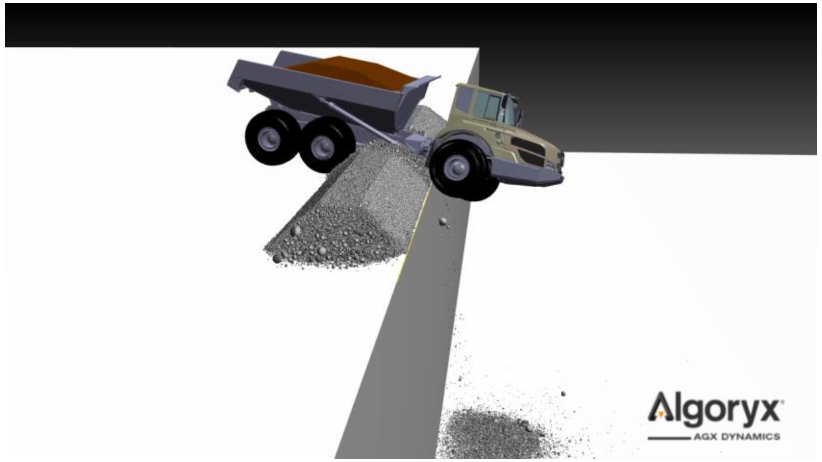
H=1.3, B=1.0

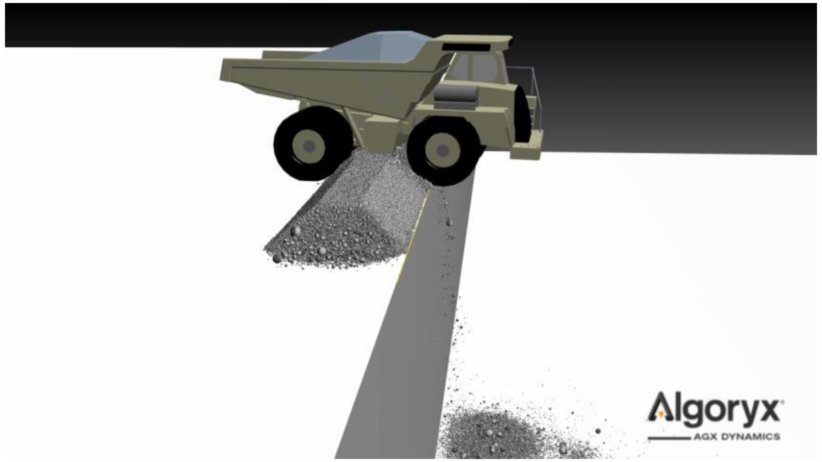




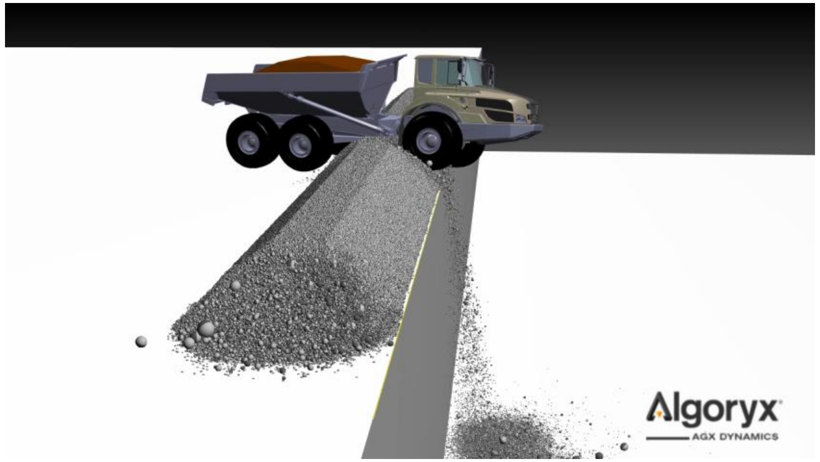
Numerical Modelling: ADT vs. RDT, Material 1, 75°, loaded, v=15km/h

