THE EFFECTS OF CASED AMMUNITION EXPLOSIONS CONFINED IN CONCRETE CUBICLES – KASUN-III

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ABSTRACT

The debris throw from explosively overloaded concrete structures has been a long time research effort of the KLOTZ Group, an international group of explosives safety experts. Two previous experimental programs, Kasun-I and Kasun-II, were performed with uncased explosive charges, and the results have been presented at earlier DDESB Explosives Safety Seminars.

The Kasun-III research program was initiated and funded by the KLOTZ Group, together with Norwegian and Swedish authorities, to study the influence of weapons casing on the failure mode of the structure and the debris mass distribution and dispersal in a combined theoretical, numerical and experimental approach. This paper deals with the experimental part of the research program.

Three tests with artillery shells and two tests with bare plastic explosives were done in 2008 in a joint Norwegian-Swedish effort. The tests resulted in a debris database of more than 21.500 entries, as well as detailed external blast pressure recordings. Debris densities and the relative contribution of concrete, reinforcement steel and weapon fragments to the debris inhabited building distance (IBD) can be determined from the debris database. Differences in structural breakup caused by the weapons fragments were documented with high speed cameras.

Even though only a limited number of tests have been performed, the obtained data is a valuable contribution to the current knowledge of detonation of cased charges inside concrete structures. The data also supports the continued development of the KLOTZ Group Engineering Tool for debris throw prediction.

1. INTRODUCTION

The detonation of explosives within a concrete structure can produce lethal debris thrown out to large distances. This debris can often be the most important hazard parameter following an accidental detonation. Within the KLOTZ Group (KG), an international group of experts on the safe storage of ammunition, the study of breakup, debris formation and debris throw has been a long term collaborative research effort between the member nations. Methodology and software (KG Engineering Tool) for predicting debris throw from concrete magazines (van Doormal et al. 2005) have been developed to this end. The methodology is based on state of the art knowledge and available test data from detonations within reinforced concrete structures.

Two previous test series, Kasun-I (Langberg et al. 2004) and Kasun-II (Berglund et al. 2006) have been focusing on the breakup, debris formation and debris dispersion from the use of uncased explosives in a concrete cubicle, now commonly known as a "Kasun". In an effort to expand the KG Engineering Tool to include storage of cased ammunition, KG has initiated and funded a theoretical/numerical and

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14. ABSTRACT
The debris throw from explosively overloaded concrete structures has been a long time research effort of the KLOTZ Group, an international group of explosives safety experts. Two previous experimental programs, Kasun-I and Kasun-II, were performed with uncased explosive charges, and the results have been presented at earlier DDESB Explosives Safety Seminars. The Kasun-III research program was initiated and funded by the KLOTZ Group, together with Norwegian and Swedish authorities, to study the influence of weapons casing on the failure mode of the structure and the debris mass distribution and dispersal in a combined theoretical, numerical and experimental approach. This paper deals with the experimental part of the research program. Three tests with artillery shells and two tests with bare plastic explosives were done in 2008 in a joint Norwegian-Swedish effort. The tests resulted in a debris database of more than 21.500 entries, as well as detailed external blast pressure recordings. Debris densities and the relative contribution of concrete, reinforcement steel and weapon fragments to the debris inhabited building distance (IBD) can be determined from the debris database. Differences in structural breakup caused by the weapons fragments were documented with high speed cameras. Even though only a limited number of tests have been performed, the obtained data is a valuable contribution to the current knowledge of detonation of cased charges inside concrete structures. The data also supports the continued development of the KLOTZ Group Engineering Tool for debris throw prediction.

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experimental programme (Kasun-III) to increase the knowledge on the influence by ammunition casing on structural breakup, debris formation and debris dispersion. The experimental programme was completed in Sweden in 2008 in a joint Norwegian-Swedish effort with additional instrumentation support from the Netherlands, and debris collection support from the Netherlands, Singapore and the US.

This paper gives an overview of the experimental setup, and briefly presents results concerning initial structural breakup, debris density and mass distribution of concrete debris which previously was presented by Grønsten et al. (2009, b). Also presented are debris masses of both rebars and shell casing fragments, debris number densities, horizontal launch angles and IBD distances due to fragments and debris (Grønsten et al. 2009, a).

2. TEST SET UP

The experimental setup followed closely that of the Kasun-II programme and with the same test structures (Kasun). The Kasuns are concrete cubicles with 8 m^3 internal volumes, and double reinforced walls and roof, originally designed for weapon storage (see Figure 1 and Table 1).

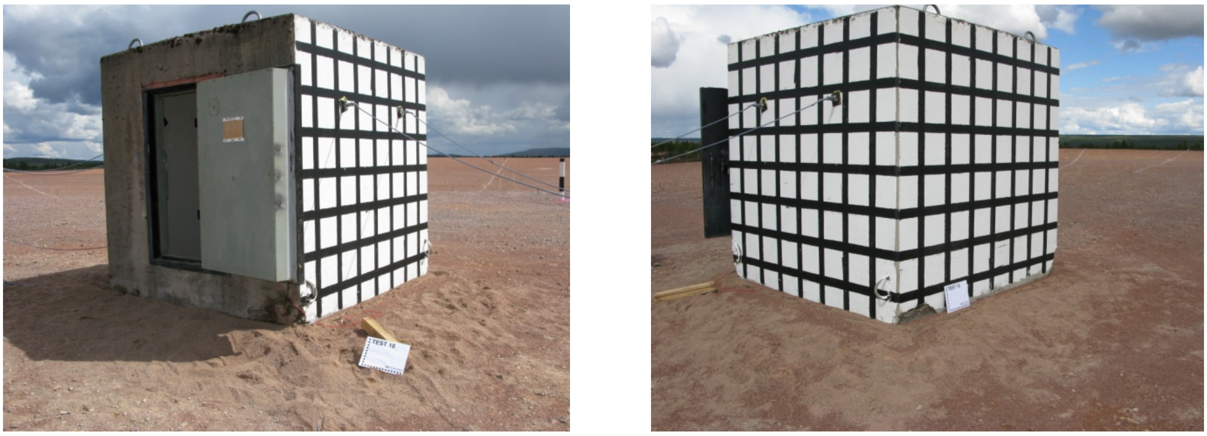


Figure 1. External view of the Kasun structure.

Table 1. Properties of the Kasun structure.

Wall thickness	0.15 m
Concrete quality	C35
Concrete compressive strength	48 MPa*
Reinforcement type	Doubly reinforced
Reinforcement dimension	12 mm
Reinforcement spacing	100 mm
External concrete cover	25 mm
Internal concrete cover	20 mm
Reinforcement strength	400 MPa (nominal)
Door opening	0.90 x 1.70 m
Structure total weight	approx. 11 ton

*) Mean value of the five Kasuns in the test series

The test series comprised five tests with 1, 4 and 16 pieces of 155 mm artillery shells in three separate tests and 6.9 kg and 110 kg bare plastic explosives in two reference tests (see Figure 2 and Table 2). The artillery shells were primed and detonated simultaneously.

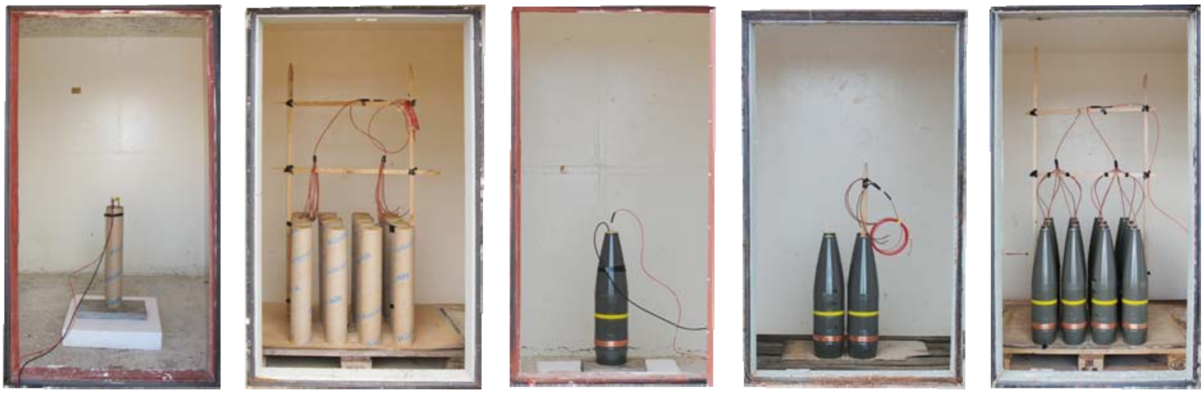


Figure 2. The charge configurations used in Kasun-III were 6.9 kg uncased, 100 kg uncased, one 155 mm shell, four 155 mm shells and sixteen 155 mm shells (from left to right).

Table 2. Kasun-III test series.

Test	**Charge type**	**Loading density [kg/m^3]**
6	6.9 kg uncased	0.9
7	110 kg uncased	13.8
8	1 x 155 mm shell	0.9
9	4 x 155 mm shells	3.5
10	16 x 155 mm shells	13.8

Digital high speed video cameras were used to capture the initial breakup and debris throw. Pressure gauges were installed along two radials from 20 m to 80 m to measure the incident blast pressure in the free field. Internal blast gauges were instrumented by TNO, the Netherlands (Van de Kasteele 2008). Following each test, debris were collected in collection zones extending from 20 m to 400 m covering azimuth angles -25º to 115º with respect to the rear wall normal. All recovered debris were individually weighed and catalogued. Concrete debris smaller than 0.050 kg and steel debris smaller than 0.011 kg were not catalogued.

