METRO – Scale Model Tests

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www.foi.se

FOI-R--3402--SE
ISSN 1650-1942 February 2012

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Titel	METRO – Modellförsök
Title	METRO – Scale Model Tests
Rapportnr/Report no	FOI-R--3402--SE
Månad/Month	Februari/February
Utgivningsår/Year	2012
Antal sidor/Pages	34 p
ISSN	1650-1942
Kund/Customer	MU
FoT område	Fortifikatoriskt skydd
Projektnr/Project no	B20013
Godkänd av/Approved by	Patrik Lundberg
Ansvarig avdelning	Försvars- och säkerhetssystem

Sammanfattning

Som en del av projektet METRO (Work Package 5), utfördes experiment i modellskala av en explosion inuti en tågvagn belägen i en tunnel. Experimentella data jämfördes med numeriska simuleringar av tryckbelastning inom och utanför vagnen som gjordes tidigare i projektet [1].

I modellskale-experimenten antogs explosionen ske i mitten av vagnen. Det antogs också att belastningen från explosionen delvis släpptes ut genom sönderbrytningen av sidoväggen och taket i vagnen. Vagnmodellen utrustades därför med en öppning i närheten av laddningen. I de flesta försöken täcktes denna öppning med tunna aluminiumplåtar.

Strukturen på modellvagnen var i övrigt utformad stel, liksom väggarna i tunneln. Storleken på öppningen i vagnen, massan av den explosiva laddningen och antalet vagnar varierades för att simulera olika scenarier.

Denna rapport beskriver utformningen av testobjektet samt experimentens genomförande och resultaten från tryckmätningar presenteras.

Nyckelord: bombattentat, tåg, tunnel, tryck

Summary

As a part of the project METRO (Work Package 5), scale model tests of explosions inside a modelled train carriage located in a tunnel were carried out. The scale model tests aimed to verify the numerical simulations of pressure loadings inside and outside the carriage that were made earlier in the project in the same Work Package [1].

In the scale model tests, the explosion was assumed to take place in the centre of the carriage. It was also assumed that the explosion immediately ripped up a hole in the side walls and ceiling of the carriage with a specific area. The modelled carriage was therefore equipped with a slot near the charge, and in most tests the slot was covered with thin aluminium plates that would simulate the break-up of the side walls and the roof at the time of explosion. The structure of the carriage was otherwise designed rigid, as well as the inside walls of the tunnel. The slot area, the weight of the explosive charge and number of carriages were varied in order to simulate different scenarios.

This report describes the design of the test object and the test matrix, and the results from the pressure measurements are presented.

Keywords: explosion sabotage, train, tunnel, blast

Contents

1. TEST OBJECT

1.1 Design of the model carriage

The dimensions of the model carriage were chosen by taking the real carriage with model number X1 into account, which was intended to be used in a forthcoming full scale test. The dimensions were scaled 1:10 to get a suitable model size to work with. The exterior dimensions of the model carriage were 300 x 300 x 2400 mm (Figure1-2).

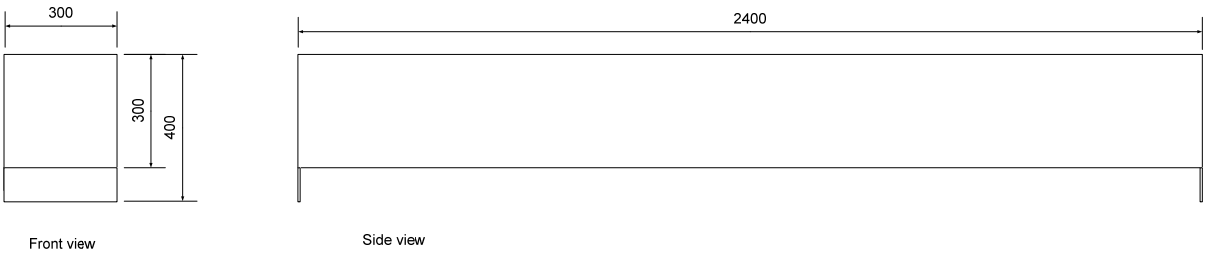


Figure 1. Exterior dimensions of the model carriage (mm)

Figure 2. Exterior view of the model carriage

To simulate the interior of the real carriage, 20 model seats with the dimensions 100 x 100 x 2 mm were made of steel. The seats were then attached in two rows inside the carriage model (Figure 3-4).

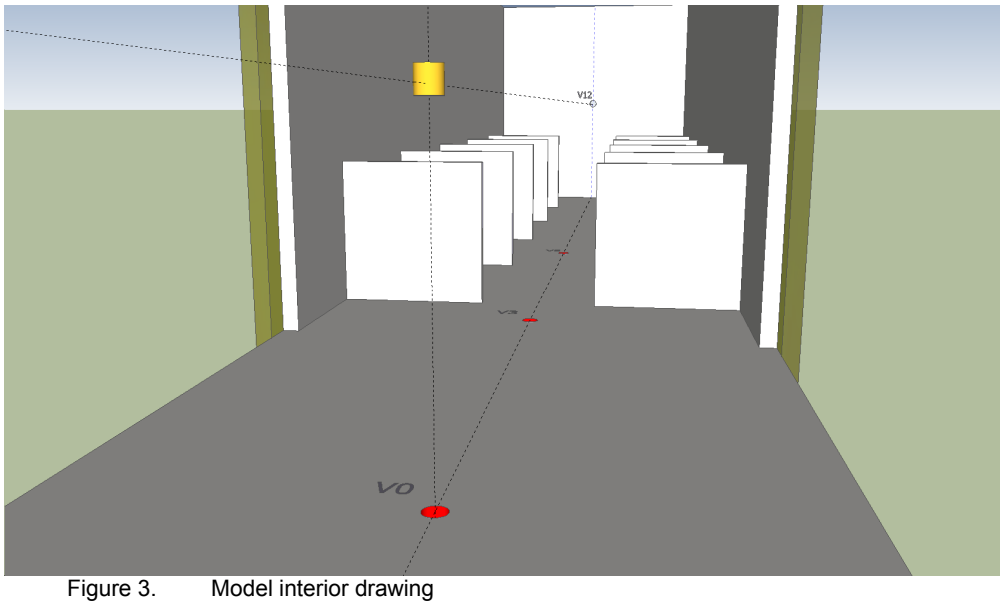


Figure 3. Model interior drawing

Figure 4. Model interior photo

The model carriage was equipped with a slot in the centre of the carriage with sliding walls and roof sections for varying venting areas (Figure 5). The test started without coverage of the slot but after the first tests the slot was covered with 1mm thick aluminium plates to get a more realistic pressure inside the carriage by simulating the resistance in the walls and roof at the time of break-up (Figure 6).

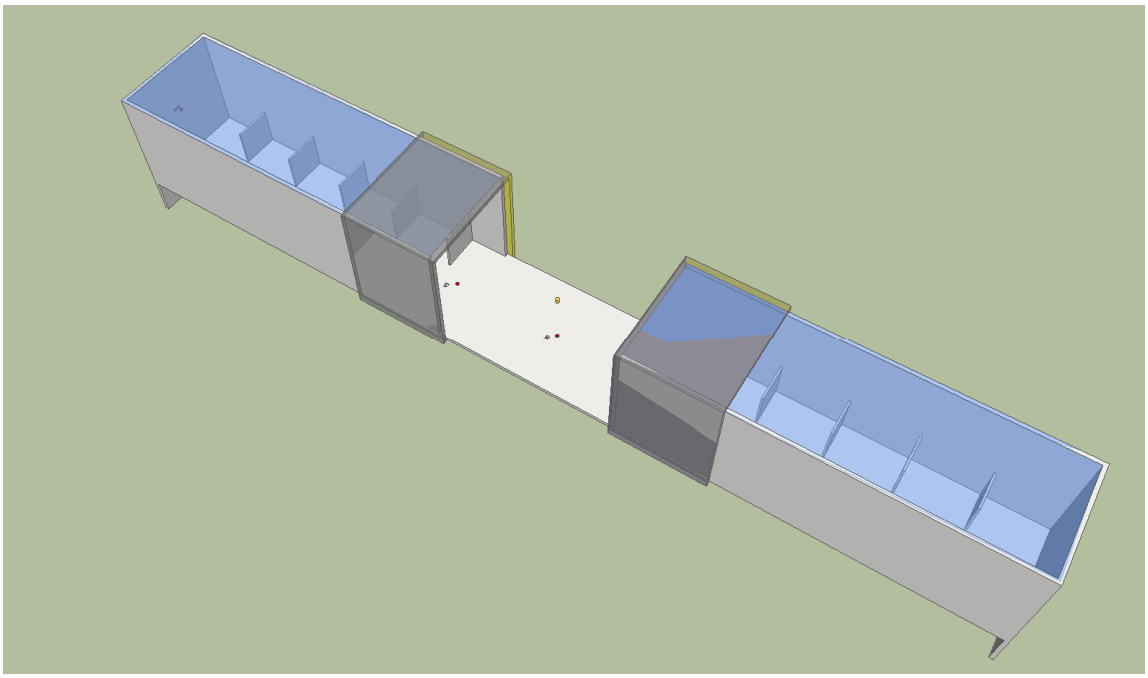


Figure 5. Slot with sliding wall- and roof sections

Figure 6. Covered slot

Ten concrete blocks with dimensions 500 x 500 x 2000 mm and wooden boards were used for the tunnel (Figures 7-8). The tunnel was covered with heavy steel plates that were removed when fitting the model car in the tunnel (Figure 9).
The inner dimensions of the tunnel were 700 x 700 x 10000 mm, which corresponds to 100 meters in 1:10 scale of the Brunsberg tunnel that would be used for an upcoming full-scale test.

During the tests with the carriage placed in the tunnel it was located centred in the tunnel.

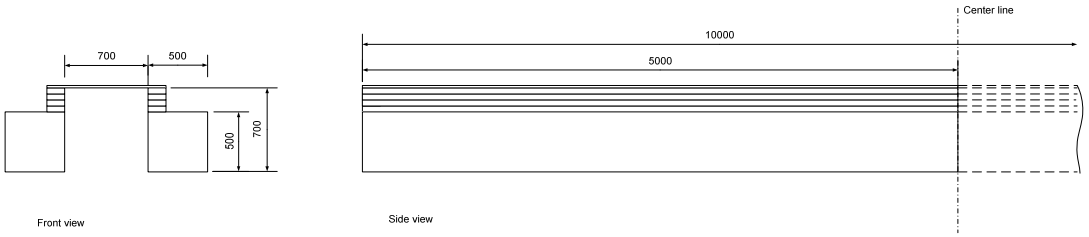


Figure 7. Tunnel dimensions (mm)

Figure 8. Inside tunnel view

Figure 9. Outside tunnel view

Pressure gauges were placed at locations which the numerical calculations showed to be useful for the comparability between the numerical calculations and the model tests (Figure 10-11). The gauges V0 and T0 were removed after the first tests as they were exposed to pressure levels which could damage the gauges.

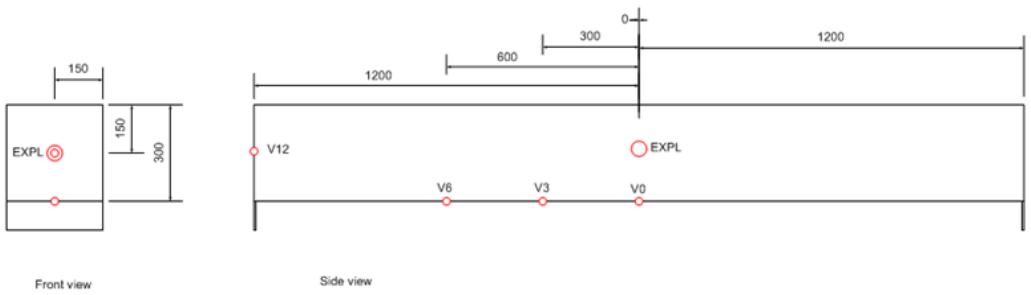


Figure 10. Gauge location in carriage (mm)

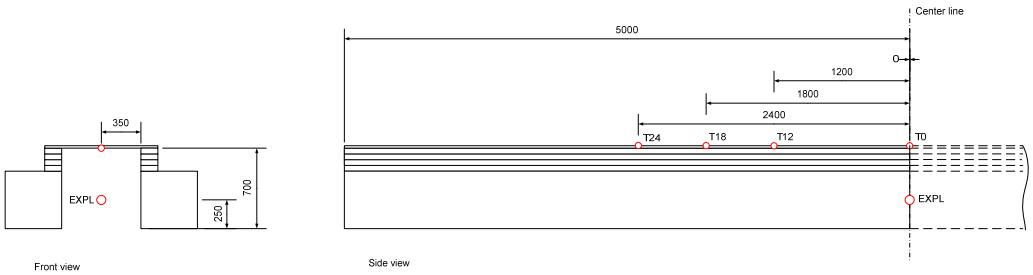


Figure 11. Gauge location in tunnel (mm)

1.2 Sensor characteristics and recorder settings

A Nicolet Odyssey high speed transient data acquisition system was used as data recorder in the scale model tests. Two OD-200 cards gave maximum 8 channels. It has a maximum sampling rate of 10 MHz using 14 bit sampling depth. A sampling rate of 2 MHz was used in the model test. Piezoelectric pressure sensors from PCB were used. The sensors have to be charged and amplified and this was done by a PCB584 signal conditioner, 16 channel and 100 kHz bandwidth. An extra coaxial cable was put directly into the charge. On detonation this wire was short-cut and the exact time of detonation was recorded. Pressure gauge data are given in Table 1.

Name	Manufacturer	Model	Serial number	Gauge sensitivity kPa/V
V0	PCB	102A04	27734	1349
V3	PCB	102M69	3759	313.7
V6	PCB	102A16	25848	139.3
V12	PCB	102A16	25849	139.1
T0	PCB	102A04	27735	1351
T12	PCB	102A16	25850	142.7
T18	PCB	102A18	26355	70.37
T24	PCB	102A18	26356	68.40

Table 1. Pressure gauge data

In addition to pressure gauges the tests were documented with a Casio Exilim EX-F1 camera running at 300 frames per second. The camera was placed 10 m in front of the tunnel opening (Figure 12).

Figure 12. Camera view of tunnel

2. TEST MATRIX / RESULTS

Table 2 summarizes the completed tests and the results of these.

Upper value: peak-pressure p (kPa) lower: total impulse density i_t(Pas).