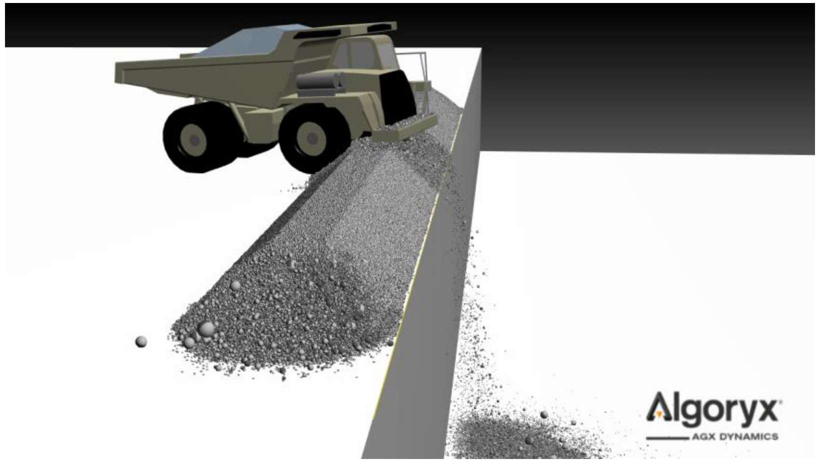
H=1.0, B=1.0



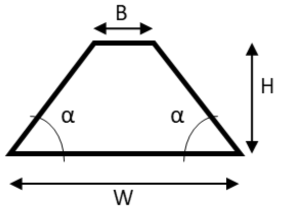


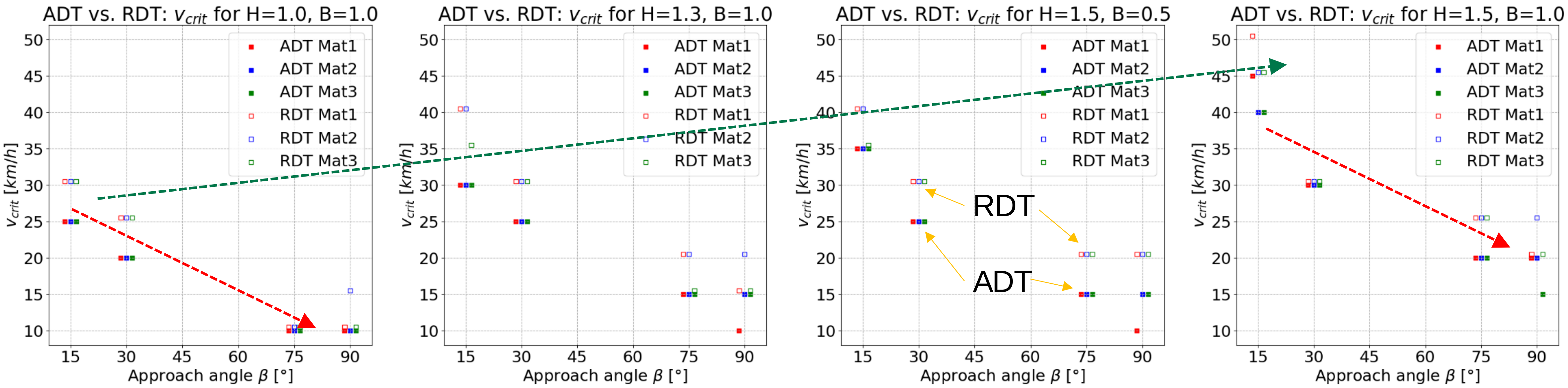
H=1.3, B=1.0





Numerical Modelling: Summary ADT vs. RDT (loaded)

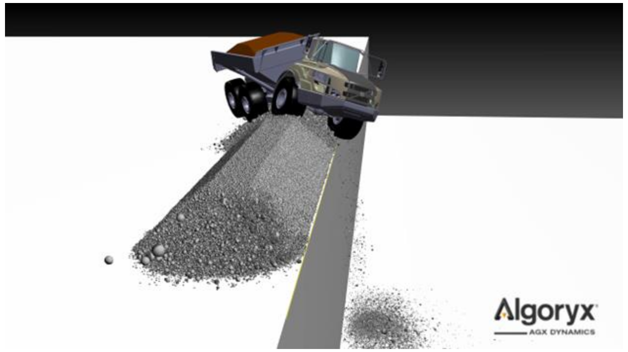


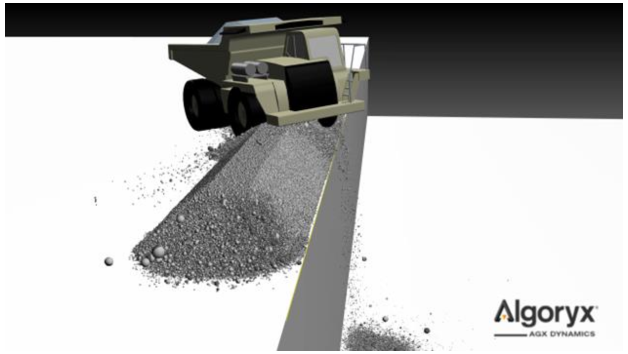


- Simulations show that an increase in height and width generally also increases the critical velocity.
- A clear trend is also visible for the approach angle, the steeper the approach angle, the less efficient the bund, i.e., a head-on collision is the worst-case scenario. It should be noted that a head-on collision would generally only occur in a high-risk area, where the bund height should be increased anyway.
- When comparing the ADT with the RDT it can be noted that the critical velocity for the RDT is generally 5 to 10 km/h higher.
- The three materials tested perform similarly well, all three materials were well-graded.