3. RESULTS AND DISCUSSION

External blast pressure

Recorded incident blast peak pressures and impulse densities from external gauges were compared to calculated (BEC 2006) values for an open storage TNT charge with different equivalence factors[1]. Also results from previous test series, Kassun II (Berglund et al. 2006), were included. From the comparisons between calculated (BEC 2006) pressure and impulse density values and recorded during the tests, best fit equivalence factors were evaluated (Figure 3).

[1] With equivalence factor means the relation in weight between a charge detonating in the open and a charge detonating confined that gives the same maximum pressure or the same impulse density.

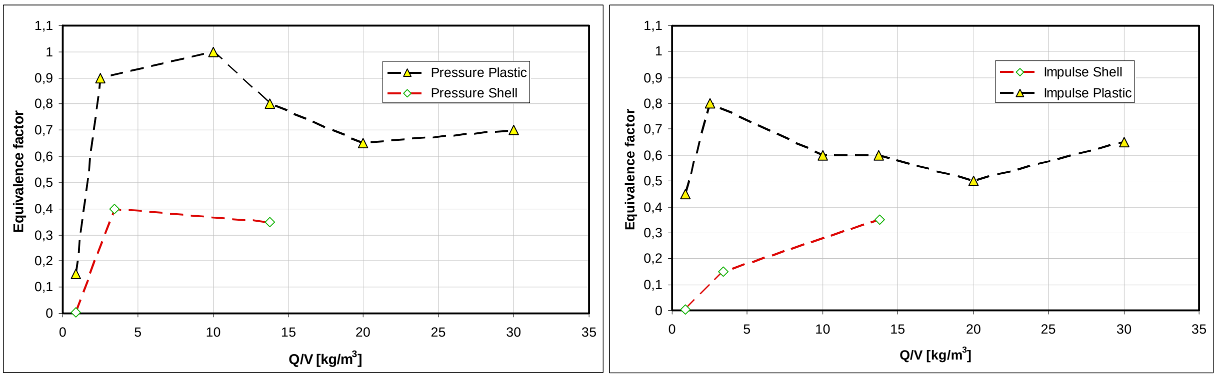


Figure 3. Evaluated equivalence factors based on maximum pressure (left) and impulse density (right) versus loading density (Q/V).

The results indicate that a charge which explodes contained in a concrete building as a Kasun will get a significantly lower equivalence factor if the charge consists of shells instead of uncased charges (Table 3).

Table 3. Evaluated equivalence factors.

Parameter	Charge type	Charge weight (kg)	Equivalence factor
Pressure	Uncased	6.9	0.15
		> 6.9	0.65 - 1
	Cased	6.9	0.001
		> 6.9	0.4
Impulse density	Uncased		0.45 - 0.8
	Cased	6.9	0.001
		> 6.9	0.15 – 0.35

Initial structural breakup

The high speed videos gave telling footage of the initial breakup of the Kasuns. With 6.9 kg uncased charge, the Kasun first failed along the wall-floor interface, followed by failure along the wall-wall joints starting from the floor and moving upwards. The breakup of the Kasun with one 155 mm shell was different, with severe cracking and subsequent complete breakup of the lowest part of the wall. Both the Kasun with 110 kg uncased charge and the Kasun with 16 x 155 mm shells showed the same dominant deflection in the central, lower part of the wall closest to the charges (Figure 4). As for the smaller uncased charge, the Kasun with 110 kg failed along the edges followed by venting of the detonation products. Again, the breakup of the Kasun with cased charges was different. Breaching and venting through the breached wall occurred before failure along the edges.

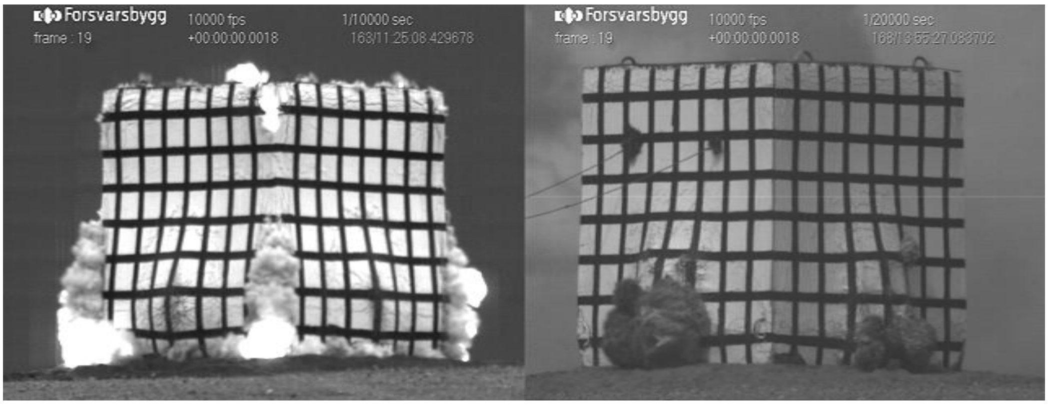


Figure 4. Early breakup of the Kasun with 110 kg uncased charge (left) and 16x155 mm shells (right).

Debris velocity

The breakup and disintegration of the Kasun resulted in massive amounts of debris being thrown out (Figure 5). A simplified procedure was applied to gain some insight into the overall distribution of the debris velocities. Some select individual debris were tracked on a frame-by frame basis in three zones; at the leading edge (fastest debris; I in Figure 5); around the main debris cloud (slowest debris, II) and in between I and II. A summary of the obtained velocities are listed in Table 4 and shown as a jittered plot in Figure 6.

Figure 5. Still images from the high speed video footage showing the debris throw from 6.9 kg uncased charge (left) and 1x155 mm shell (right). The images are at identical elapsed time since detonation.

Table 4. Summary of observed debris velocities.

Test	Charge	N*	Min. [m/s]	1st Quartile [m/s]	Median [m/s]	Mean [m/s]	3rd Quartile [m/s]	Max. [m/s]
6	6.9 kg	92	29	39	50	52	61	92
8	1 shell	81	26	31	36	38	43	58
7	110 kg	150	173	198	216	224	241	331
10	16 shells	205	74	114	139	165	191	423

z*) Number of evaluated debris pieces

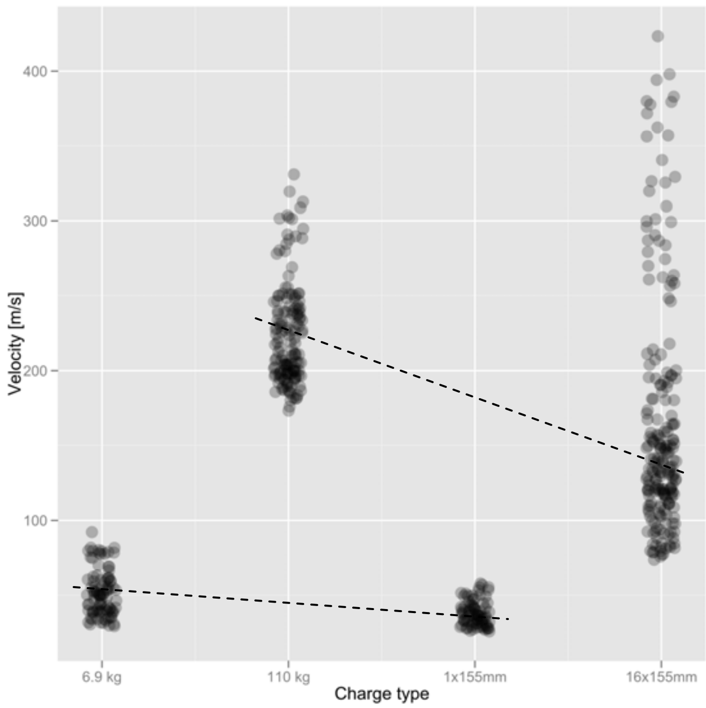


Figure 6. Jittered plot showing the variation of the debris velocity within each test. The dotted lines indicate the change of median velocities going from uncased to cased charges.

Although the data was limited, the results indicated that the median velocity of the observed debris decreased when using a cased charge. This seemed to hold true for both the single shell charge and 16 shells charge. The spread in the data was larger for the 16 shells charge than the 110 kg uncased charge (Figure 6).

Debris mass characteristics

Close to 21,500 debris pieces were collected, weighed and catalogued from the five tests. A summary of the recovered concrete debris is shown in Table 5. Going from a 6.9 kg uncased charge to one shell shifted the debris mass towards smaller masses as all quartile values were lower. The difference between cased and uncased charge at the highest loading density was small. Increasing loading density shifted the debris masses towards smaller masses for both uncased and cased charges, although the summary data were almost identical between a single shell charge and a four shell charge.

Table 5. Summary of recovered concrete debris masses.