Experiment ID	Charge, Slot area, tunnel, dummy	Carriage			Tunnel			Remark
		V3	V6	V12	T12	T18	T24	
Shot 1	**1g, 2cm, no tunnel**	**p: 69** i_t: 28	**p: 61** i_t: 52	**p: 54** i_t: 60				No walls
Shot 2	**1g, 2cm, no tunnel**	**p: 81** i_t: 37*	**p: 50** i_t: 55	**p: 55** i_t: 62				No walls
Shot 3	**1g, 2cm, no tunnel**	**p: 86** i_t: 58*	**p: 47** i_t: **	**p: 59** i_t:*, **				Walls made of double aluminium foil
Shot 4	**1g, 20cm, no tunnel**	**p: 102** i_t: 18	**p: 50** i_t: 19	**p: 49** i_t: 27				No walls
Shot 5	**5g, 20cm, no tunnel**	**p: 114** i_t: 22	**p: 54** i_t: 26	**p: 44** i_t: 32				No walls, incomplete detonation
Shot 6	**5g, 20cm, no tunnel**	**p: 637** i_t: 220	**p: 247** i_t: 117	**p: 294** i_t: 284				Walls 22 cm wide aluminium
Shot 7	**1g, 2cm, no tunnel**	**p: 105** i_t: 31	**p: 65** i_t: 36	**p: 59** i_t: 53				Walls 7cm wide aluminium
Shot 8	**1g, 2cm, no tunnel**	**p: 115** i_t: 29	**p: 57** i_t: 35	**p: 64** i_t: 32				Walls 5 cm wide aluminium
Shot 9	**1g, just tunnel**				**p: 14** i_t: 4	**p: 11** i_t: 5	**p: 10** i_t: 5	
Shot 10	**5g, just tunnel**				**p: 58** i_t: 44	**p: 38** i_t: 58	**p: 28** i_t: 56	
Shot 11	**10g, just tunnel**				**p: 98** i_t: 77	**p: 78** i_t: 162	**p: 51** i_t: 101	
Shot 12	**1g, 2cm, in tunnel**	**p: 110** i_t: 31	**p: 72** i_t: 42	**p: 47** i_t: 40	**p: 11** i_t: 4	**p: 8** i_t: 5	**p: 4** i_t: 4	walls 5 cm wide aluminium
Shot 13	**5g, 20cm, in tunnel**	**p: 1700** i_t: 205 ***	**p: 300** i_t: 133	**p: 362** i_t: 246	**p: 78** i_t: 52	**p: 47** i_t: 65	**p: 32** i_t: 65	walls 22 cm wide aluminium
Shot 14	**5g, 20cm, in tunnel**	**p: 1400** i_t: 200	**p: 295** i_t: 130	**p: 285** i_t: 200	**p: 72** i_t: 46	**p: 36** i_t: 57	**p: 28** i_t: 56	walls 22 cm wide aluminium
Shot 15	**5g, 20cm, in tunnel, 1 dummy**	**p: 1347** i_t: 177	**p: 244** i_t: 130	**p: 332** i_t: 242	**p: 58** i_t: 57	**p: 42** i_t: 69	**p: 34** i_t: 69	walls 22 cm wide aluminium
Shot 16	**1g, 20cm, in tunnel, 1 dummy**	**p: 116** i_t: 29	**p: 72** i_t: 40	**p: 44** i_t: 31	**p: 7** i_t: 5	**p: 6** i_t: 6	**p: 5** i_t: 5	walls 22 cm wide aluminium

*** Desturbance in the signal**

**** Zero line shift, no readable value**

***** Gauge bottomed (probably hit by a fragment), uncertain value**

Table 2.Test matrix and gauge result

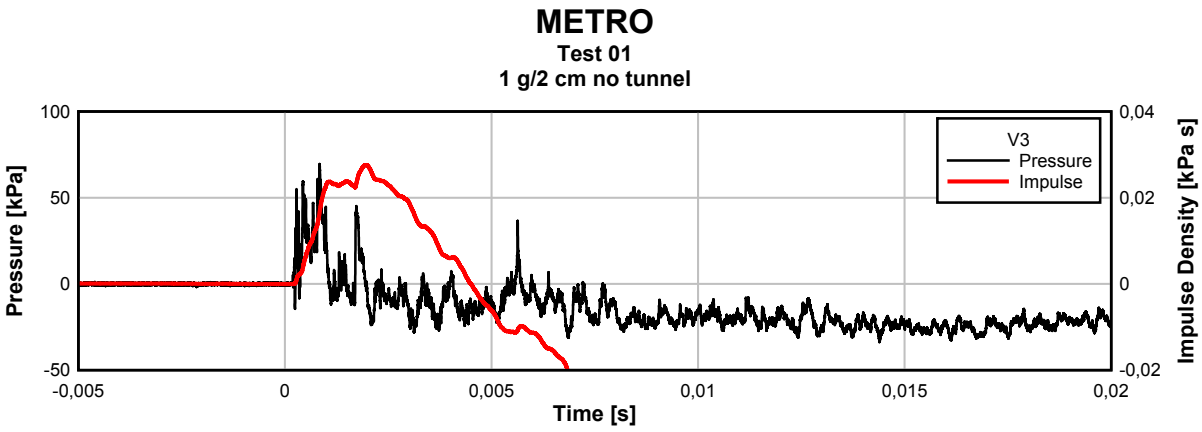
3. CONCLUSIONS

For conclusions and comparison of results with numerical calculations and full-scale test see [1].

4. REFERENCES

[1] Bryntse A, Meyer G "METRO-Calculated pressure from explosion in train coach" FOI-RH--1211--SE, Tumba, Sweden, 2011