Concluding Remarks

- Current bund "design" is mostly based on rules of thumb, such as the minimum height should at least be equal to 50% of the largest tyre diameter in use.
- Most guidelines focus on big vehicles and RDTs. Only *SME Mining Engineering Handbook (2011)* mentions ADTs and recommends berm dimensions in excess of 66% of the wheel diameter.
- Early research in the US (*Stecklein and Labra, 1981*) advised that bunds with 4 times the axle height would be required to stop vehicles over 85 t. This calculation was based on energy balance and did not consider the energy absorption capacity of the granular material the bunds are made of. The latter can only be considered in an advanced numerical model.
- Any robust design calculation "be competent person" needs to consider truck size/type, approach conditions (angle and velocity), shape and material.
- Strict speed limits should be enforced and drivers should be made aware of the strict speed limit and why it is in place (e.g. bunds are only effective up to a certain speed).
- Proper training of personnel is crucial for safe operation.





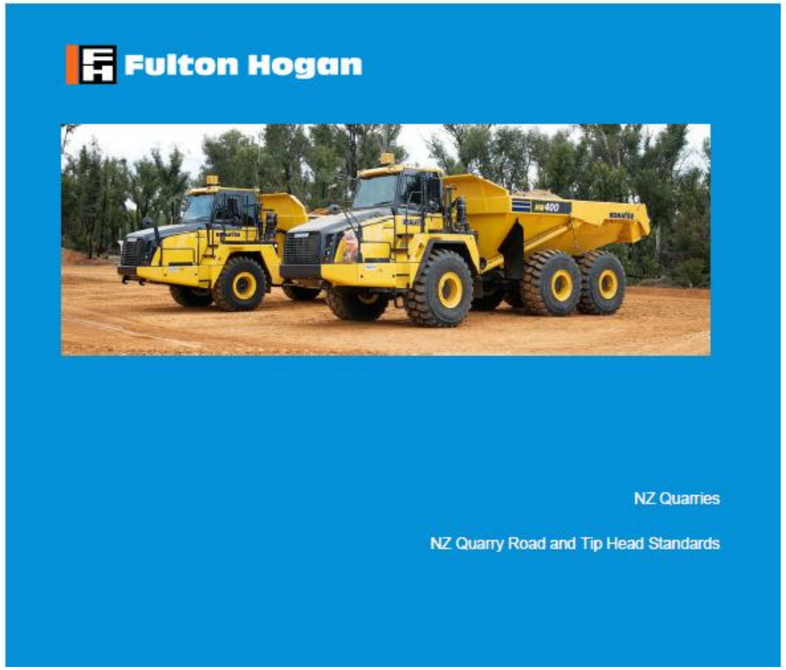
Implementation

So what did we do with the learnings?

For Fulton Hogan and Stevenson Aggregates, this has meant taking the projects findings and using it to develop a functional standard to be applied across the Quarry business.

New Standard.

Analysis of the data lead to the creation of a table that simply described how to limit speed in the quarry based on the type of Truck and the dimensions of the Bund.



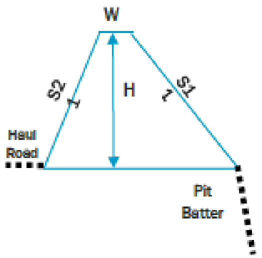
STEVENSON

Fulton Hogan Quarries

NZ Quarry and Tiphead Haul Road - minimum standards

Haul road bunding

Standard bund design



W = Top width =..............m

H = Bund height =............m

S1 = Bund slope = ...H to V

S2 = Bund slope = ...H to V

Material type = ...

Speed limit = ...

If the bunds can't meet these minimum standards then a SWMS is required

Things to consider

- ✓ Material type to build the bund
- ✓ Height required
- ✓ Alternatives like concrete or Armco
- ✓ Signage
- ✓ Traffic management plans/speed or gear restrictions
- ✓ Run off areas
- ✓ Road surfaces
- ✓ Maintenance

Minimum standard

W= 0.5m,

H = 66% of the largest wheel (truck or loader) on site.

S1 = Outer bund edge 2H to1V (need to consider material type)

S2 = Haul Road bund edge 1V to 1H (need to consider material type)

Speed = (refer table below and under section 6)

Travelling on Straight Road Tables

	Payload up to 35t		Payload 35 to 55t		Payload 55 to 90t	
Bund Height (m)	Bund width 0.5m	Bund Width 1.0m	Bund width 0.5m	Bund Width 1.0m	Bund width 0.5m	Bund Width 1.0m
1.0	20kph	25kph	NA	NA	NA	NA
1.3	25kph	30kph	20kph	25kph	NA	NA
1.5	30kph	35kph	25kph	30kph	30kph	30kph
2.0					35kph	35kph

Travelling on Bends, intersections and down ramp Tables

	Payload up to 35t		Payload 35 to 55t		Payload 55 to 90t	
Bund Height (m)	Bund width 0.5m	Bund Width 1.0m	Bund width 0.5m	Bund Width 1.0m	Bund width 0.5m	Bund Width 1.0m
1.0	10kph	15kph	NA	NA	NA	NA
1.3	15kph	20kph	10kph	15kph	NA	NA
1.5	20kph	25kph	15kph	20kph	20kph	20kph
2.0					25kph	25kph

Speed is directly related to the size of the bund required for safe operations. The higher the speed, the larger the bund needed (see table above)

Refer report section 6

Requires a SWMS