Charge	**1st Quartile [10^{-3}kg]**	**Median [10^{-3}kg]**	**Mean [10^{-3}kg]**	**3rd Quartile [10^{-3}kg]**	**Max [10^{-3}kg]**
6.9 kg	79	138	310	328	5600
1 shell	68	109	206	216	4399
4 shells	69	107	203	220	4400
110 kg	61	81	118	127	1106
16 shells	61	83	118	132	910

The cumulative mass distribution, *N(>L)*, of the recovered concrete debris larger than 0.050 kg is shown in Figure 7, where the debris mass, *m*, has been converted to debris length according to the formula

$$L=(m/2400)^{(1/3)}$$

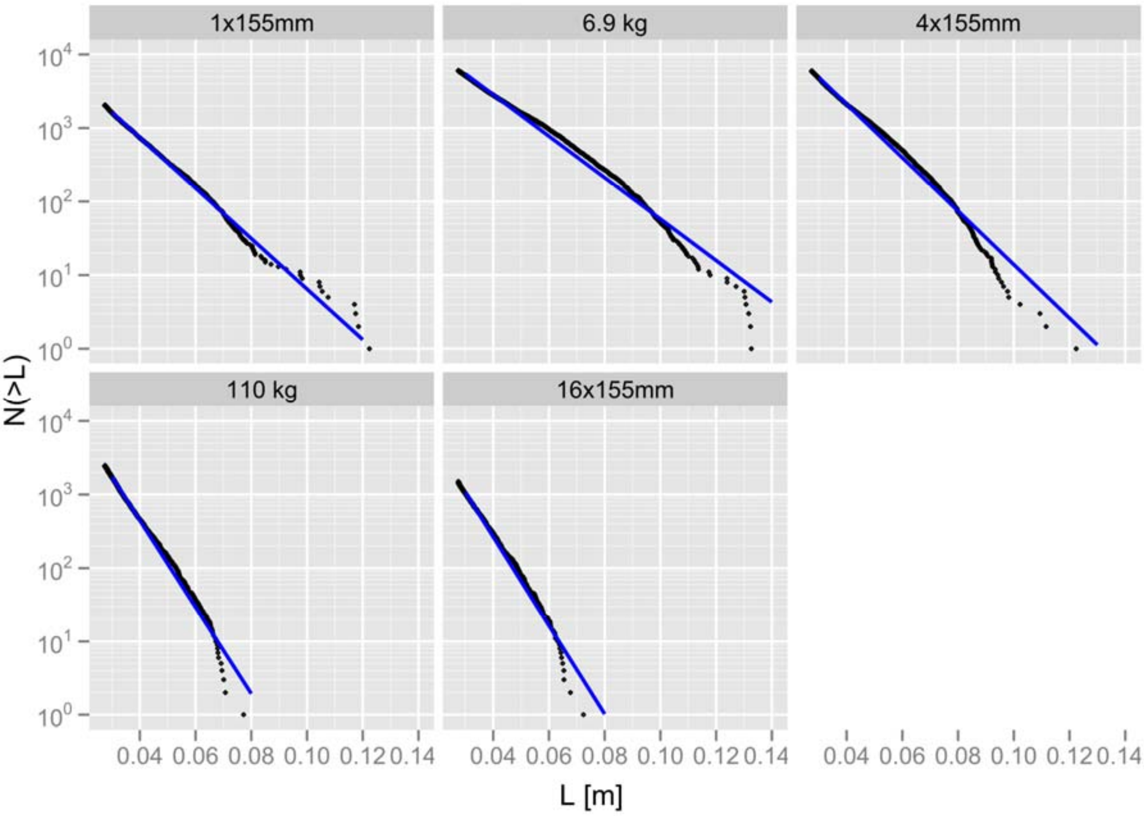


Figure 7. Cumulative mass distributions for concrete debris.

The cumulative mass distribution in terms of debris length, *L*, is often described by a function of the form

$$N(>L) = N_0 \bullet e^{-L/L_{char}}$$

where N_0 is the total number of debris and L_{char} is a scaling parameter. A weighted least square fit (van Doormal et al. 2005) to the data in Figure 7 yielded the coefficient listed in Table 6.

Table 6. Coefficients of weighted least square fit to cumulative mass distribution.

Charge	N_0	L_{char}
6.9 kg	38486	0.01540
110 kg	102654	0.00735
1x155 mm	17381	0.01265
4x155 mm	60409	0.01194
16x155 mm	71830	0.00718

The slope (-1/L_{char}) of the 110 kg uncased charge and the 16 shells charge were almost identical, but the total number of debris were fewer for the cased charge. A possible explanation could be related to the 0.050 kg lower limit in the debris recovery.

The total recovered debris mass (Table 7), showed a decreasing trend with increasing loading density (Figure 8).

Table 7. Total number of fragments N and total debris mass recovered.

Charge	**Concrete**		**Rebar**		**Casing**	
	N	***m* [kg]**	***N***	***m* [kg]**	***N***	***m* [kg]**
6.9 kg	6019	1864	114	260	-	-
1 shell	2054	424	24	64	22	0.6
4 shells	5957	1208	181	354	447	14.1
110 kg	2463	291	218	359	-	-
16 shells	1494	176	269	341	1876	66.6

Since we only catalogued concrete debris larger than 0.050 kg, and steel debris larger than 0.010 kg, an increasing proportion of the total generated debris would thus be unaccounted for. Hence, the total mass and total number of the collected debris would also be decreasing with increasing loading. This is consistent with the collection data.

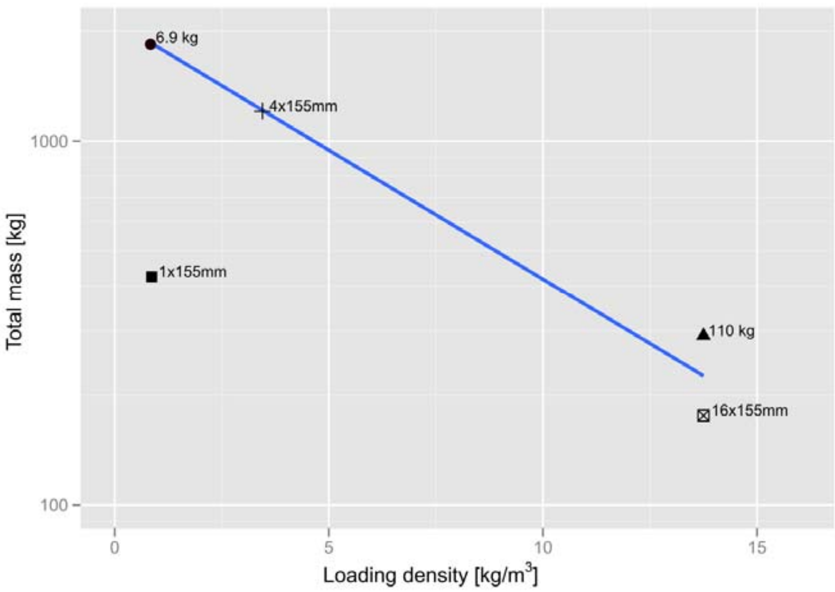


Figure 8. Total recovered mass versus loading density. An exponential line is fitted to the data with the one shell test ("1x155 mm") excluded.

The total recovered mass from the one shell test ("1x155 mm" in Figure 8) seemed anomalous compared to the other tests. However, large quantities of concrete with embedded rebar were found right next to the floor slab after the detonation (Figure 9). While concrete in the corner and edge areas were blown away, most of the roof concrete and large pieces of the upper section of the walls still remained. Considering also that the debris were collected from 20 m outwards, this would explain the smaller total mass in the one shell test.

Figure 9. Concrete from the roof and upper section of the walls found next to the floor slab in the one shell test.

Debris number density and horizontal launch angles

The debris dispersion was directionally dependent. The main bulk of the debris deposited in the sectors along the perpendiculars to the walls as shown in Figure 10. The debris density equals the number of debris found in a collection zone divided by the area of that collection zone.