5. APPENDIX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Pressure [kPa]
Impulse Density [kPa s]
Time [s]
V3
Pressure
Impulse
100
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-50
0,04
0,02
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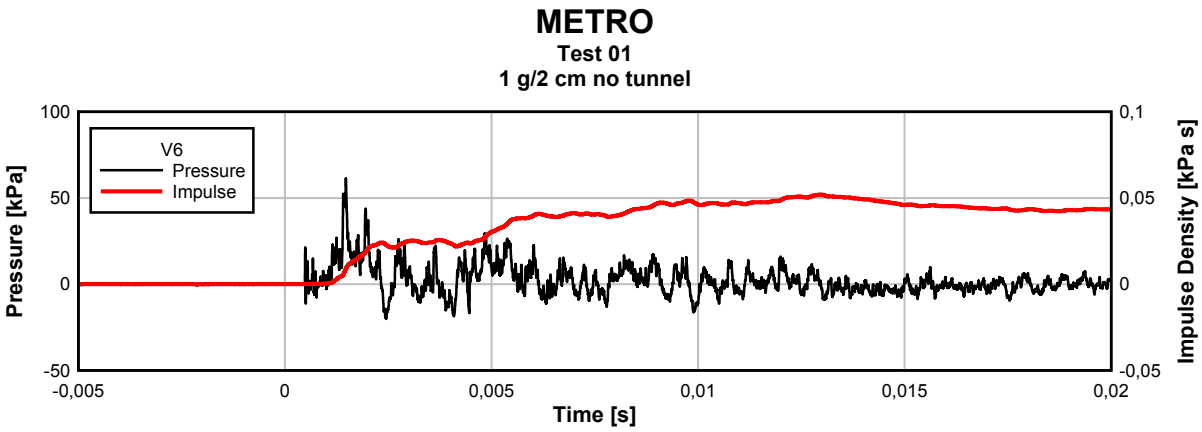
0,02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Pressure [kPa]
Impulse Density [kPa s]
Time [s]
V6
Pressure
Impulse
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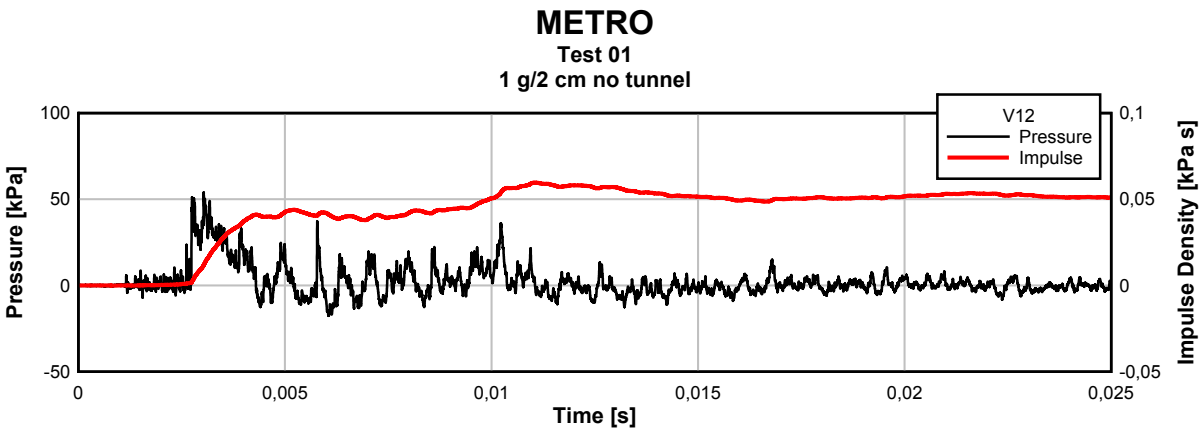
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Time [s]
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Pressure
Impulse
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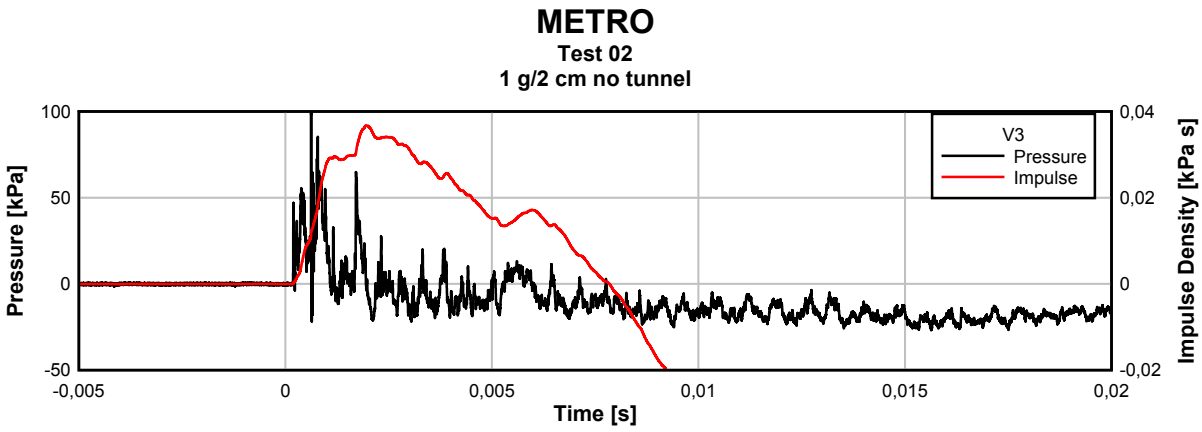
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Pressure
Impulse
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
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0,02
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0,01
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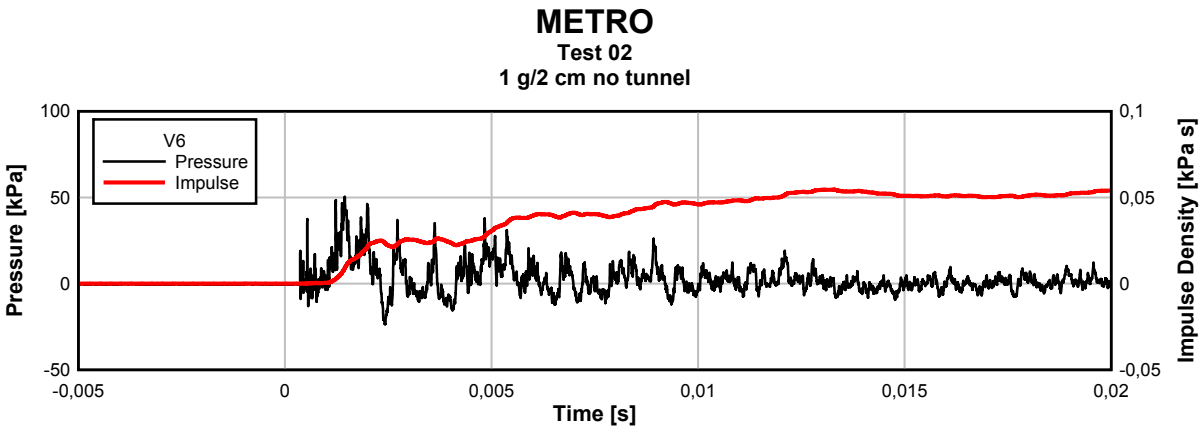
0,02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Test 02
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V6
Pressure
Impulse
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
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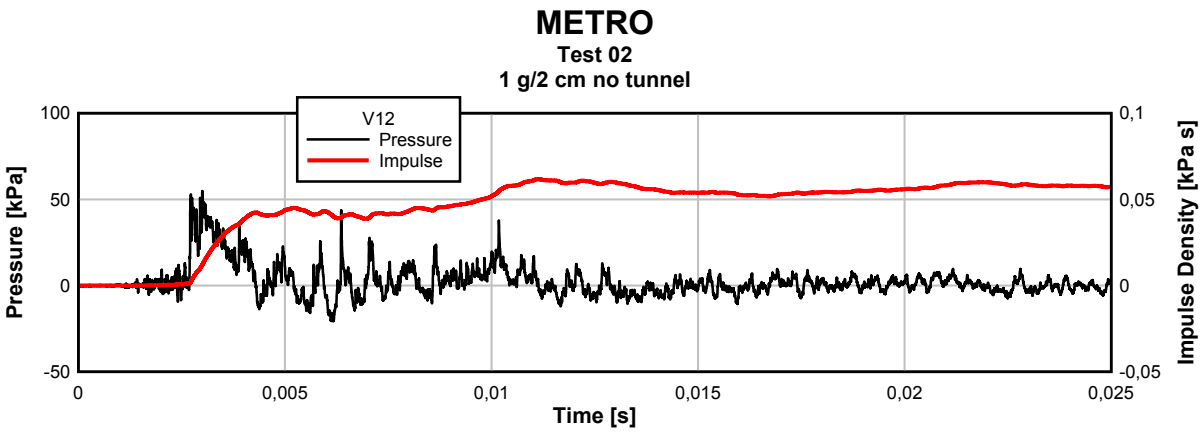
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V12
Pressure
Impulse
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
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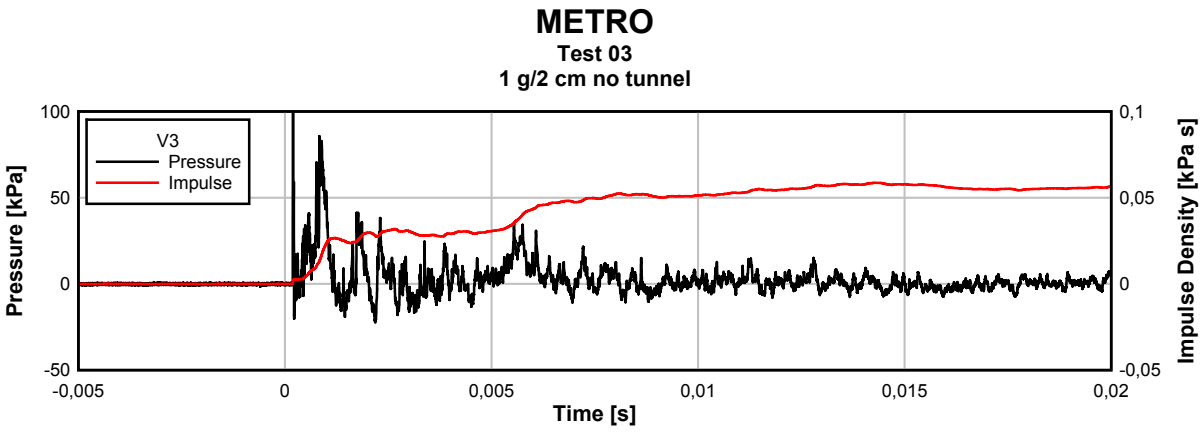
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Pressure
Impulse
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
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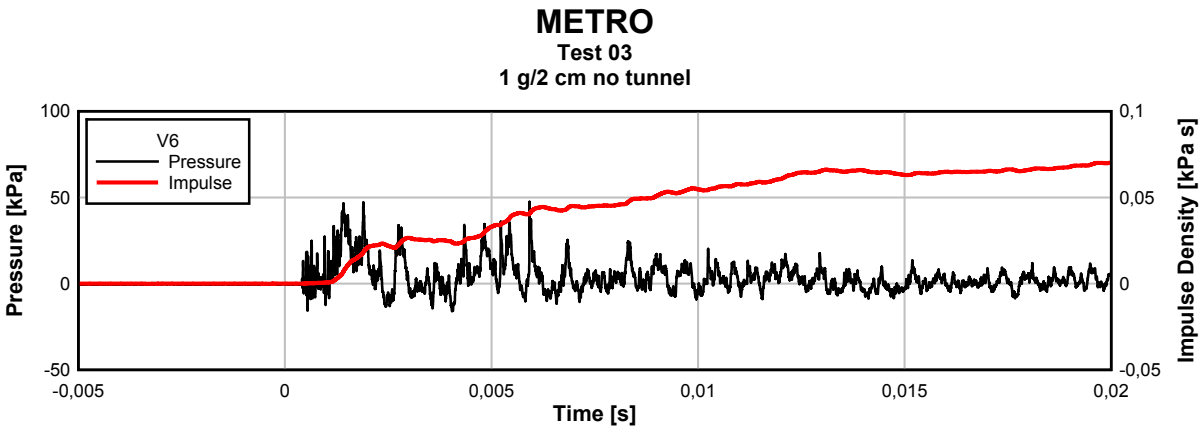
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Pressure
Impulse
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
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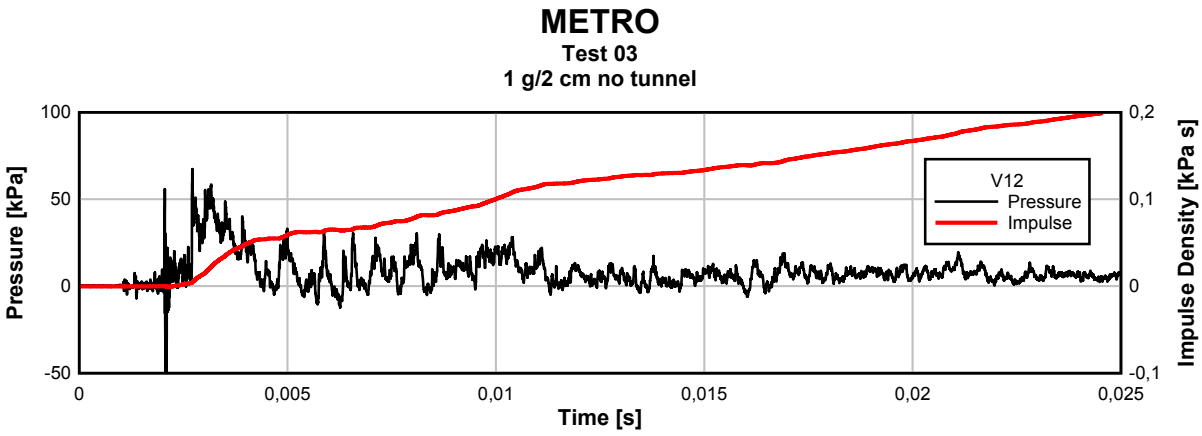
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Impulse
Pressure [kPa]
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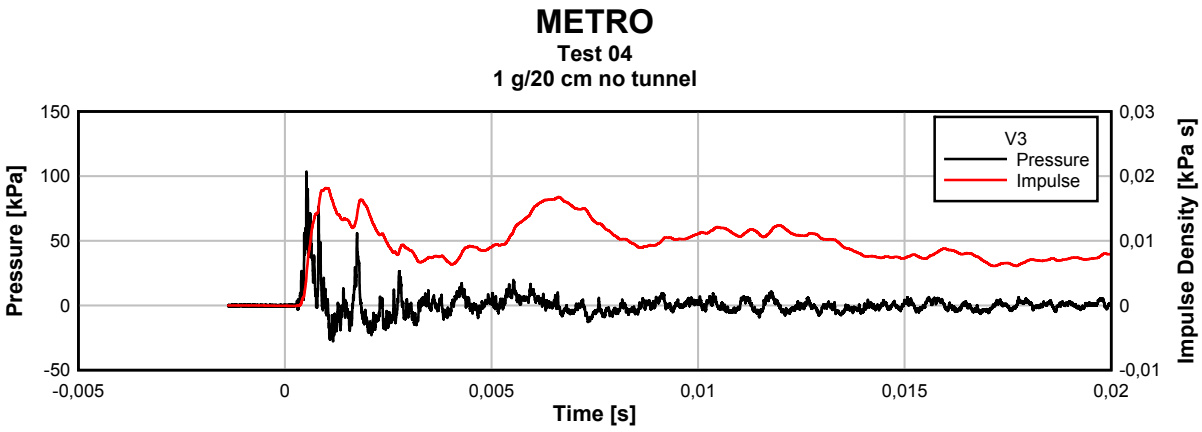
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Pressure
Impulse
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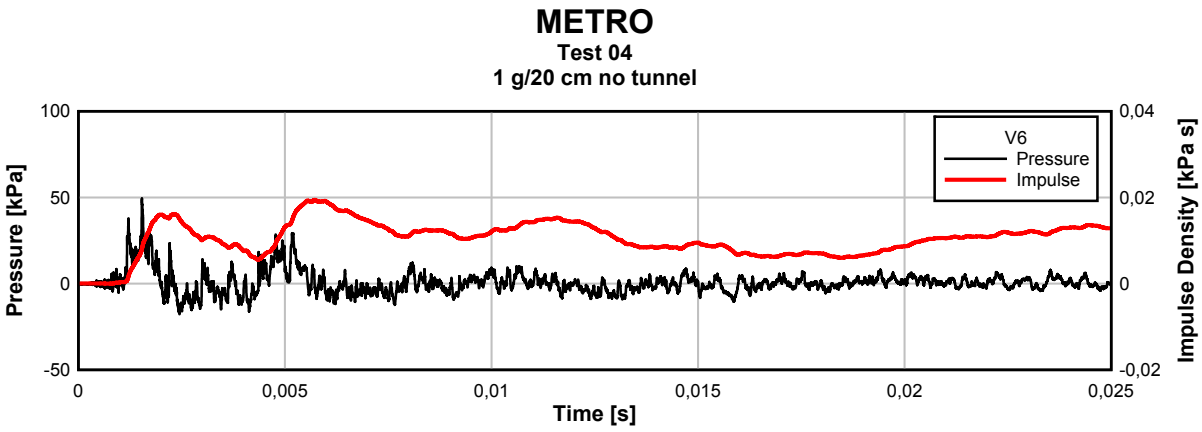
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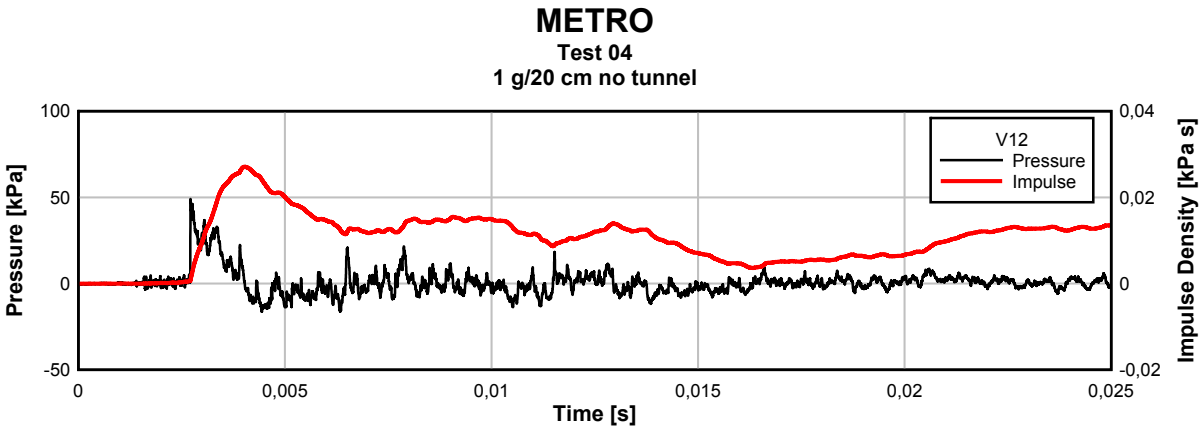
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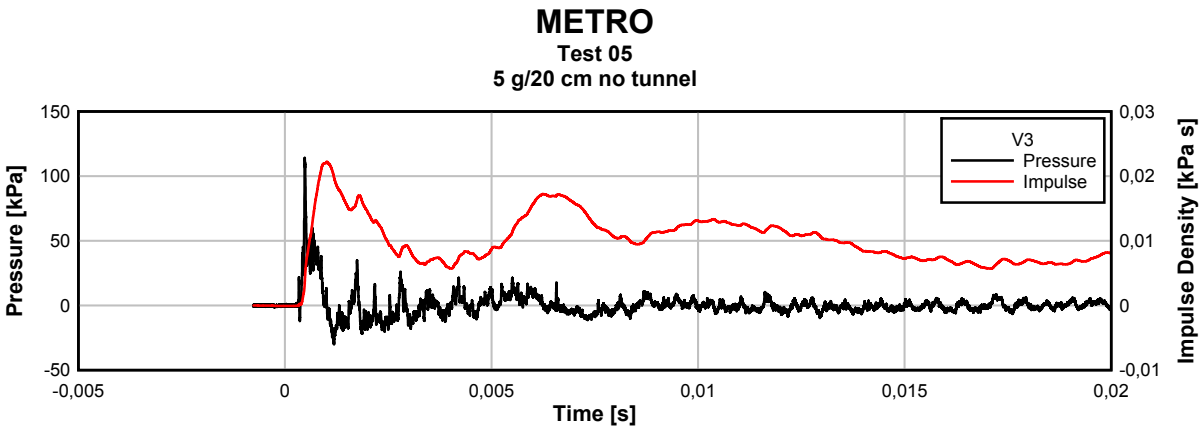
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Impulse Density [kPa s]
Time [s]
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Pressure
Impulse
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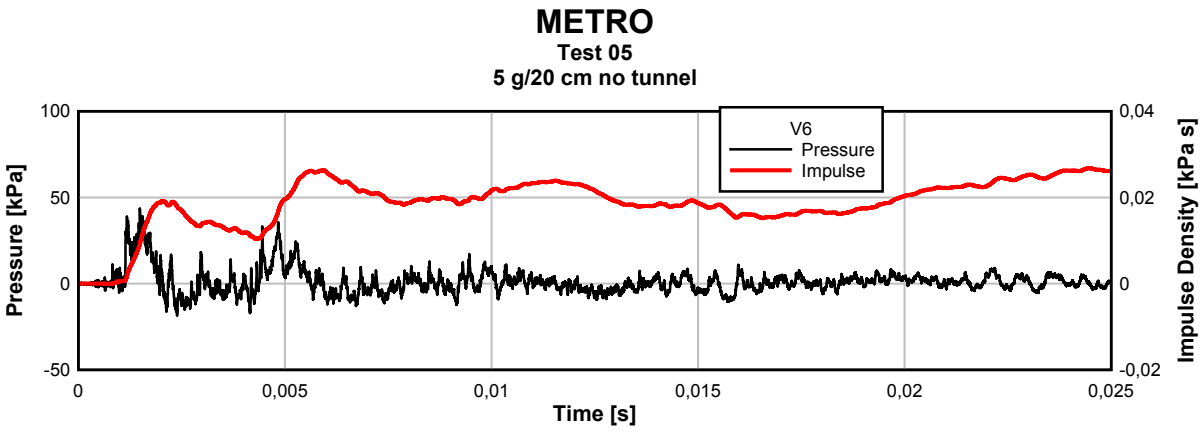
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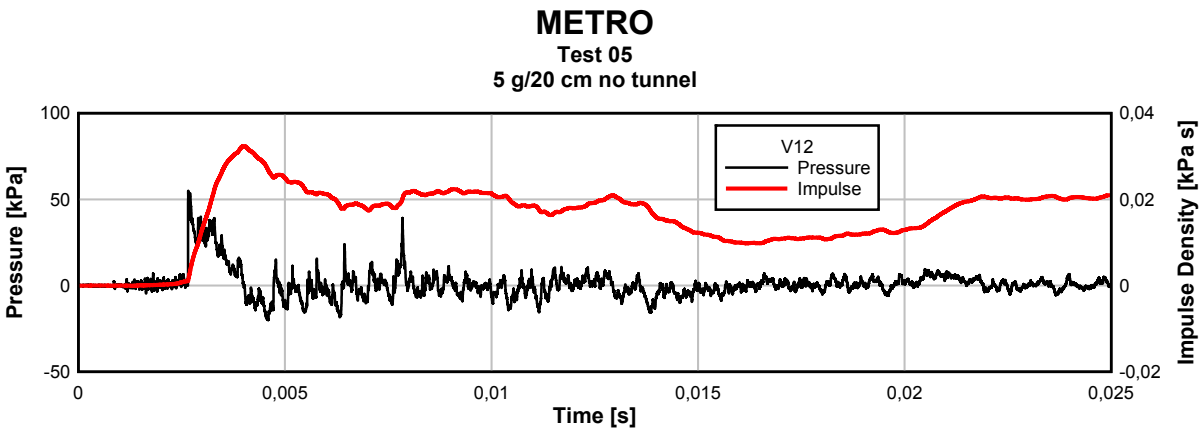
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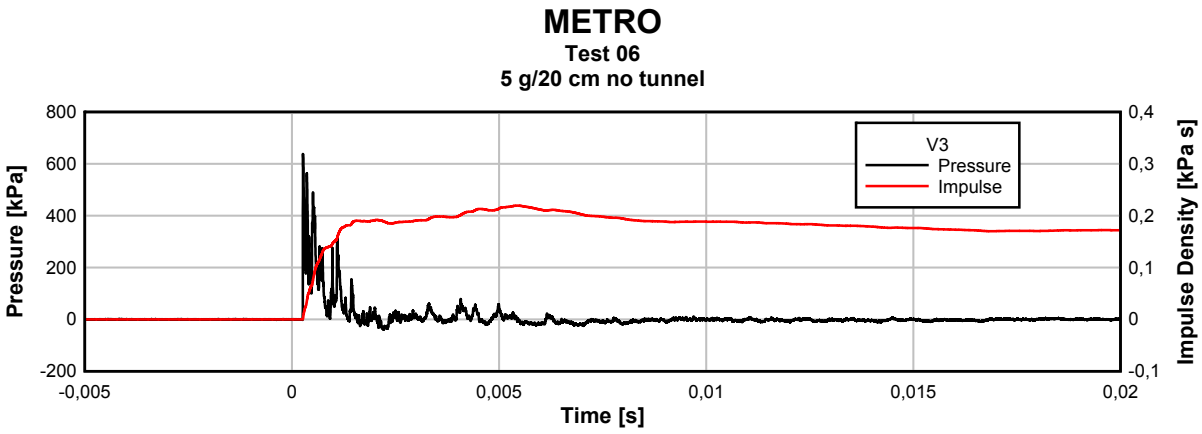
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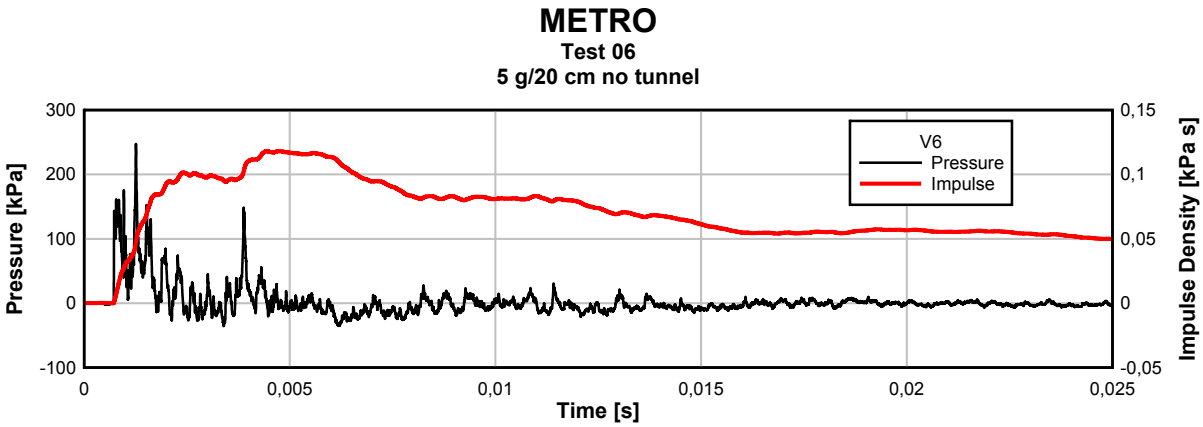
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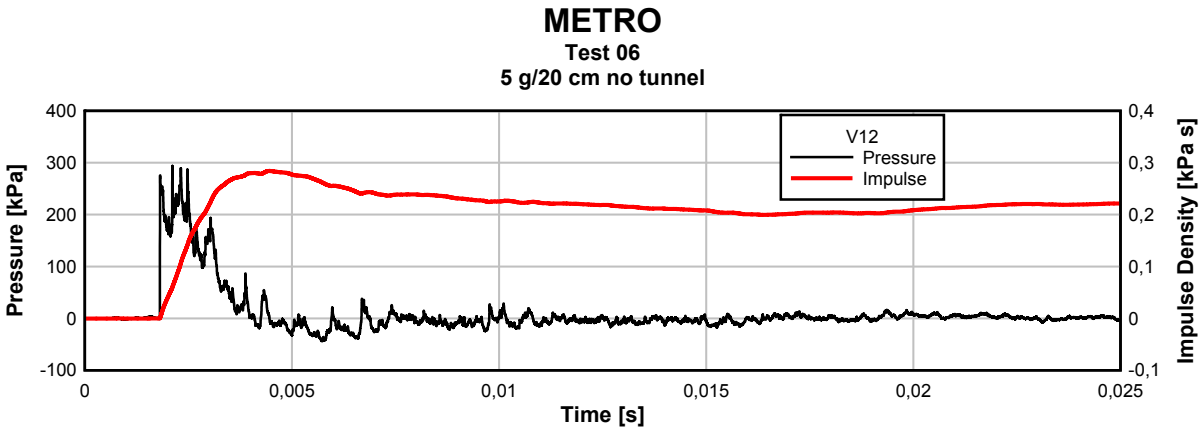
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Impulse Density [kPa s]
Time [s]
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Pressure
Impulse
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100
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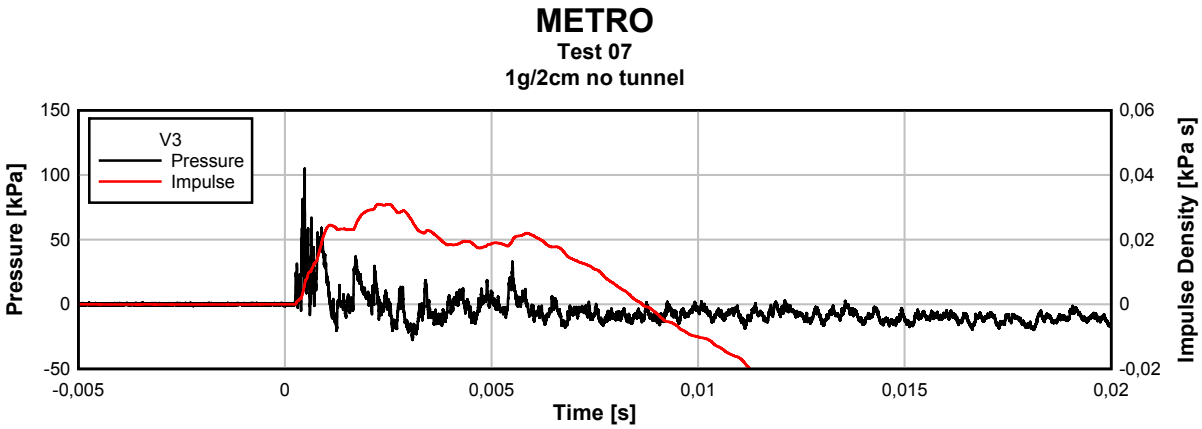
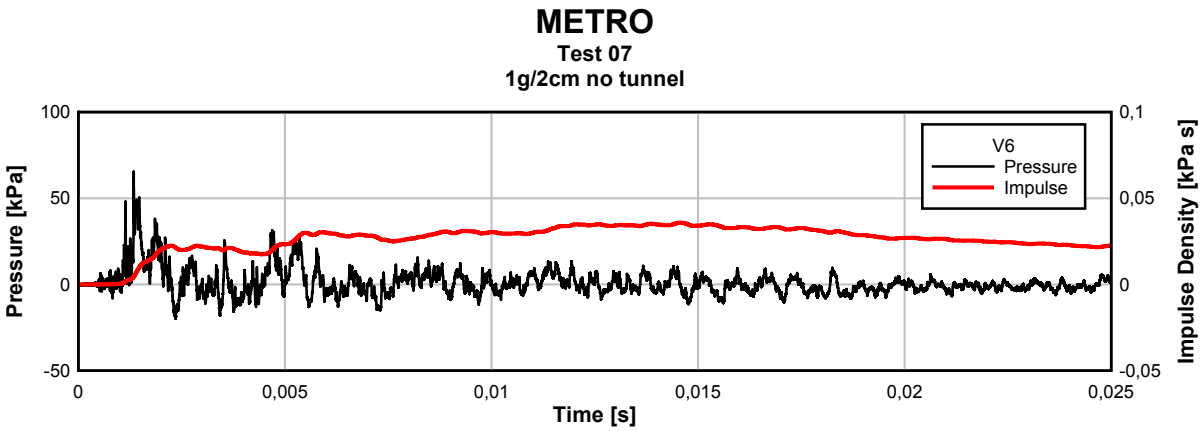
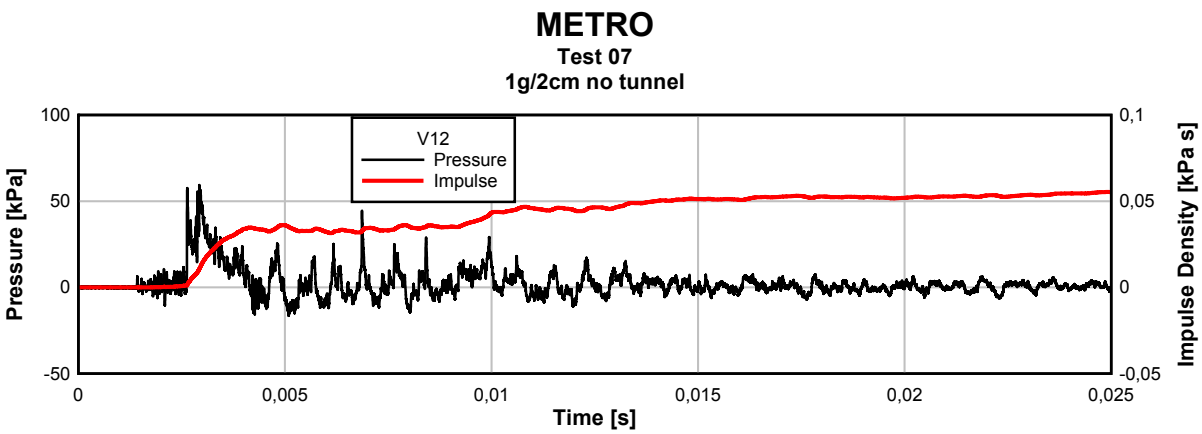
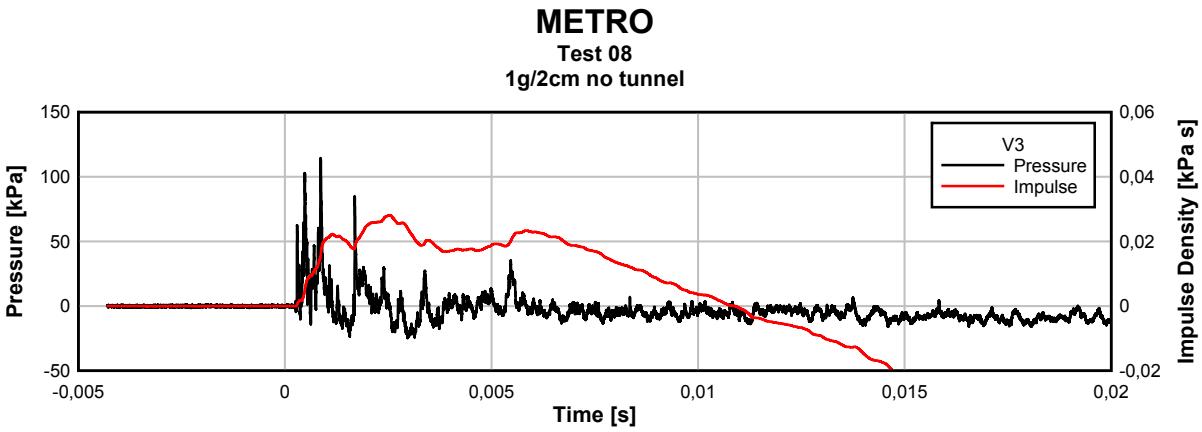
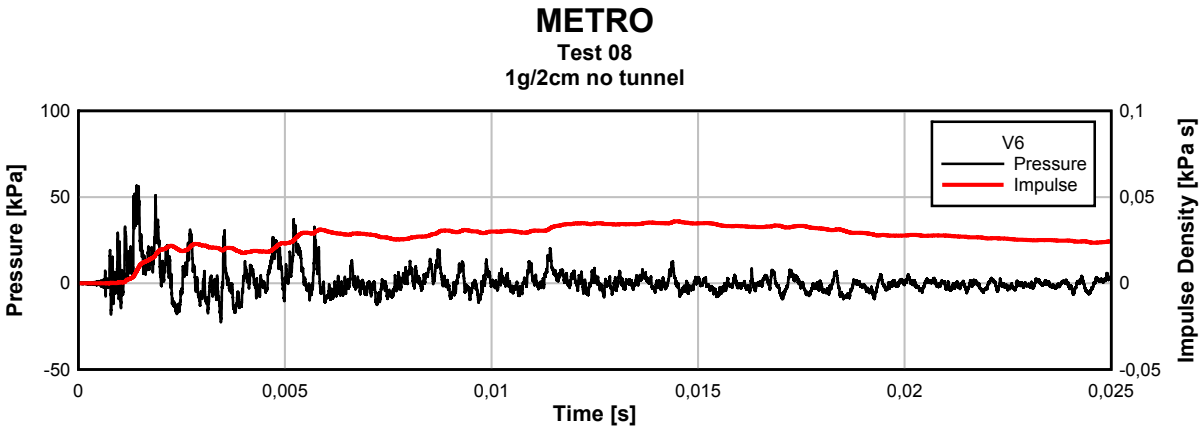
0,3
0,2
0,1
0
-0,1
0
0,005
0,01
0,015
0,02
0,025