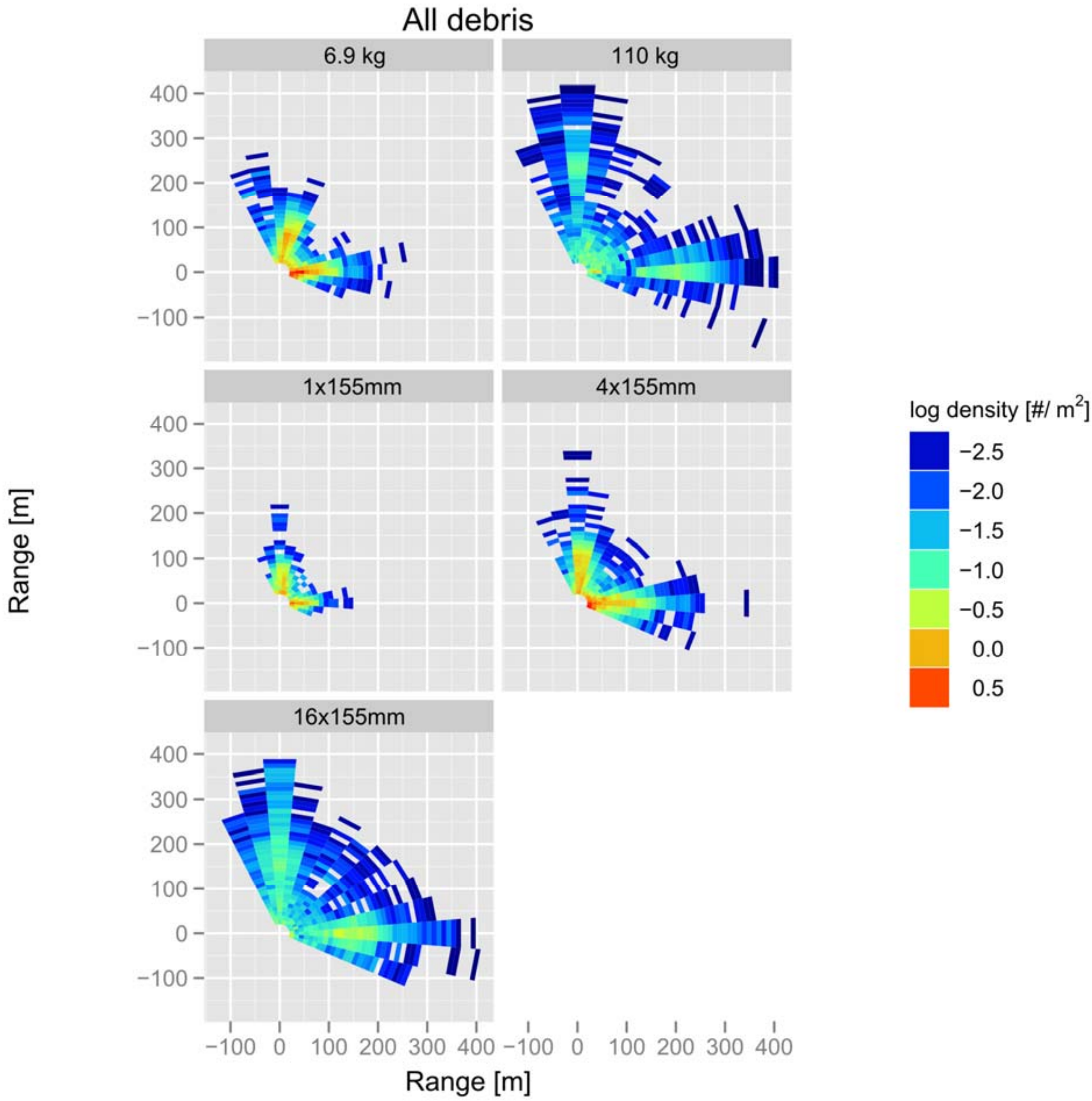


Figure 10. Total debris density (# /m²) in Test 6-10, as function of range from the Kasun. The Kasun was located at the origin (x=0, y=0) with the door facing to the left.

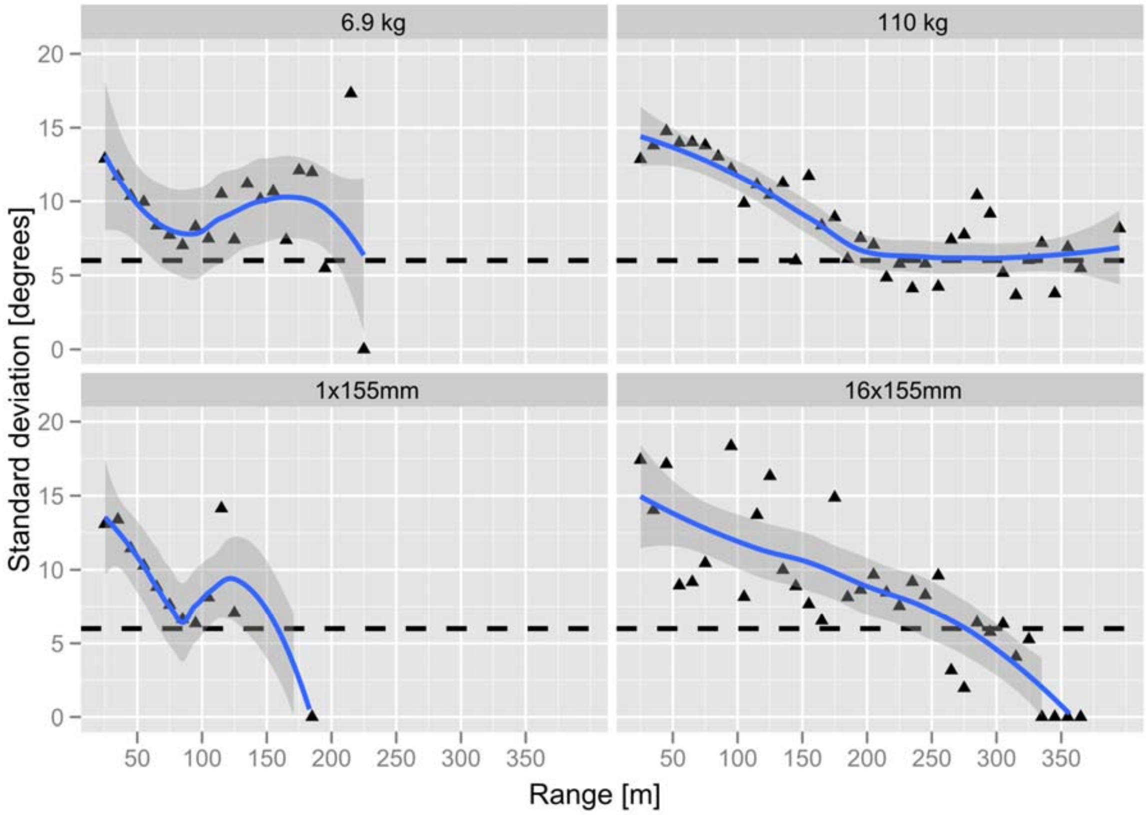
The mean horizontal launch angles and corresponding standard deviations for concrete debris as a function of distance along the rear and side wall normal were determined from the pickup data in the collection zones extending ±25° to each side of the normal (Table 8).

Table 8. Concrete debris horizontal launch angle properties.

Charge	**Rear wall**			**Side wall**		
	Mean launch angle[1)] [º]	**Standard deviation[1)] [º]**	***N*[2)]**	**Mean launch angle [º]**	**Standard deviation [º]**	***N***
6.9 kg	1.7	7.8	3401	-4.7	9.4	2232
110 kg	2.7	7.5	1217	-0.4	8.7	899
1 shell	1.4	8.0	873	-3.4	8.9	1018
4 shells	-0.8	8.8	3518	-5.0	8.1	2039
16 shells	-0.2	8.7	848	-0.1	8.4	535

[1)] Averaged over all distances
[2)] Number of debris evaluated

The horizontal launch angle standard deviations were higher at distances closer to the Kasun than farther out, which was most likely caused by the wider debris deposition pattern of the roof debris (Figure 11). The averaged values of standard deviation in each direction were slightly higher than the KG-ET assumption of a 6º standard deviation in the horizontal launch angle.



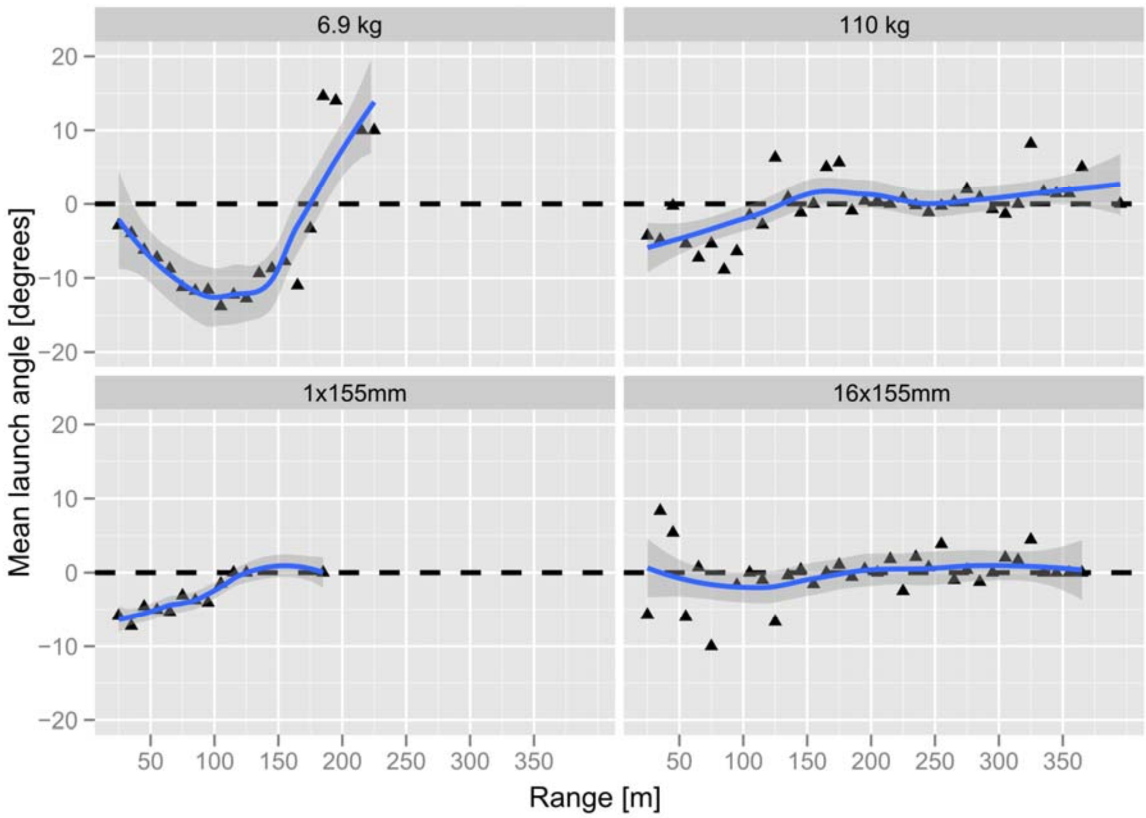
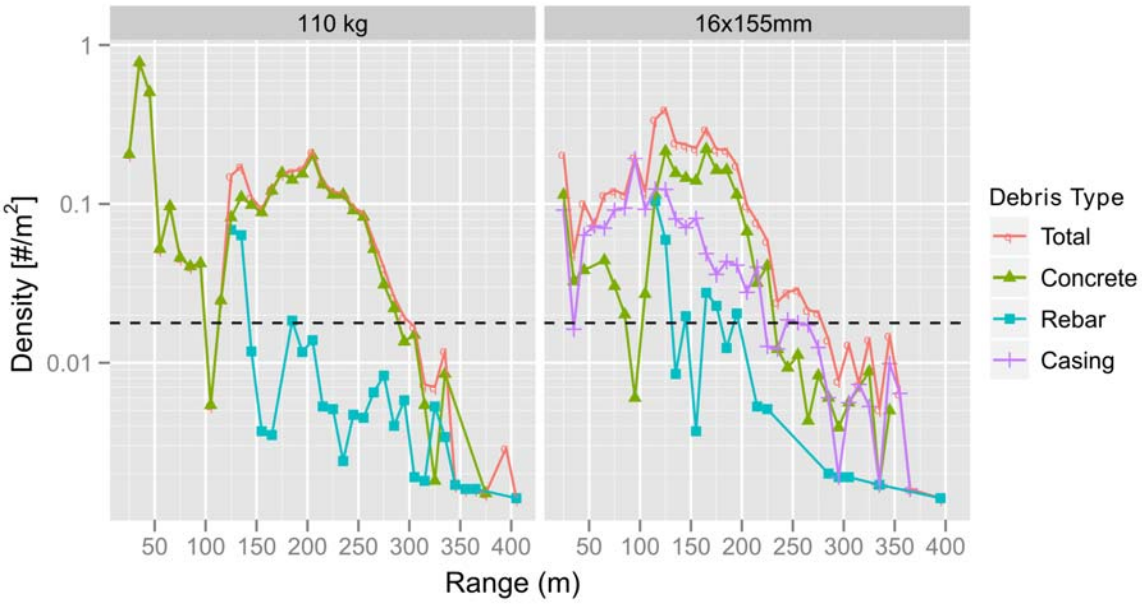


Figure 11. Observed (▲) and smoothed (—) launch angle standard deviations (top)and mean launch angles (bottom) along the side wall perpendicular in Test #6, 7, 8 and 10. The KG Engineering Tool assumption of 6º standard deviation is also shown (— —).

Debris number density and IBD

The evaluated debris number density (concrete debris ≥ 0,050 kg, steel fragments ≥ 0,010 kg) versus range shows that the concrete debris pieces generally dominate above rebars and shell casing fragments (Figure 12 – Figure 13).



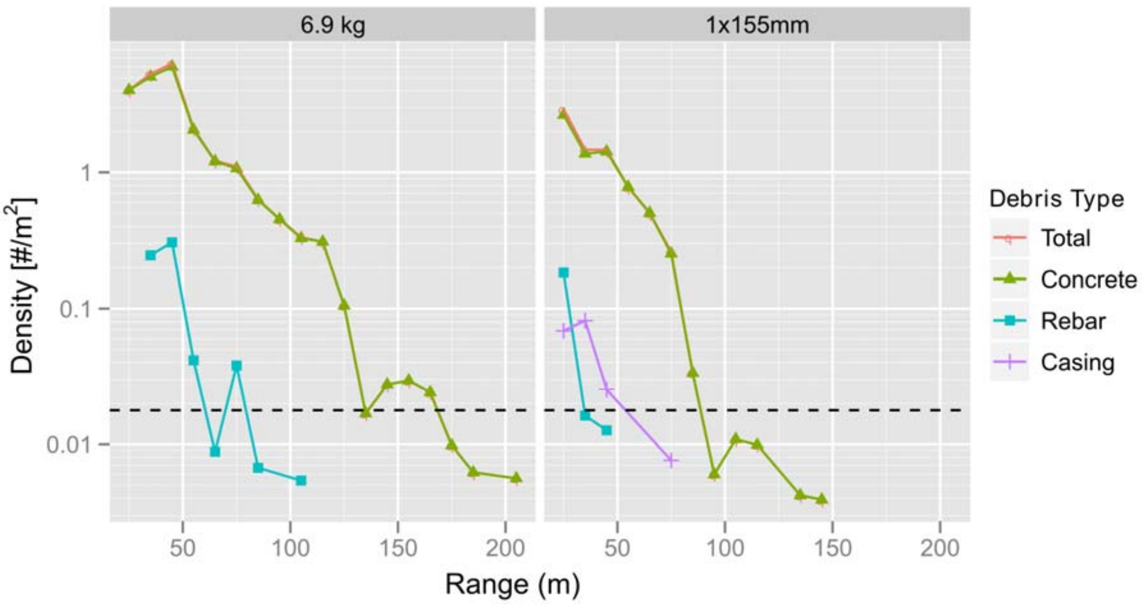


Figure 12. Debris number densities from the 110 kg uncased charge (top left) compared with the 16 shells charge (top right), and the 6.9 kg uncased charge (bottom left) compared with the 1 shell charge (bottom right) vs. range perpendicular to rear wall. The 1/56 m² debris criterion is also shown for comparison (--).

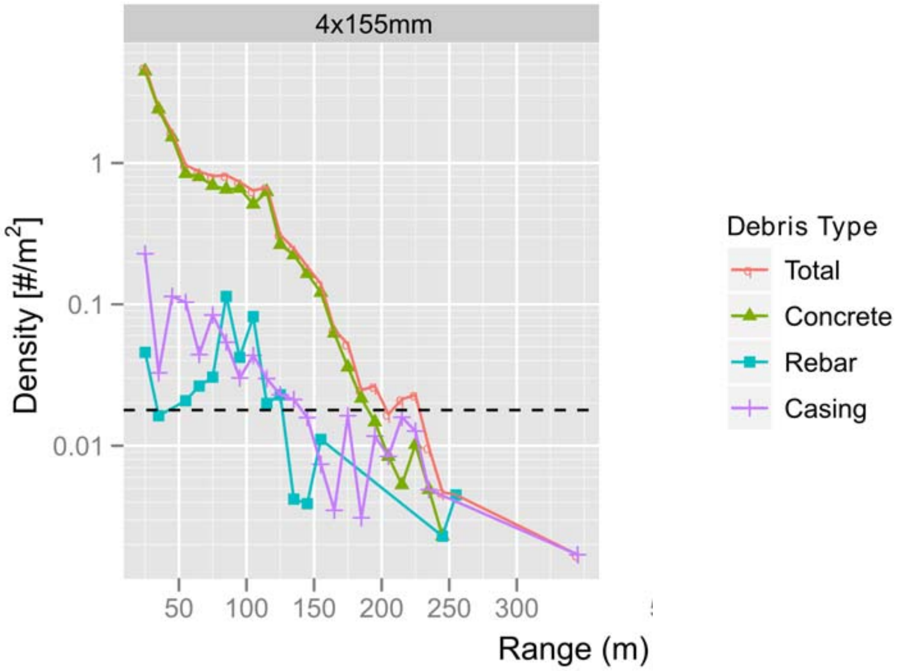


Figure 13. Debris number densities from the 4 shells charge vs. range perpendicular to rear wall. The 1/56 m² debris criterion is also shown for comparison (--).

The distance from the Kasun where the total debris density (density of all debris types of concrete $\geq$ 0.050 kg and of steel $\geq$ 0.010 kg) dropped below 1/56 m^{-2} are shown in Figure 14 as function of azimuth angle. The largest distances where found in the wall directions as expected. The maximum debris IBD is shorter for cased charges than uncased charges at the lowest loading densities. The difference in maximum IBD at the highest loading densities is small.