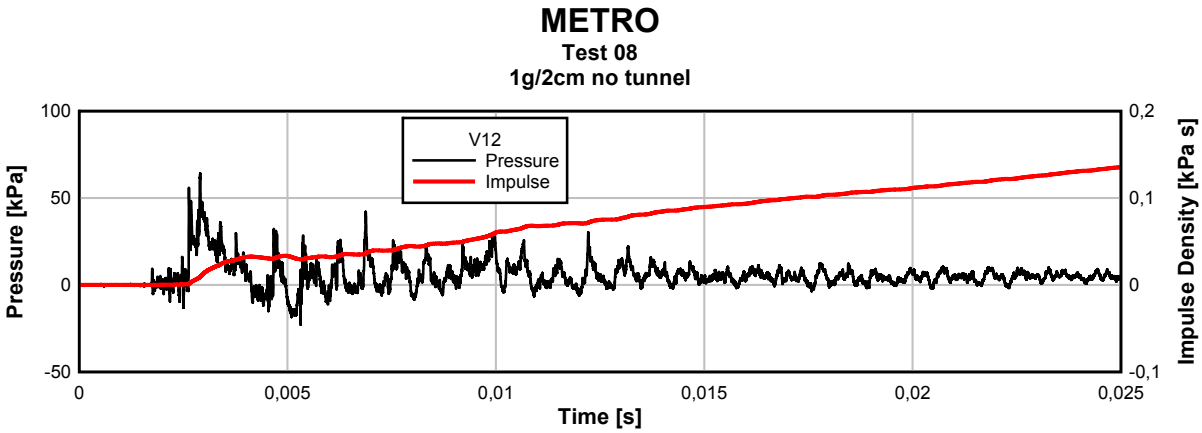

METRO
Test 07
1g/2cm no tunnel
V3
Pressure
Impulse
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
150
100
50
0
-50
0,06
0,04
0,02
0
-0,02
-0,005
0
0,005
0,01
0,015
0,02

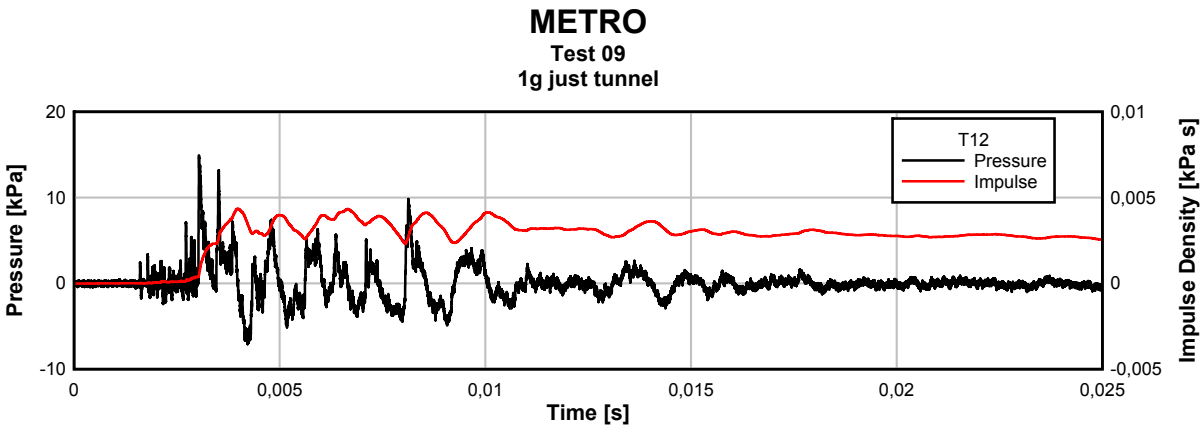

METRO
Test 07
1g/2cm no tunnel
V6
Pressure
Impulse
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
100
50
0
-50
0,1
0,05
0
-0,05
0
0,005
0,01
0,015
0,02
0,025

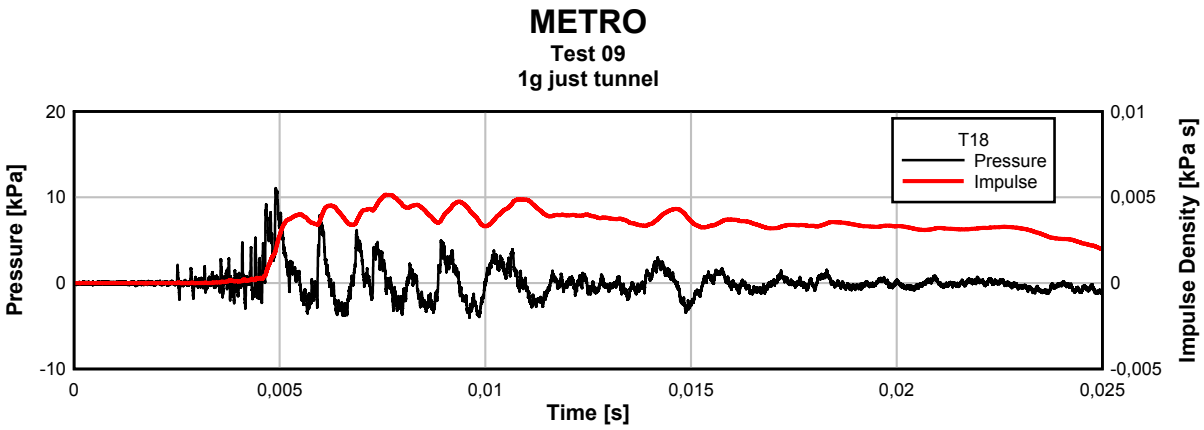

METRO
Test 07
1g/2cm no tunnel
V12
Pressure
Impulse
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
100
50
0
-50
0,1
0,05
0
-0,05
0
0,005
0,01
0,015
0,02
0,025

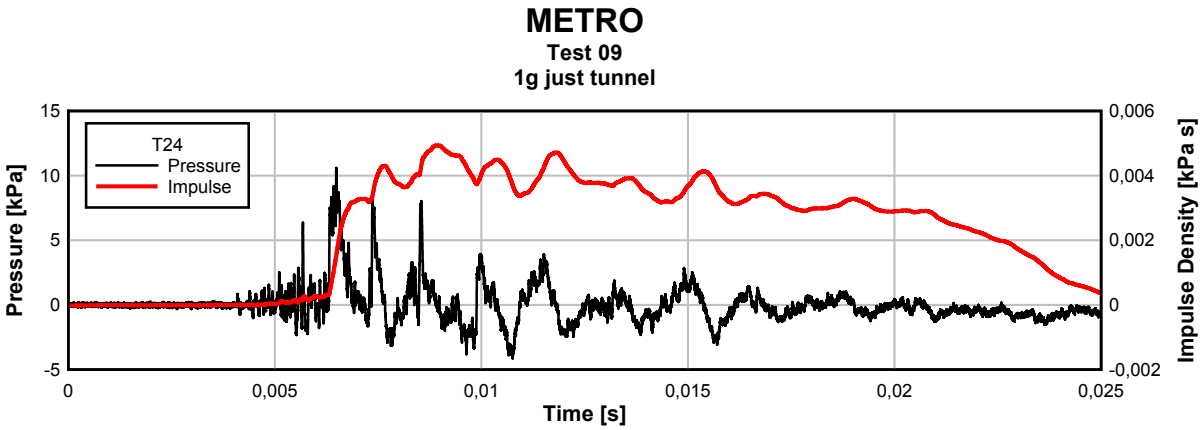

METRO
Test 08
1g/2cm no tunnel
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
V3
Pressure
Impulse
150
100
50
0
-50
0,06
0,04
0,02
0
-0,02
-0,005
0
0,005
0,01
0,015
0,02

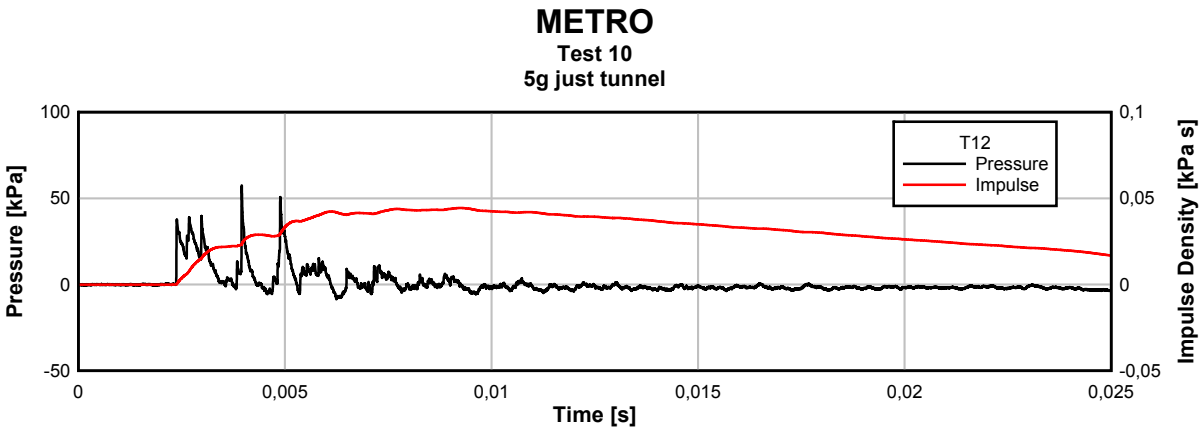

METRO
Test 08
1g/2cm no tunnel
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
V6
Pressure
Impulse
100
50
0
-50
0,1
0,05
0
-0,05
0
0,005
0,01
0,015
0,02
0,025