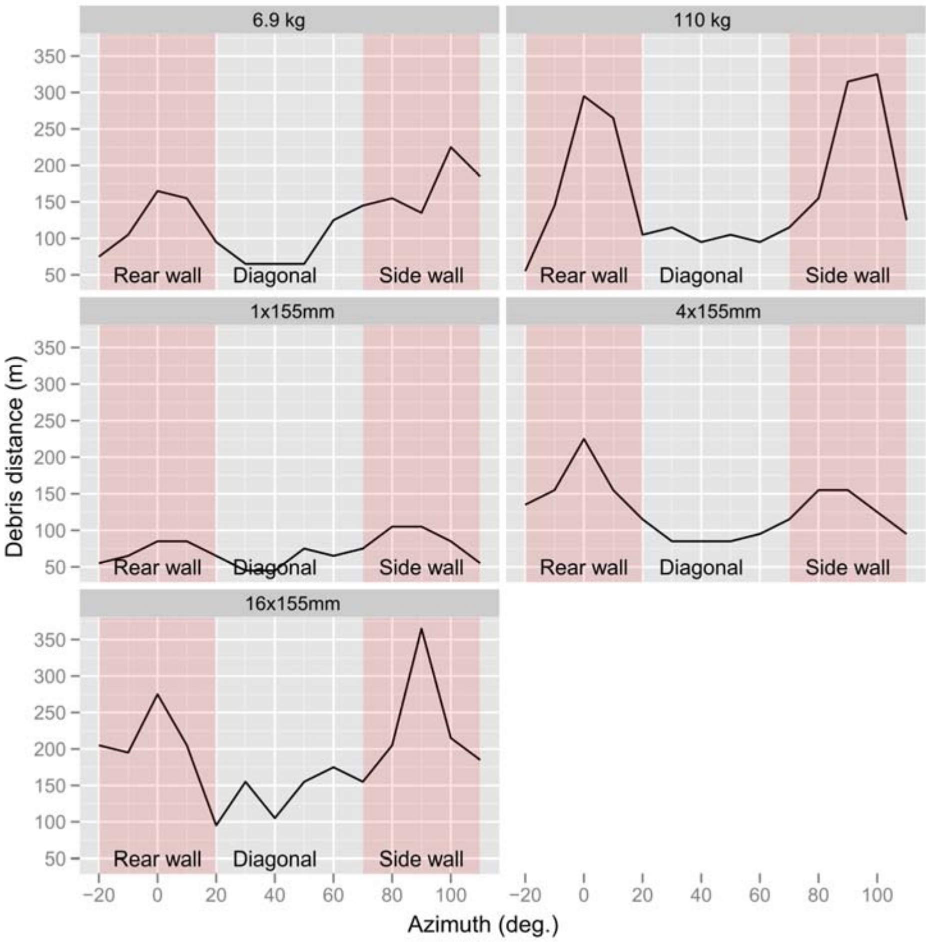


Figure 14. The figure shows at which distance the total debris number density dropped below 1/56 m^{-2} as a function of azimuth angle in Test 6-10.

4. CONCLUSIONS

The structural breakup, blast pressure, debris formation and debris throw from overloaded concrete structures using cased charges have been investigated in an experimental program.

The results indicate that a charge contained in a concrete building as a "Kasun" will get a significantly lower TNT-equivalence factor if the charge consists of shells instead of uncased charges. The smallest charge weights, 6.9 kg in a shell and 6.9 kg uncased, gave the lowest equivalence factors. Especially for the single shell the resulting equivalence factor was extremely low.

The results from the test series showed differences in the breakup caused by the shell casing. This was documented with uncased reference tests at two different loading densities. A simplified analysis on a selection of debris trajectories indicated that the median debris velocity decreased with a cased charge.

The test series resulted in a large concrete debris database with around 18,000 entries. The debris mass distribution was shifted towards smaller masses with increasing loading density. The debris mass was also shifted when comparing the one shell test and the uncased reference test. The differences in the mass distribution between the 16 shells charge and the uncased reference test were small on the other hand.

The results indicated that the median velocity of the observed concrete debris decreased when using a cased charge.

The horizontal launch angle standard deviations were higher at distances closer to the Kasun than farther out, which was most likely caused by the wider debris deposition pattern of the roof debris. The averaged values in each direction were slightly higher than the KG-ET assumption of a 6º standard deviation in the horizontal launch angle. The test series gave no clear picture about differences in horizontal launch angle standard deviations between tests with uncased and with cased charges.

The evaluated debris number density versus range showed that the concrete debris pieces generally dominate above rebars and shell casing fragments. The difference in maximum IBD considering concrete fragments only or all debris (also shell casing fragments and rebars) is negligible for the small loading density and only in the order of 50 m at the high loading density.

The test results are valuable input for the continued development of the KLOTZ Group Engineering Tool for debris throw prediction from concrete ammunition magazines with cased charges.

ACKNOWLEDGEMENT

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ONGOING AND FUTURE WORK ON COMPUTATIONAL ANALYSIS OF THE KASUN TRIALS

The KG research programme on casing effects on the break-up and debris throw also consists of a theoretical, computational part. The aim is to get qualitative and quantitative insight in the differences in loading conditions, damage development and the response of the RC-structure for bare and cased charges. The explosion itself and the fragmenting shells cause very extreme and severe loading conditions. It is realised that the available computational tools have to be used (challenged) beyond the possibilities they were designed for. Realising the (possible) limitations a step by step strategy was developed to increase the level of complexity and get information on the time-line of loading and response for the bare and cased charges. The strategy is summarized in this section. The computations and analyses are still ongoing and will be presented in a future publication.

The strategy is as follows:

- The first step is the simulation of the spatial and temporal blast load distribution of the bare and the cased charges. An Eulerian hydrocode is used for the explosion phase and a fully coupled Eulerian-Lagrange calculation is performed to determine the loading on the structure taking the venting due to structural failure, into account. See illustration Figure 15. These sophisticated calculations have been done by EMI.

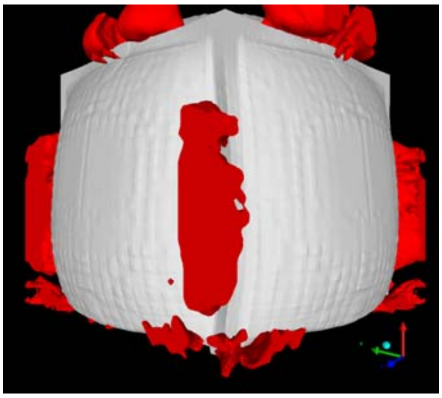

Figure 15. Failure and venting in fully coupled calculation for prediction of blast load.

- The second step concerns shell fragmentation and fragment trajectories. Using (i) available test data, (ii) a Mott mass distribution, (iii) Gurney launch velocity and (iv) Taylor equation for the launch angle, a programme was developed by EMI to predict the fragment trajectories taking fragment collisions into account with plastic momentum conservation. With this programme the spatial and temporal fragment impact distribution and impact conditions on the structure were calculated.
- The third step (by TNO) is the detailed response calculation due to the load without fragment penetration damage. To study the effect of the cased charges, first the response due to only the blast load is determined, next the loading was increased by taking the impulse due to fragment impact into account.
- The last step is to take the damage due to penetration into account. For this purpose the penetration depth was calculated for the fragments and the related elements were eroded from the mesh at the moment the fragment was stopped or perforated the structure.

The computational study is still ongoing. The first three steps seem to be feasible and give reasonable results. For the last step still solutions have to be found to deal with the severe additional damage due to fragment penetration.

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THE EFFECTS OF CASED AMMUNITION EXPLOSIONS CONFINED IN CONCRETE CUBICLES

– KASUN-III

Rickard Forsén (FOI), Roger Berglund (FOI) and Geir Arne Grønsten (NDEA)

Outline

- Introduction
- Test set up
- Results
  - Blast pressure
  - Fragment characteristics
- Conclusions

Introduction

- **Background**
  - Continuation of Kasun test series (2003 and 2006)
- **Project objective**
  - Increase the knowledge on the influence of the casing of explosives for the distribution of debris and pressure
- **Accomplishment**
  - Cased charges detonating inside small concrete buildings
  - Test series performed June 2008
  - Joint Norwegian/Swedish effort
  - Sponsored by KLOTZ-Group, Sweden and Norway

Test set-up

6.9 kg plastic expl

110 kg plastic expl

1 x 15.5 cm ≈ 6.9 kg TNT

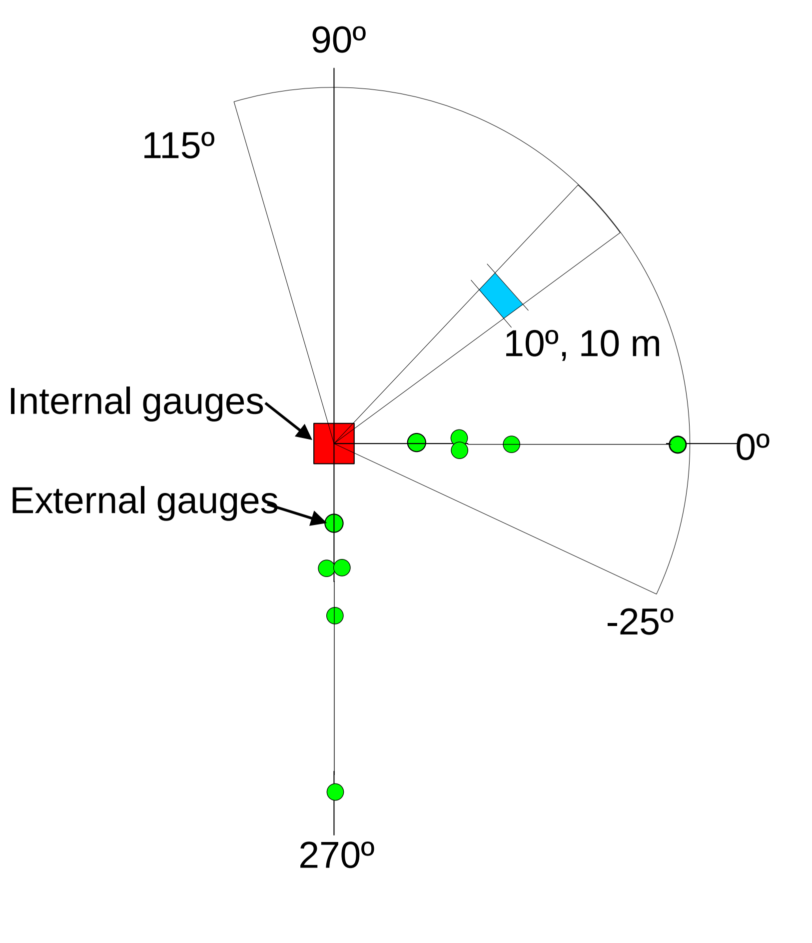
4 x 15.5 cm ≈ 27.6 kg TNT

16 x 15.5 cm ≈ 110 kg TNT

+ Free field test 110 kg plastic expl.

Test set-up - Recordings (1)

- Pressure
  - Several internal carbon gauges (TNO)
  - 10 external gauges at two directions at four distances (20, 30, 40 and 80 m)
- Debris
  - 10º zones, 10 m deep, from -25º to 115º, from 20 m to 400 m
  - Manually pick up of concrete fragments (>50 g)
  - Magnetic pick of steel fragment (>10 g)
  - Photographed and weighed



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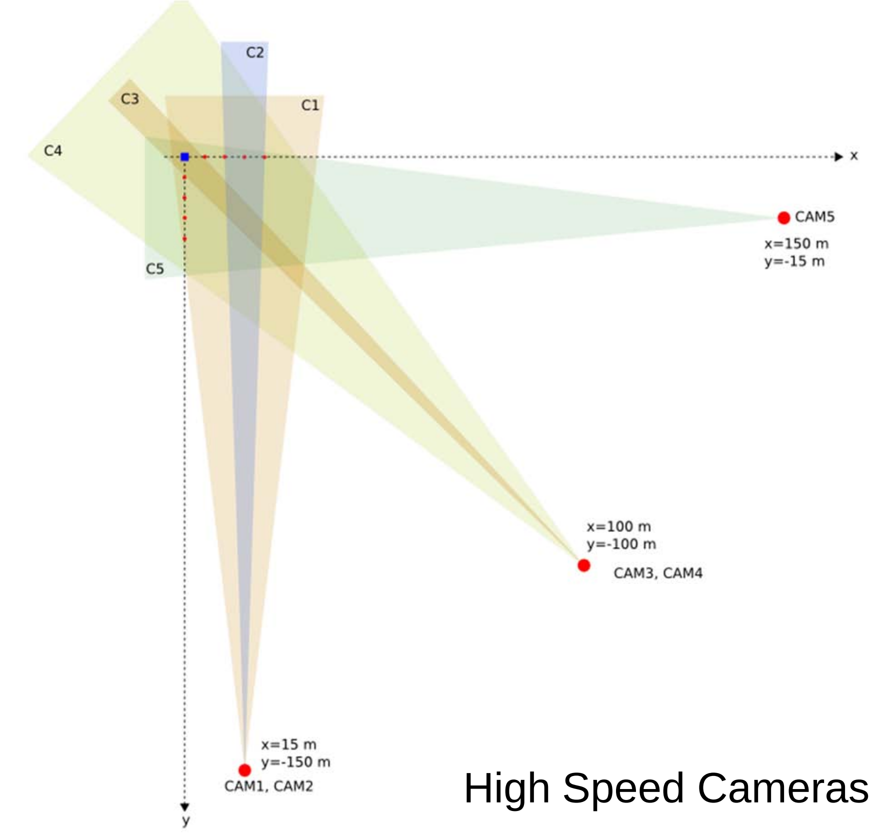
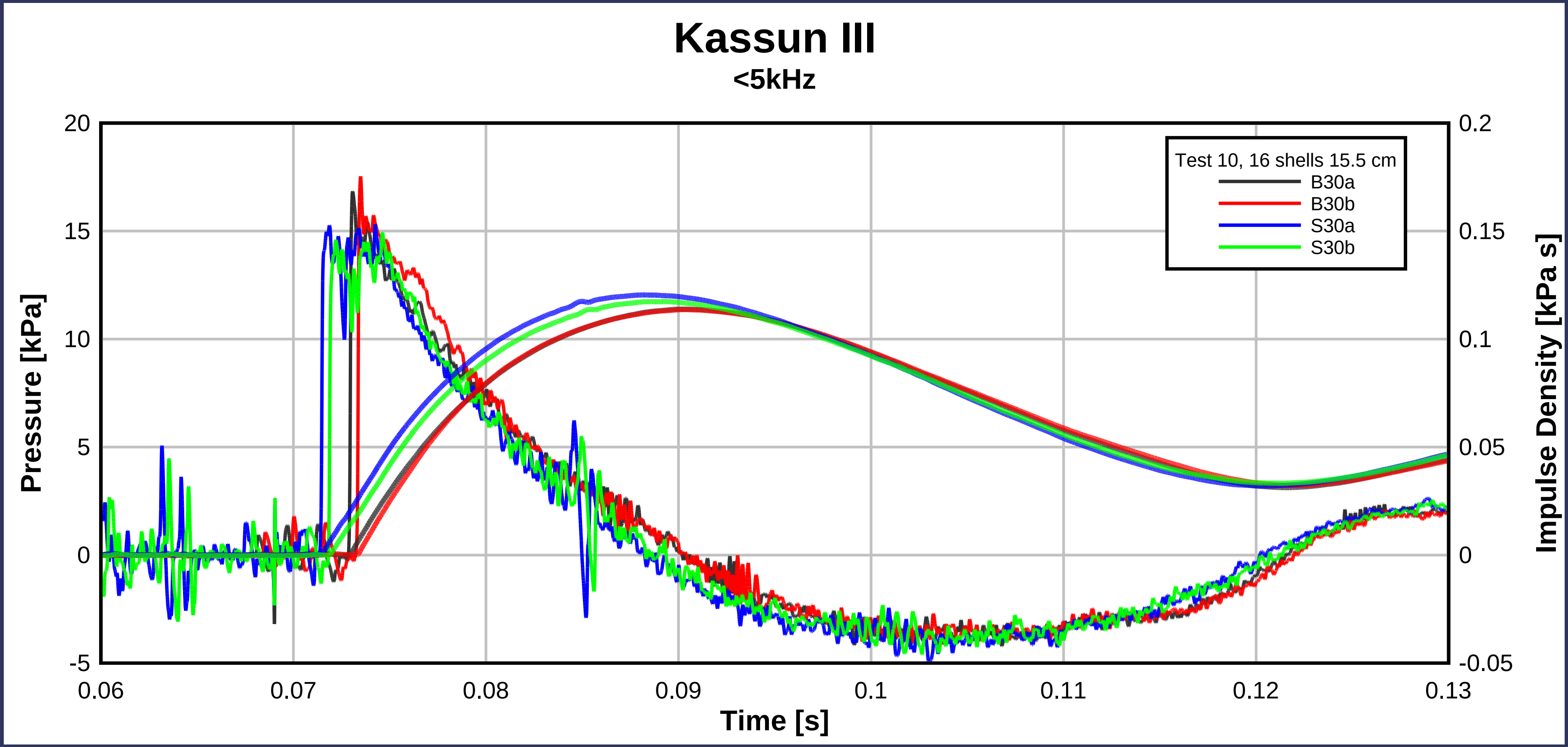
Test set-up – Recordings (2)

- **Break up**
  - Two narrow angle High Speed Cameras to get initial breakup, one diagonal and one from the side.
- **Overview**
  - One wide angle High Speed Camera
- **Launch Velocity**
  - Two wide angle High Speed Cameras with photomarkers both for distance and angle determination.
- **Bounce, slide and roll**
  - A number of ordinary DV cameras along one sector