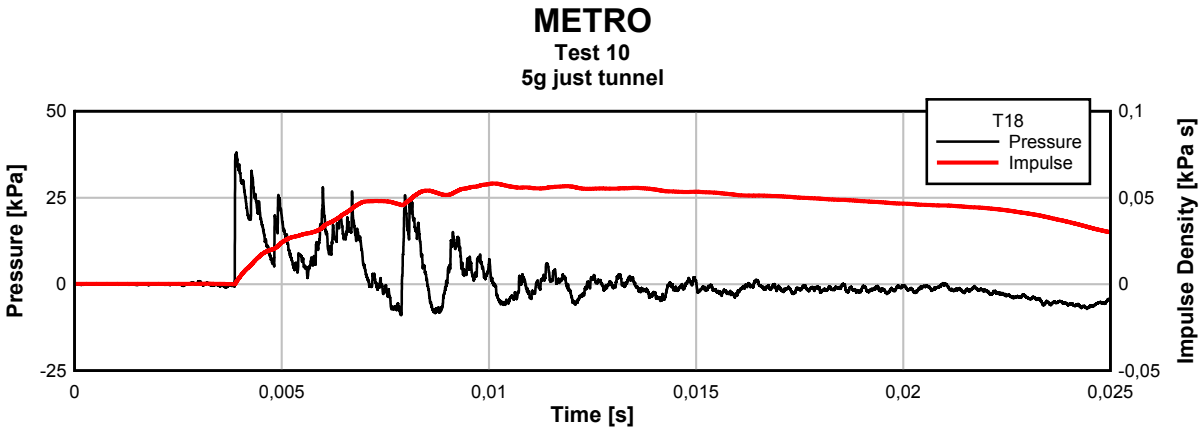

METRO
Test 08
1g/2cm no tunnel
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
V12
Pressure
Impulse
100
50
0
-50
0,2
0,1
0
-0,1
0
0,005
0,01
0,015
0,02
0,025

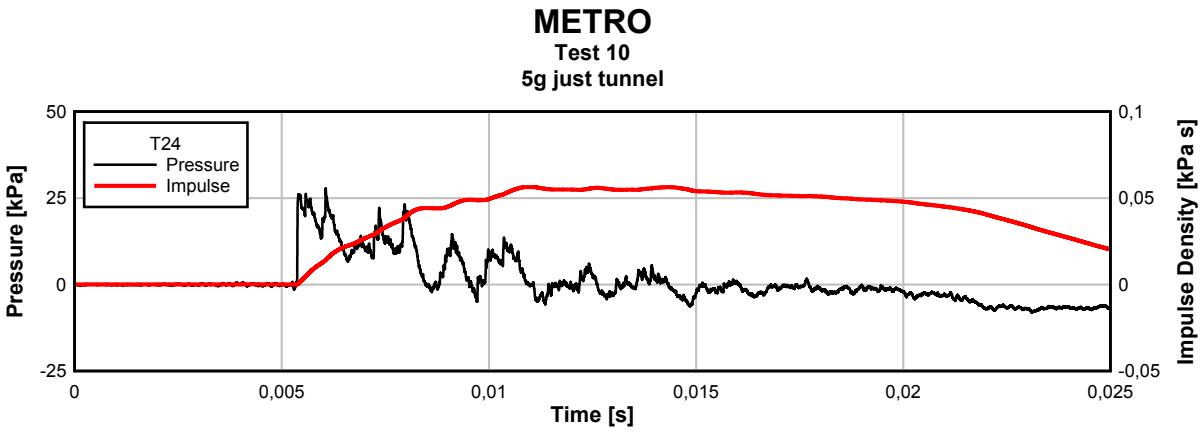

METRO
Test 09
1g just tunnel
T12
Pressure
Impulse
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
20
10
0
-10
0,01
0,005
0
-0,005
0
0,005
0,01
0,015
0,02
0,025

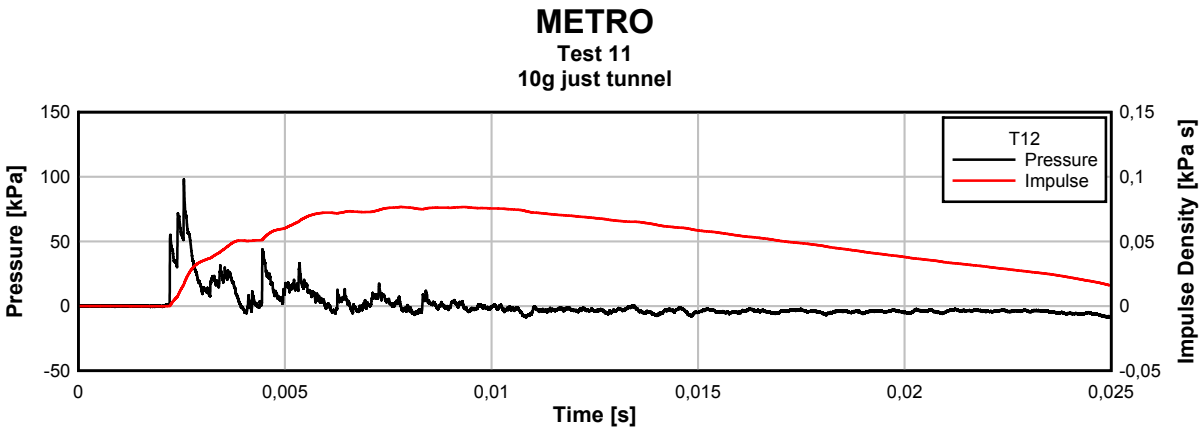

METRO
Test 09
1g just tunnel
T18
Pressure
Impulse
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
20
10
0
-10
0,01
0,005
0
-0,005
0
0,005
0,01
0,015
0,02
0,025

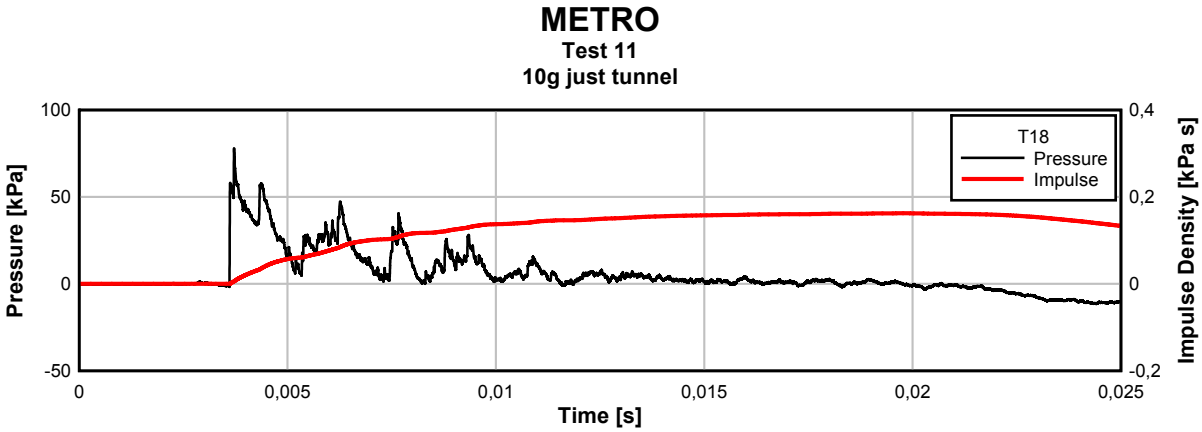

METRO
Test 09
1g just tunnel
T24
Pressure
Impulse
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
15
10
5
0
-5
0,006
0,004
0,002
0
-0,002
0
0,005
0,01
0,015
0,02
0,025

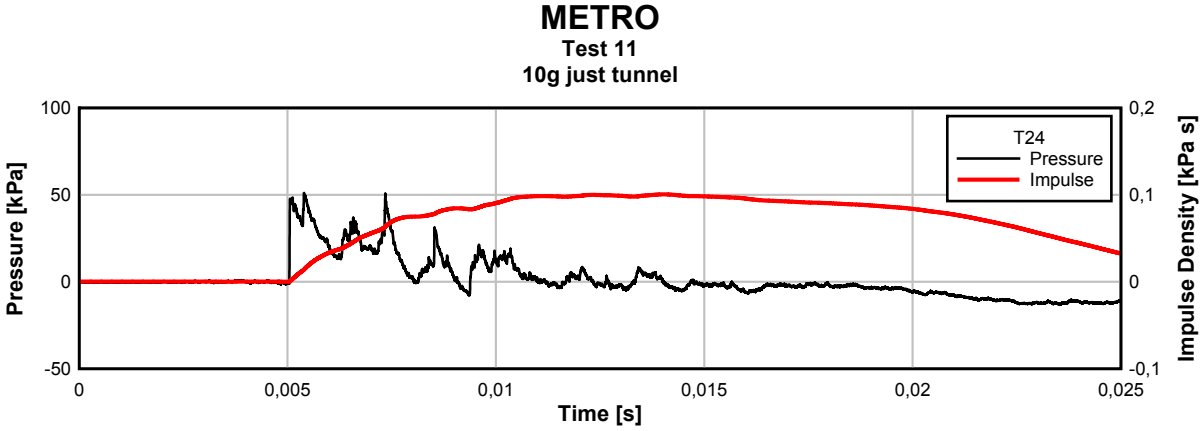

METRO
Test 10
5g just tunnel
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
T12
Pressure
Impulse
100
50
0
-50
0,1
0,05
0
-0,05
0
0,005
0,01
0,015
0,02
0,025

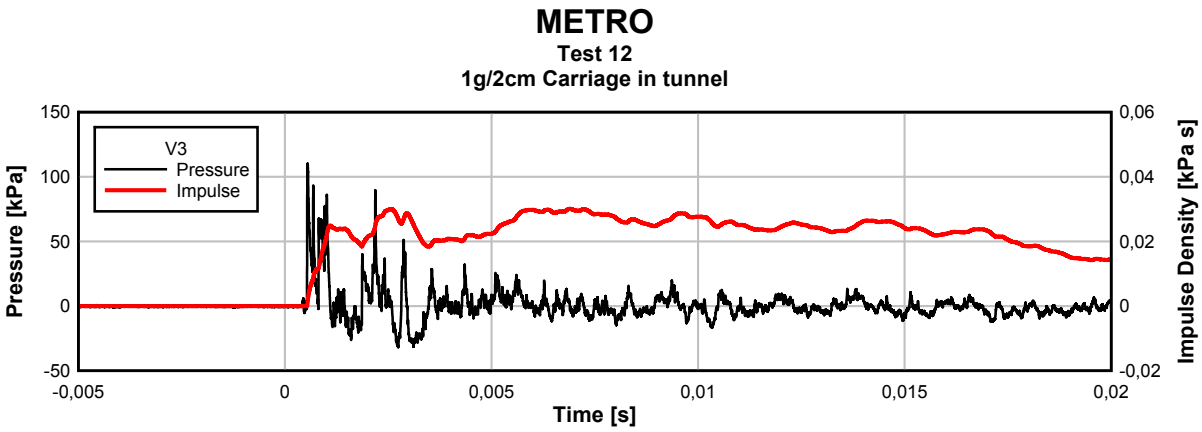

METRO
Test 10
5g just tunnel
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
T18
Pressure
Impulse
50
25
0
-25
0,1
0,05
0
-0,05
0
0,005
0,01
0,015
0,02
0,025

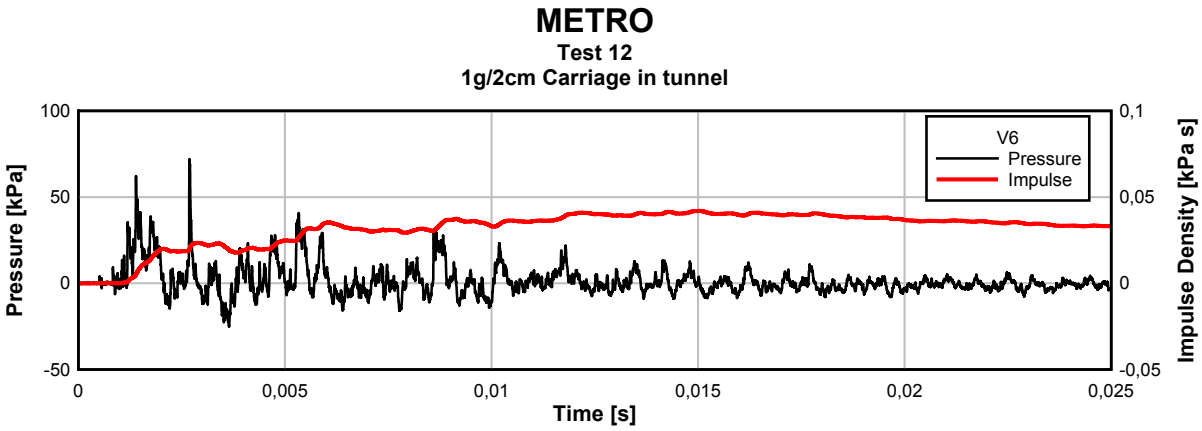

METRO
Test 10
5g just tunnel
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
T24
Pressure
Impulse
50
25
0
-25
0,1
0,05
0
-0,05
0
0,005
0,01
0,015
0,02
0,025

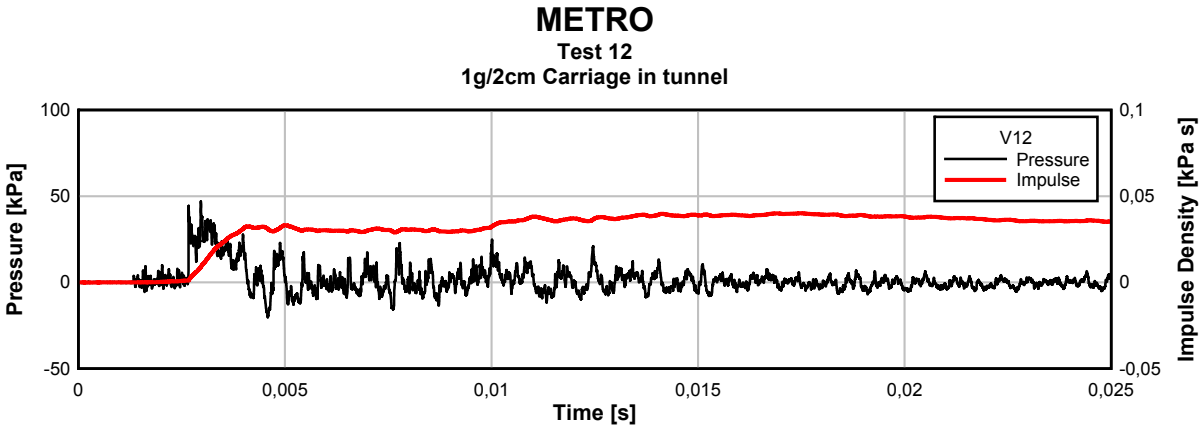

METRO
Test 11
10g just tunnel
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
T12
Pressure
Impulse
150
100
50
0
-50
0,15
0,1
0,05
0
-0,05
0
0,005
0,01
0,015
0,02
0,025

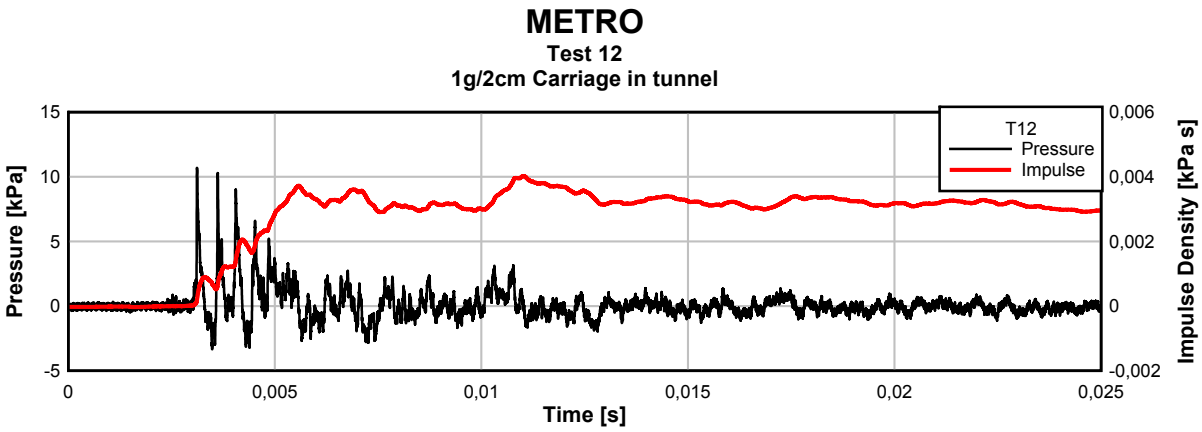

METRO
Test 11
10g just tunnel
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
T18
Pressure
Impulse
100
50
0
-50
0,4
0,2
0
-0,2
0
0,005
0,01
0,015
0,02
0,025

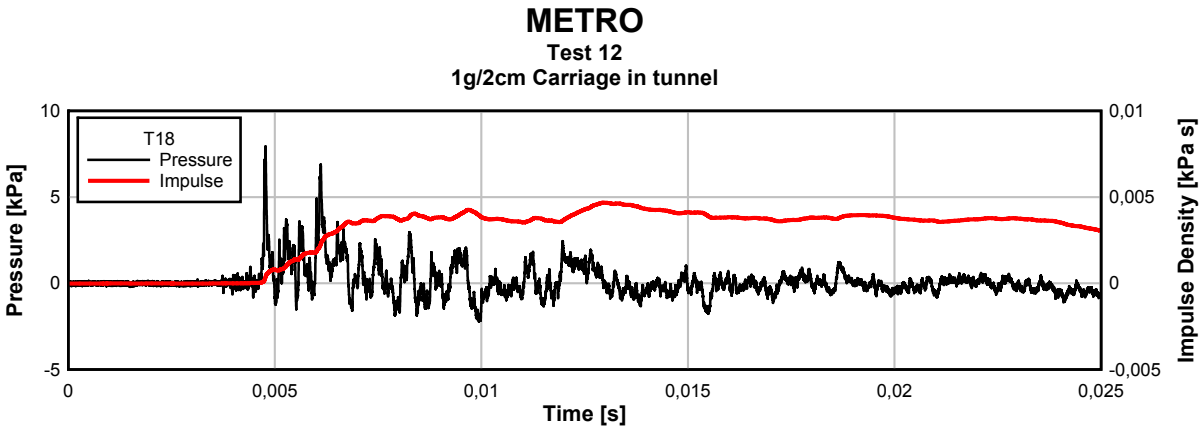

METRO
Test 11
10g just tunnel
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
T24
Pressure
Impulse
100
50
0
-50
0,2
0,1
0
-0,1
0
0,005
0,01
0,015
0,02
0,025

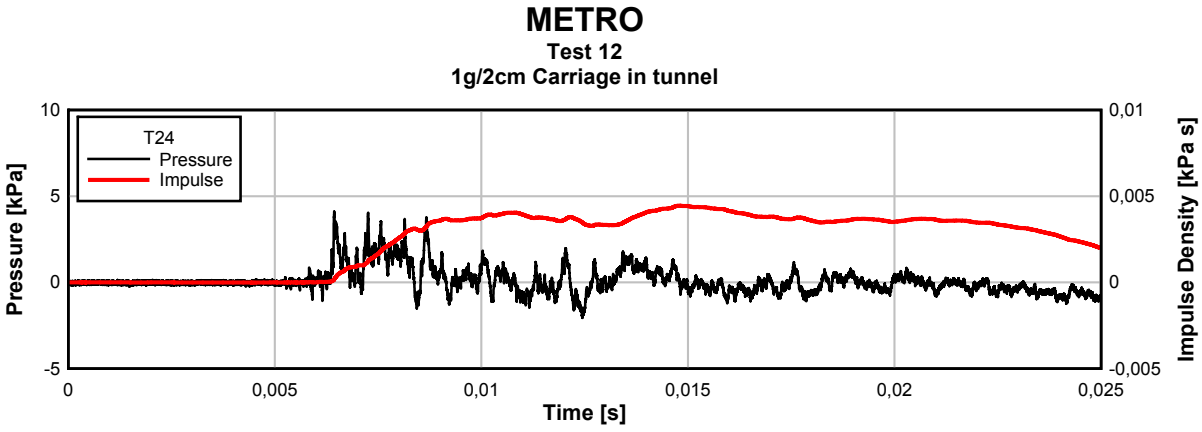

METRO
Test 12
1g/2cm Carriage in tunnel
V3
Pressure
Impulse
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
150
100
50
0
-50
0,06
0,04
0,02
0
-0,02
-0,005
0
0,005
0,01
0,015
0,02

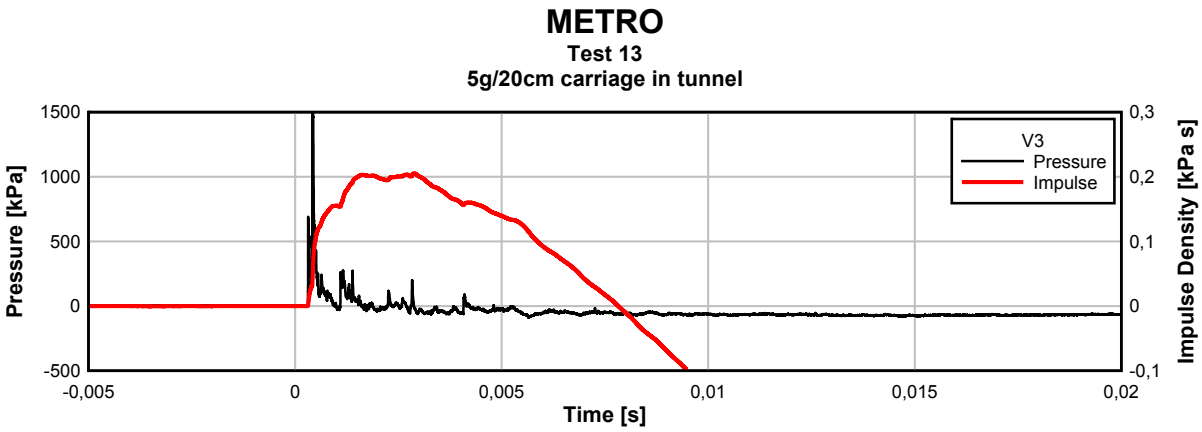

METRO
Test 12
1g/2cm Carriage in tunnel
V6
Pressure
Impulse
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
100
50
0
-50
0,1
0,05
0
-0,05
0
0,005
0,01
0,015
0,02
0,025

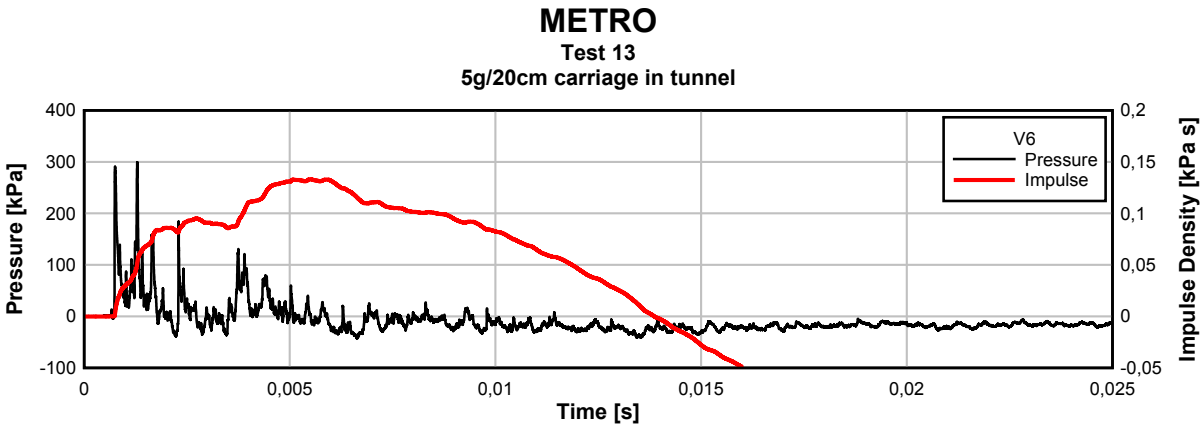

METRO
Test 12
1g/2cm Carriage in tunnel
V12
Pressure
Impulse
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
100
50
0
-50
0,1
0,05
0
-0,05
0
0,005
0,01
0,015
0,02
0,025

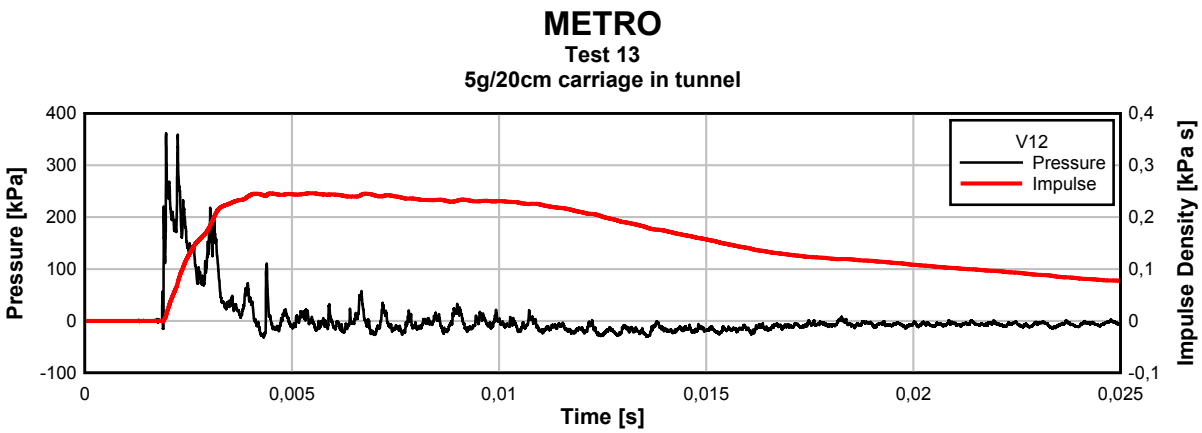

METRO
Test 12
1g/2cm Carriage in tunnel
T12
Pressure
Impulse
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
15
10
5
0
-5
0,006
0,004
0,002
0
-0,002
0
0,005
0,01
0,015
0,02
0,025

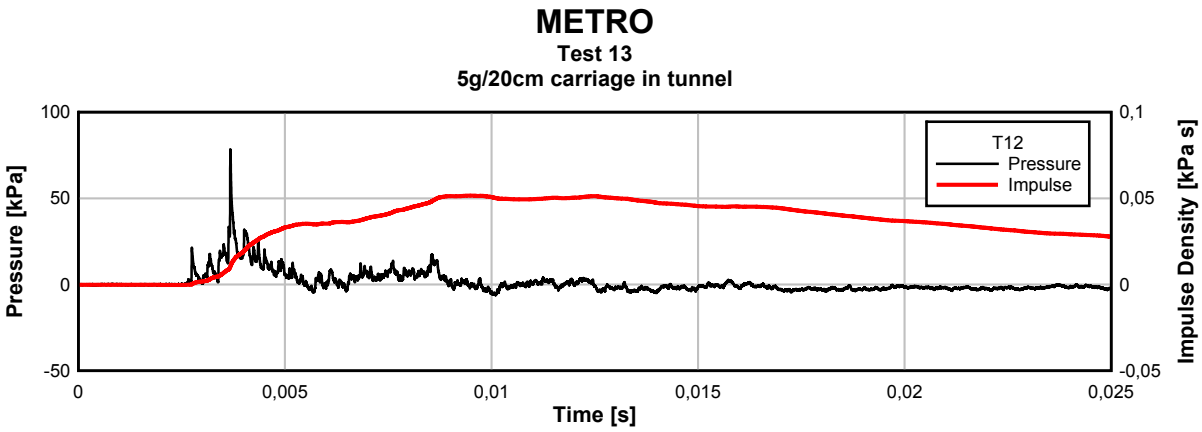

METRO
Test 12
1g/2cm Carriage in tunnel
T18
Pressure
Impulse
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
10
5
0
-5
0,01
0,005
0
-0,005
0
0,005
0,01
0,015
0,02
0,025

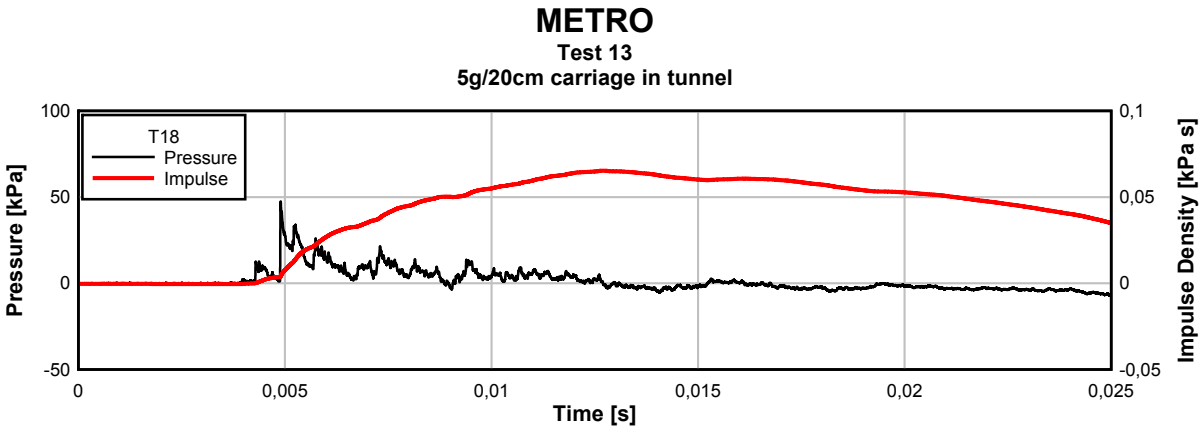

METRO
Test 12
1g/2cm Carriage in tunnel
T24
Pressure
Impulse
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
10
5
0
-5
0,01
0,005
0
-0,005
0
0,005
0,01
0,015
0,02
0,025

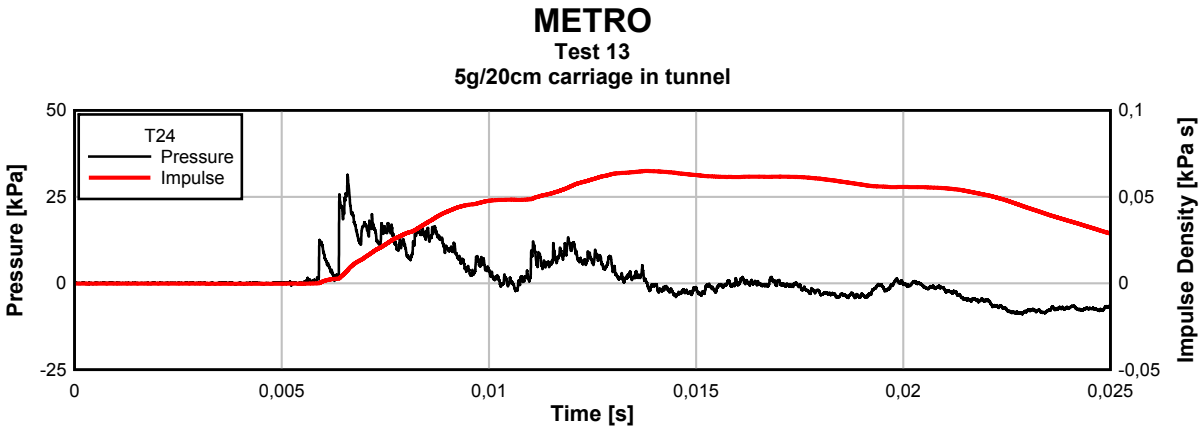

METRO
Test 13
5g/20cm carriage in tunnel
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
V3
Pressure
Impulse
1500
1000
500
0
-500
0,3
0,2
0,1
0
-0,1
-0,005
0
0,005
0,01
0,015
0,02

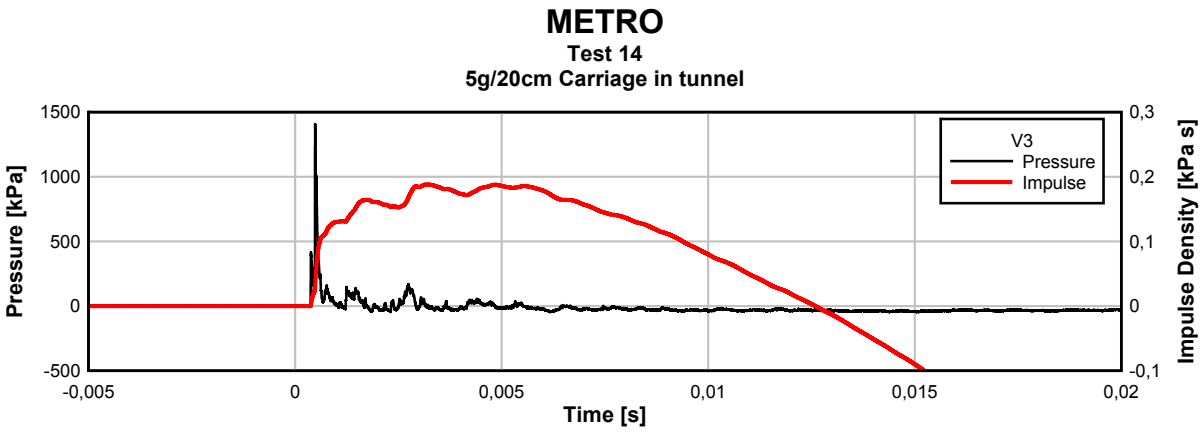

METRO
Test 13
5g/20cm carriage in tunnel
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
V6
Pressure
Impulse
400
300
200
100
0
-100
0,2
0,15
0,1
0,05
0
-0,05
0
0,005
0,01
0,015
0,02
0,025

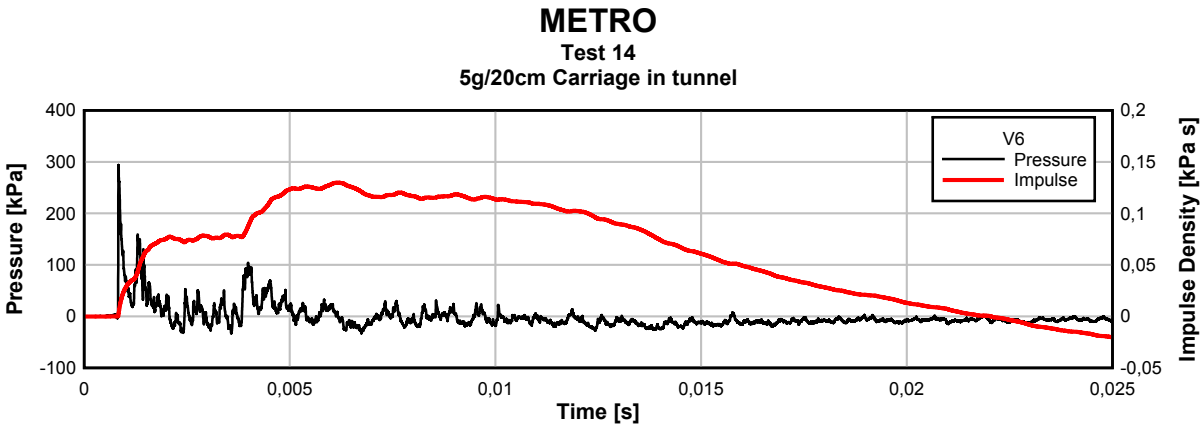

METRO
Test 13
5g/20cm carriage in tunnel
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
V12
Pressure
Impulse
400
300
200
100
0
-100
0,4
0,3
0,2
0,1
0
-0,1
0
0,005
0,01
0,015
0,02
0,025

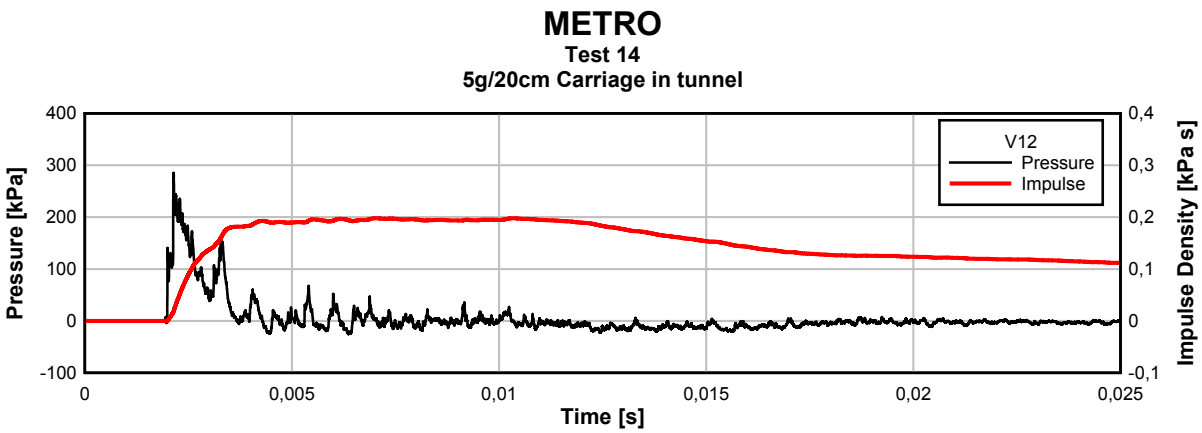

METRO
Test 13
5g/20cm carriage in tunnel
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
T12
Pressure
Impulse
100
50
0
-50
0,1
0,05
0
-0,05
0
0,005
0,01
0,015
0,02
0,025

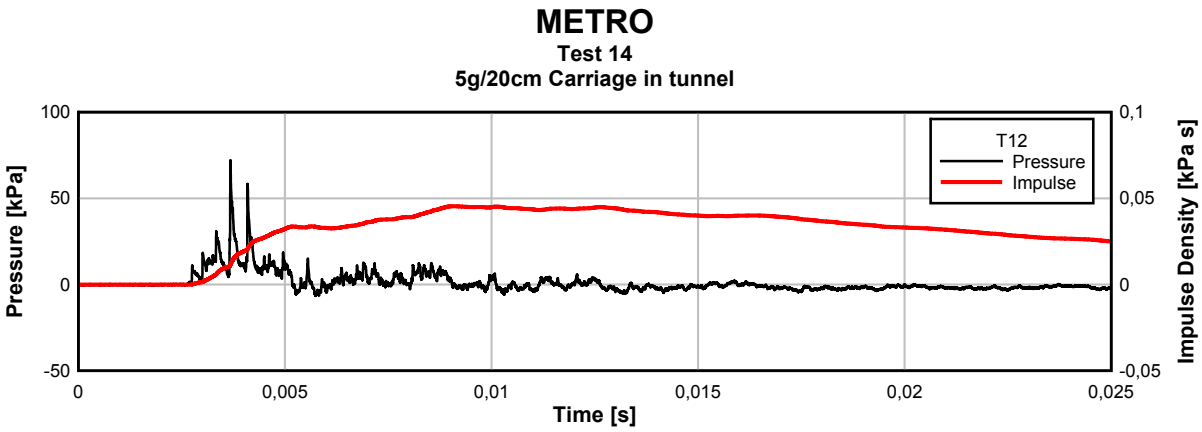

METRO
Test 13
5g/20cm carriage in tunnel
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
T18
Pressure
Impulse
100
50
0
-50
0,1
0,05
0
-0,05
0
0,005
0,01
0,015
0,02
0,025

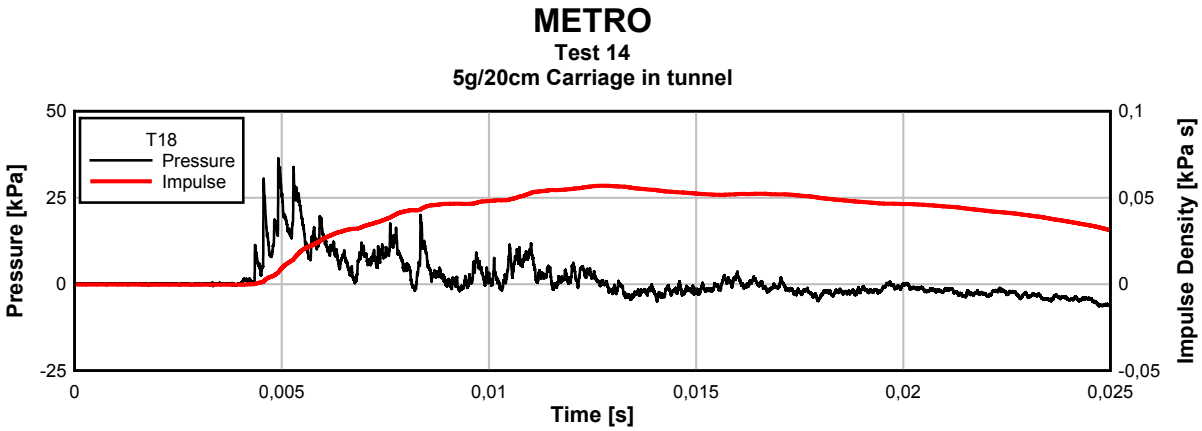

METRO
Test 13
5g/20cm carriage in tunnel
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
T24
Pressure
Impulse
50
25
0
-25
0,1
0,05
0
-0,05
0
0,005
0,01
0,015
0,02
0,025

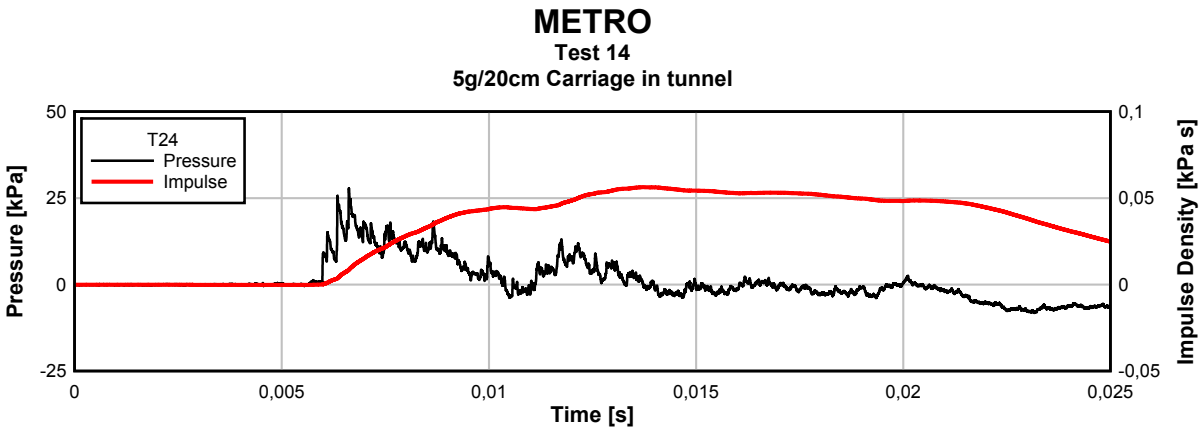

METRO
Test 14
5g/20cm Carriage in tunnel
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
V3
Pressure
Impulse
1500
1000
500
0
-500
0,3
0,2
0,1
0
-0,1
-0,005
0
0,005
0,01
0,015
0,02

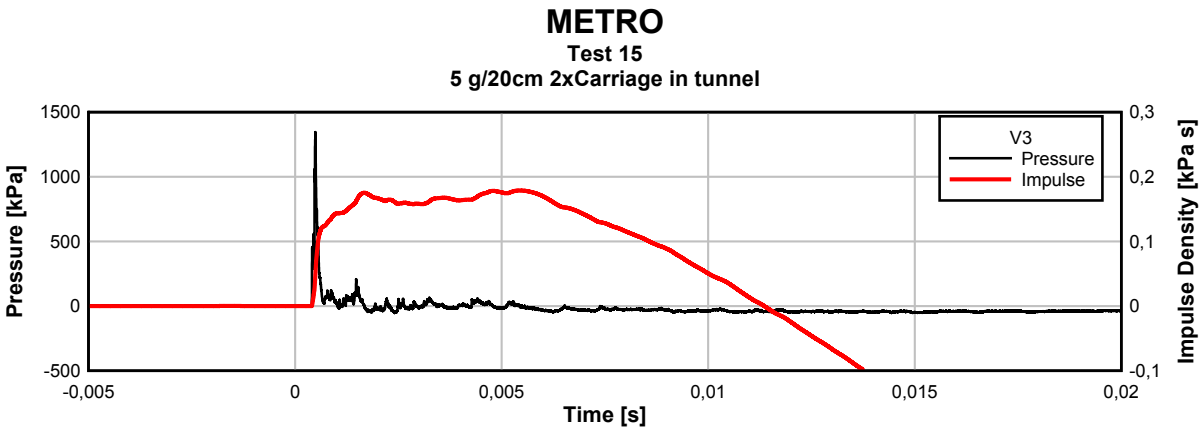

METRO
Test 14
5g/20cm Carriage in tunnel
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
V6
Pressure
Impulse
400
300
200
100
0
-100
0,2
0,15
0,1
0,05
0
-0,05
0
0,005
0,01
0,015
0,02
0,025

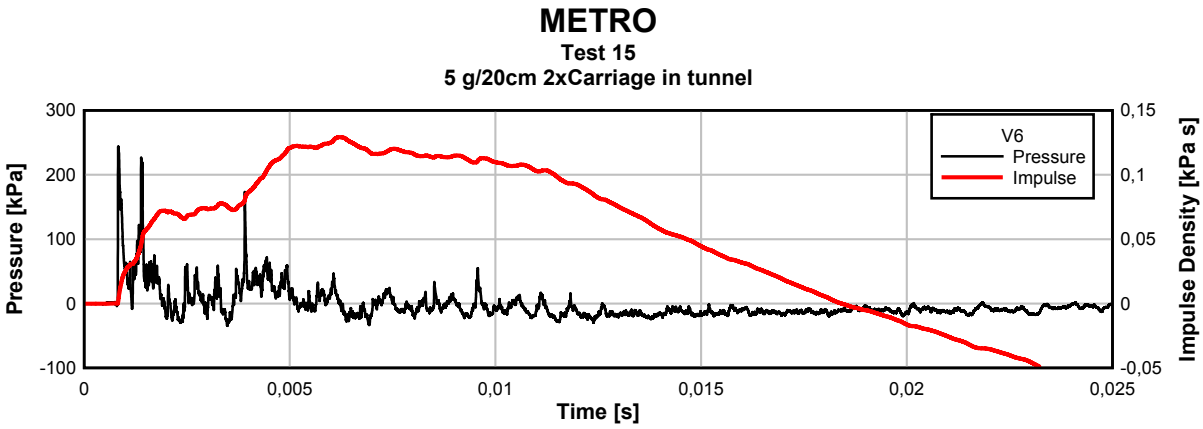

METRO
Test 14
5g/20cm Carriage in tunnel
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
V12
Pressure
Impulse
400
300
200
100
0
-100
0,4
0,3
0,2
0,1
0
-0,1
0
0,005
0,01
0,015
0,02
0,025

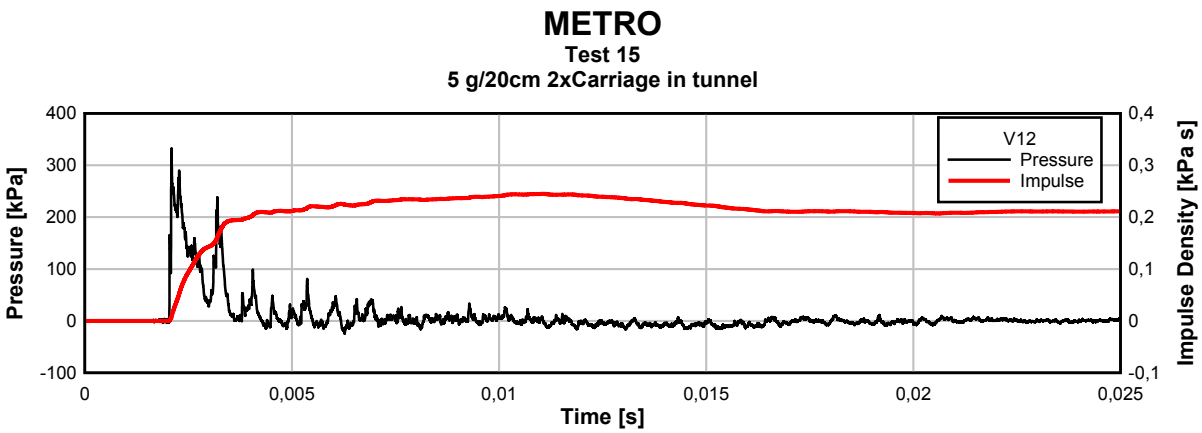

METRO
Test 14
5g/20cm Carriage in tunnel
T12
Pressure
Impulse
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
100
50
0
-50
0,1
0,05
0
-0,05
0
0,005
0,01
0,015
0,02
0,025

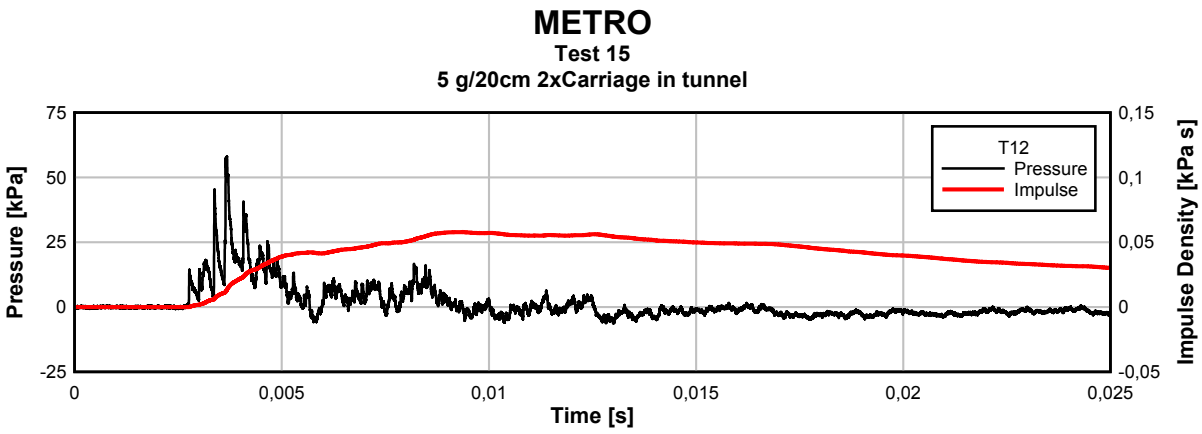

METRO
Test 14
5g/20cm Carriage in tunnel
T18
Pressure
Impulse
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
50
25
0
-25
0,1
0,05
0
-0,05
0
0,005
0,01
0,015
0,02
0,025

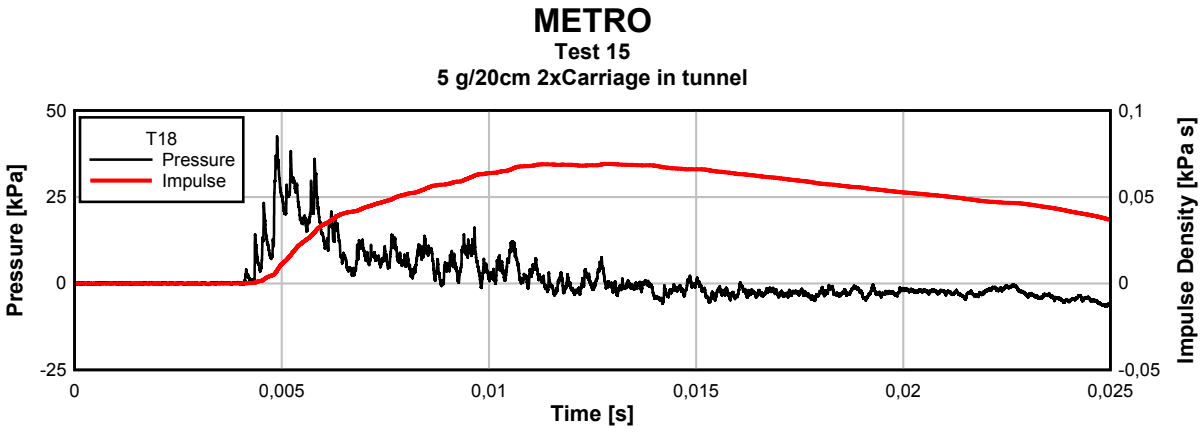

METRO
Test 14
5g/20cm Carriage in tunnel
T24
Pressure
Impulse
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
50
25
0
-25
0,1
0,05
0
-0,05
0
0,005
0,01
0,015
0,02
0,025

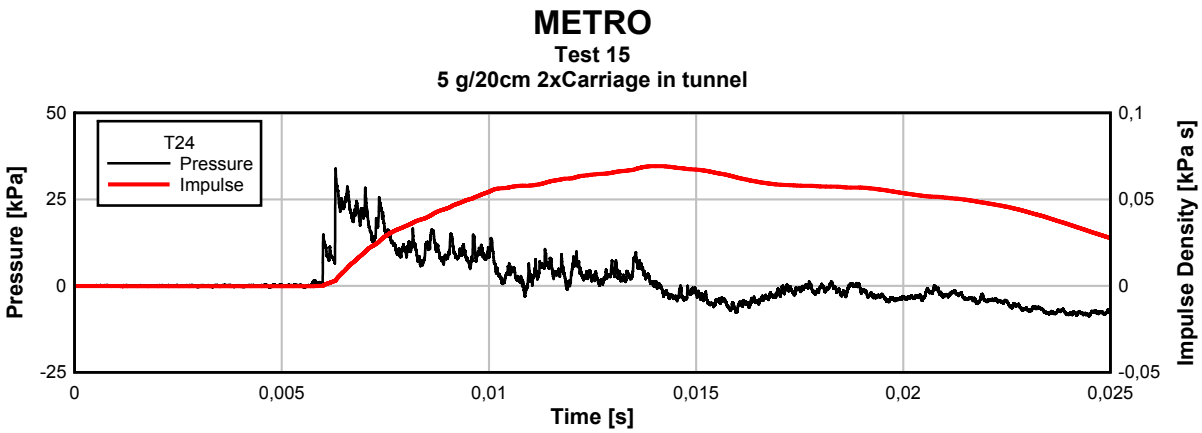

METRO
Test 15
5 g/20cm 2xCarriage in tunnel
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
V3
Pressure
Impulse
1500
1000
500
0
-500
0,3
0,2
0,1
0
-0,1
-0,005
0
0,005
0,01
0,015
0,02

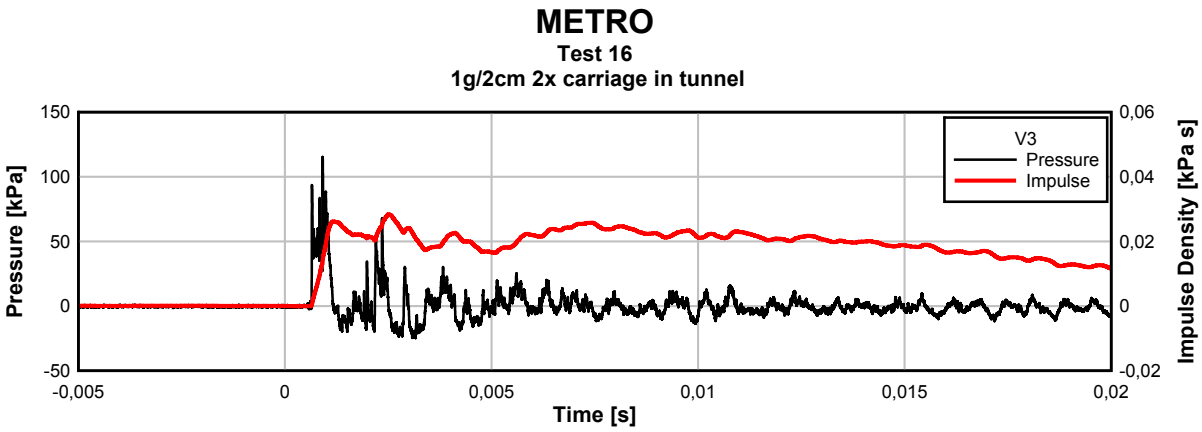

METRO
Test 15
5 g/20cm 2xCarriage in tunnel
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
V6
Pressure
Impulse
300
200
100
0
-100
0,15
0,1
0,05
0
-0,05
0
0,005
0,01
0,015
0,02
0,025

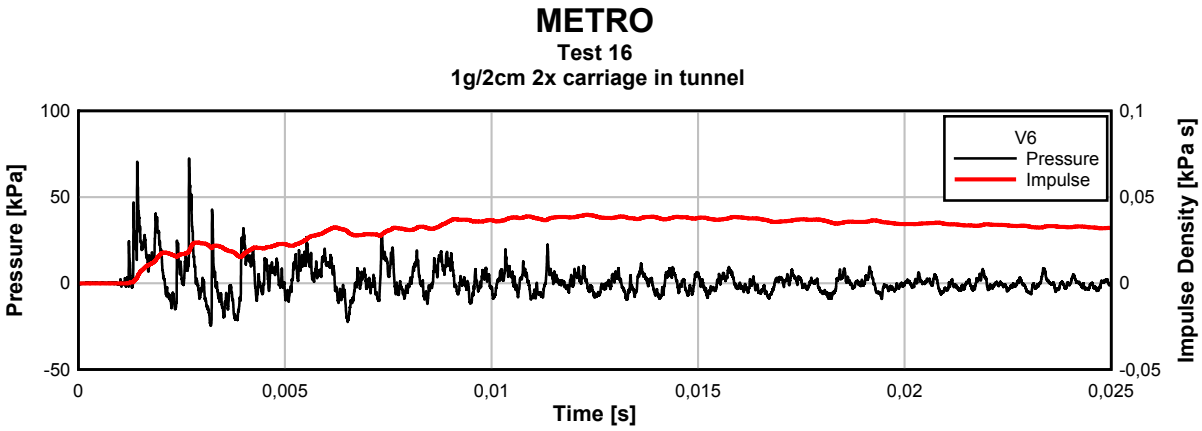

METRO
Test 15
5 g/20cm 2xCarriage in tunnel
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
V12
Pressure
Impulse
400
300
200
100
0
-100
0,4
0,3
0,2
0,1
0
-0,1
0
0,005
0,01
0,015
0,02
0,025

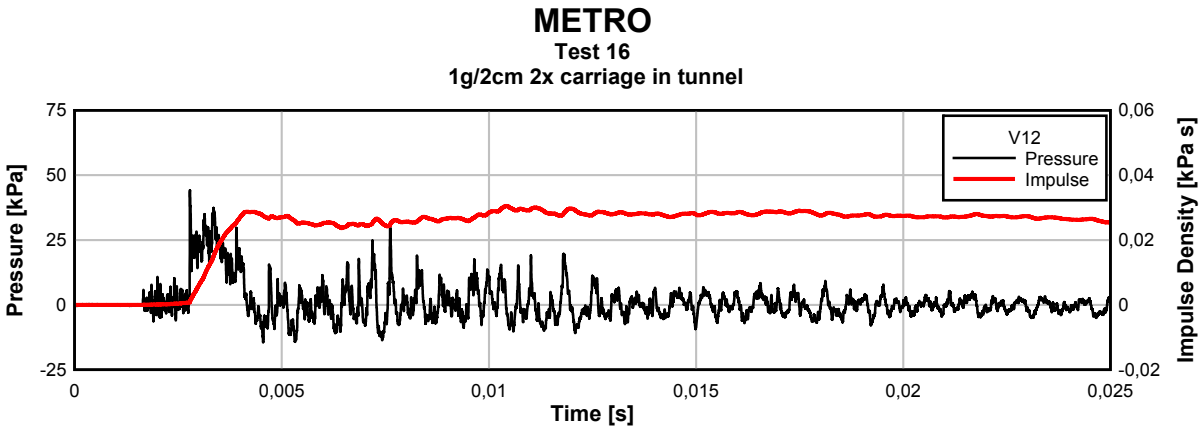

METRO
Test 15
5 g/20cm 2xCarriage in tunnel
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
T12
Pressure
Impulse
75
50
25
0
-25
0,15
0,1
0,05
0
-0,05
0
0,005
0,01
0,015
0,02
0,025

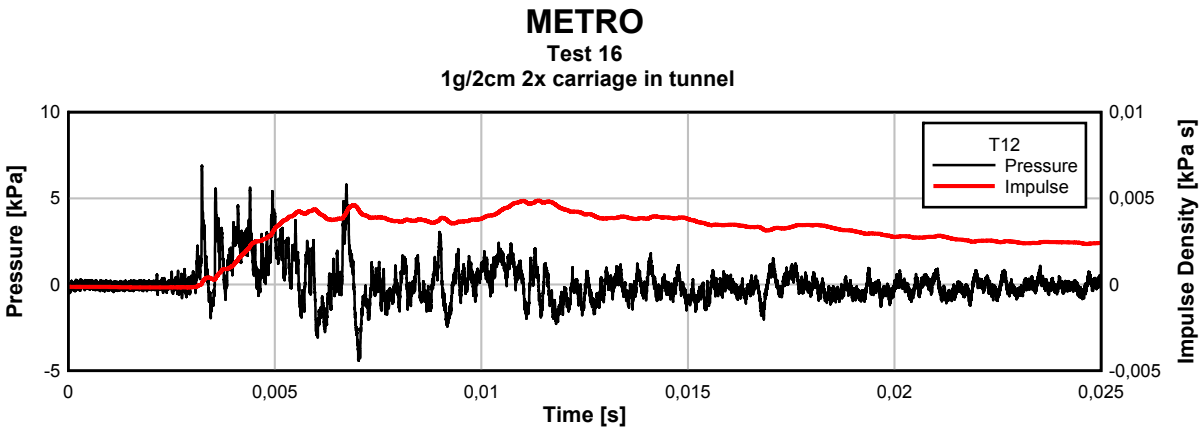

METRO
Test 15
5 g/20cm 2xCarriage in tunnel
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
T18
Pressure
Impulse
50
25
0
-25
0,1
0,05
0
-0,05
0
0,005
0,01
0,015
0,02
0,025

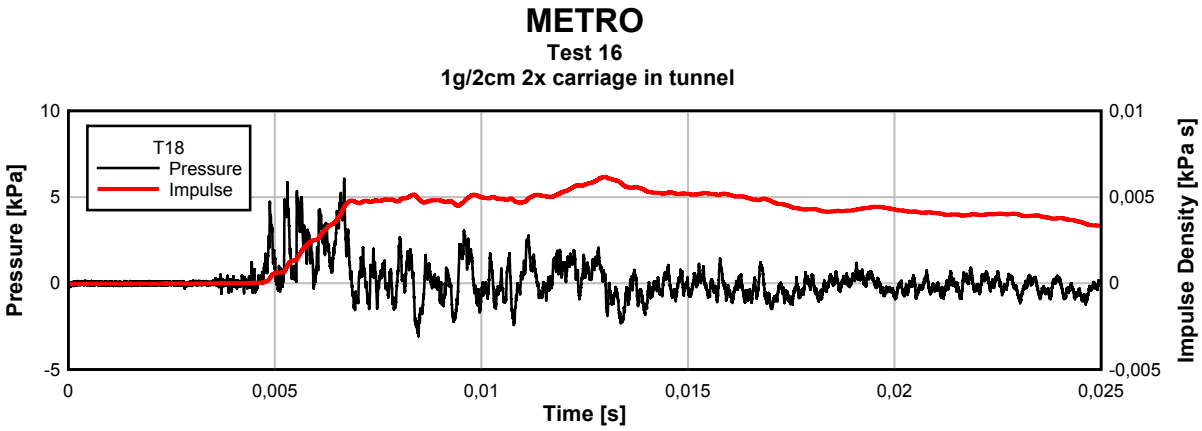

METRO
Test 15
5 g/20cm 2xCarriage in tunnel
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
T24
Pressure
Impulse
50
25
0
-25
0,1
0,05
0
-0,05
0
0,005
0,01
0,015
0,02
0,025

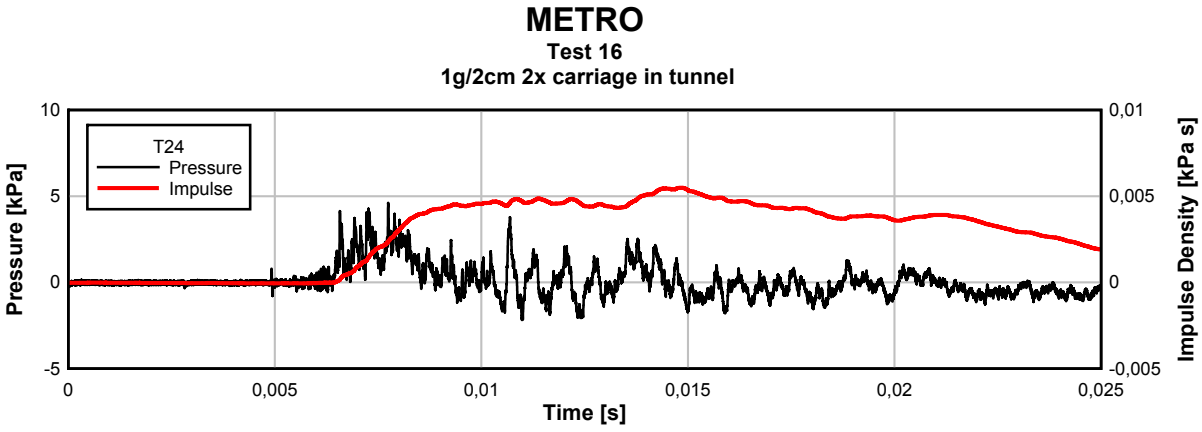

METRO
Test 16
1g/2cm 2x carriage in tunnel
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
V3
Pressure
Impulse
150
100
50
0
-50
0,06
0,04
0,02
0
-0,02
-0,005
0
0,005
0,01
0,015
0,02


METRO
Test 16
1g/2cm 2x carriage in tunnel
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
V6
Pressure
Impulse
100
50
0
-50
0,1
0,05
0
-0,05
0
0,005
0,01
0,015
0,02
0,025


METRO
Test 16
1g/2cm 2x carriage in tunnel
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
V12
Pressure
Impulse
75
50
25
0
-25
0,06
0,04
0,02
0
-0,02
0
0,005
0,01
0,015
0,02
0,025


METRO
Test 16
1g/2cm 2x carriage in tunnel
T12
Pressure
Impulse
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
10
5
0
-5
0,01
0,005
0
-0,005
0
0,005
0,01
0,015
0,02
0,025


METRO
Test 16
1g/2cm 2x carriage in tunnel
T18
Pressure
Impulse
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
10
5
0
-5
0,01
0,005
0
-0,005
0
0,005
0,01
0,015
0,02
0,025


METRO
Test 16
1g/2cm 2x carriage in tunnel
T24
Pressure
Impulse
Pressure [kPa]
Impulse Density [kPa s]
Time [s]
10
5
0
-5
0,01
0,005
0
-0,005
0
0,005
0,01
0,015
0,02
0,025