High Speed Cameras

Results – External blast pressure



Example: 16 x 155 mm shells at 30 m

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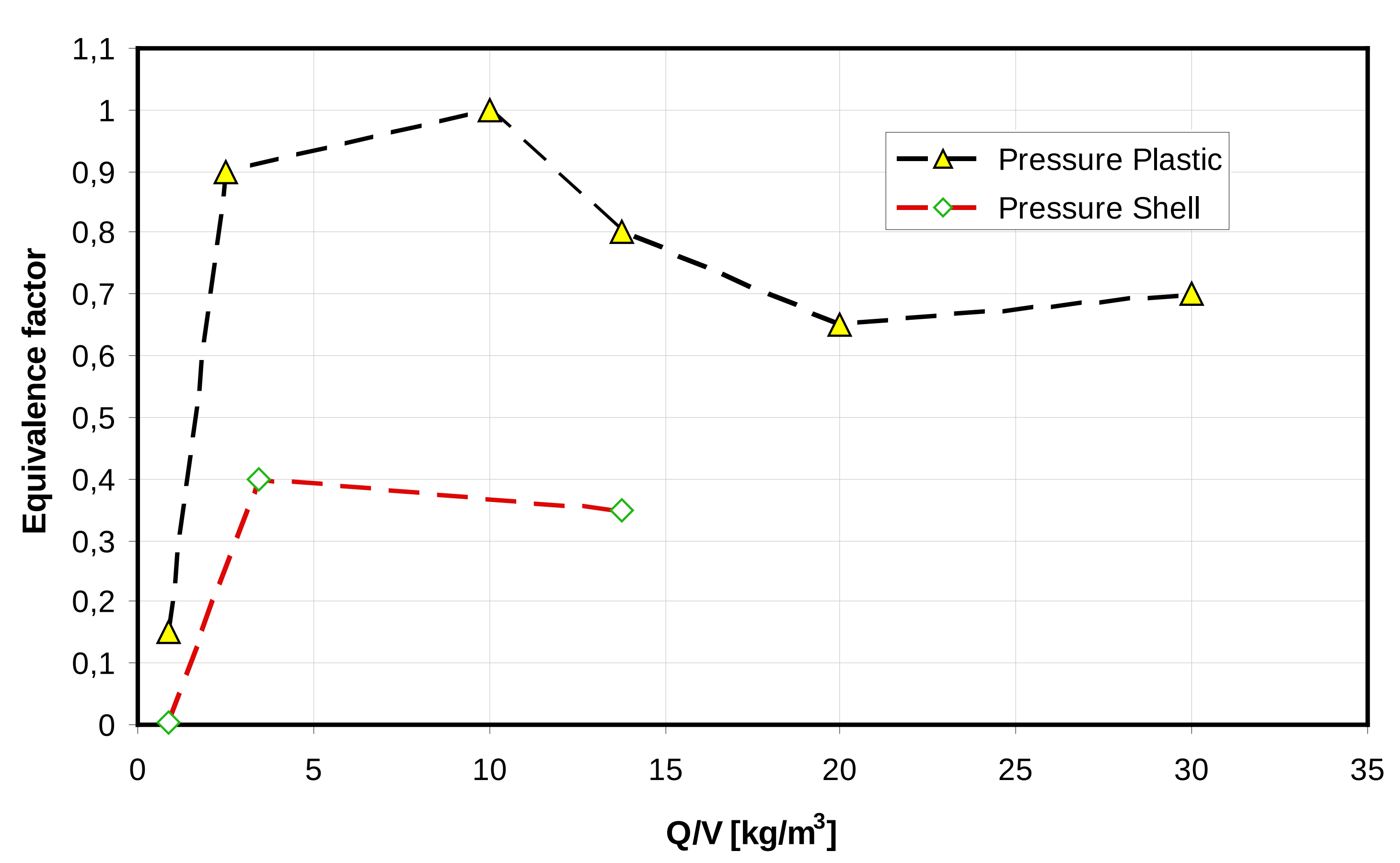
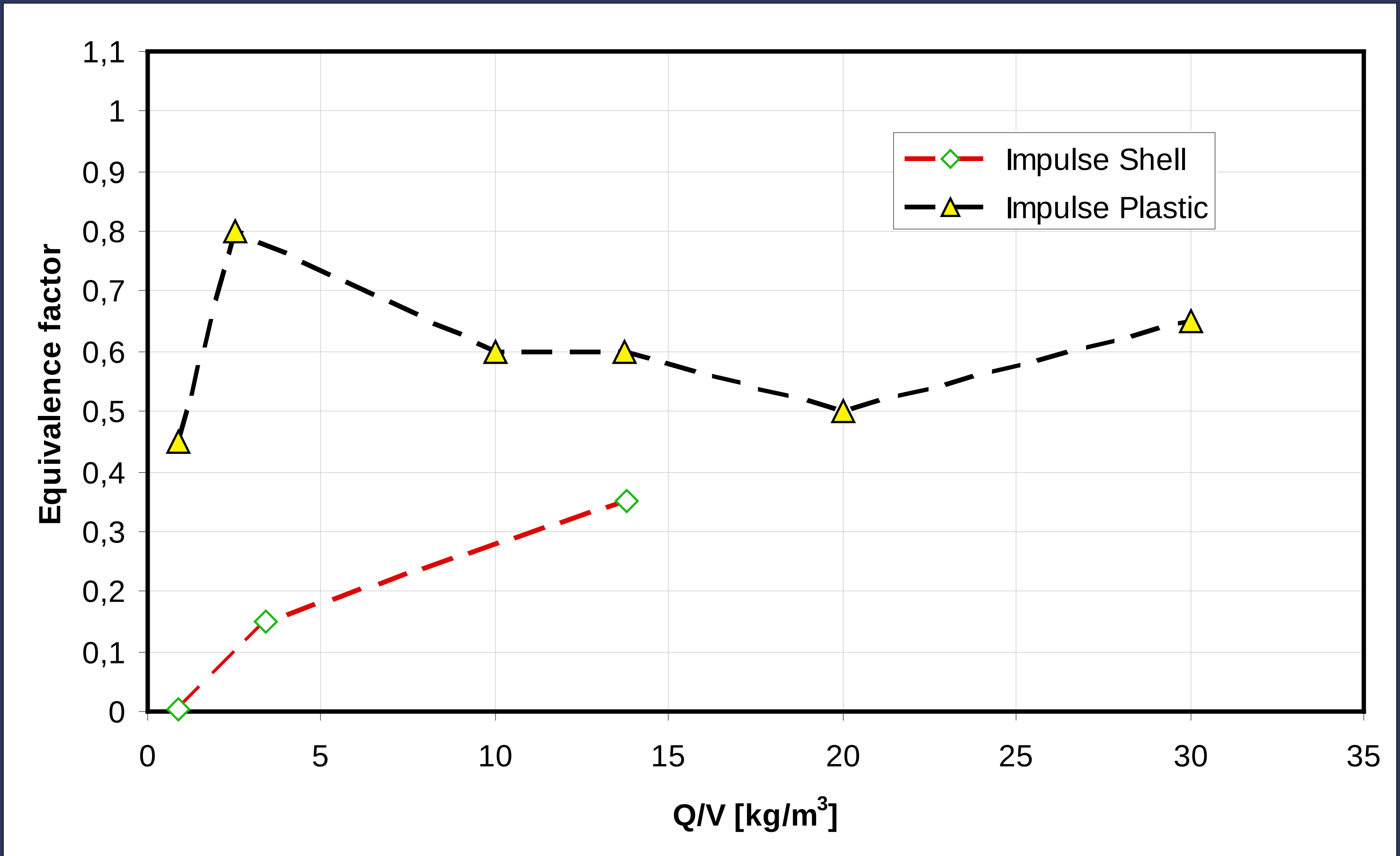
Results – External blast pressure



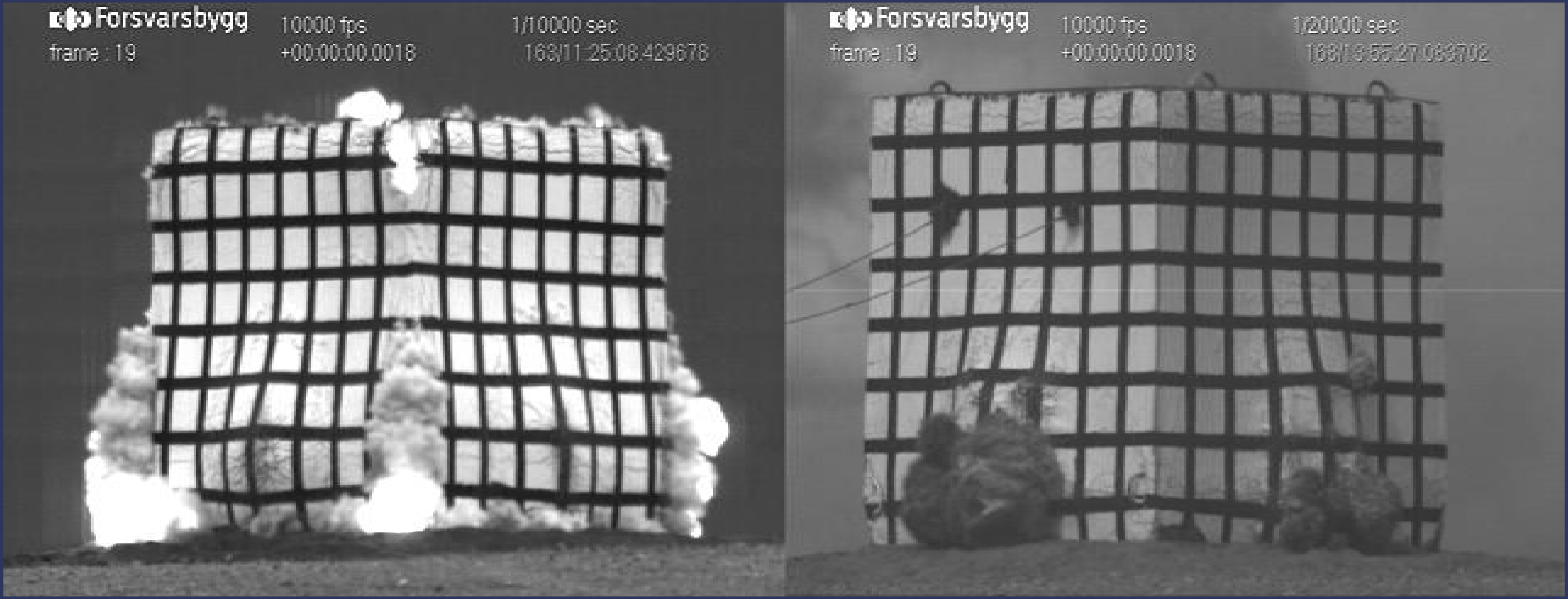
Open air equivalence factor - pressure

Results – External blast pressure



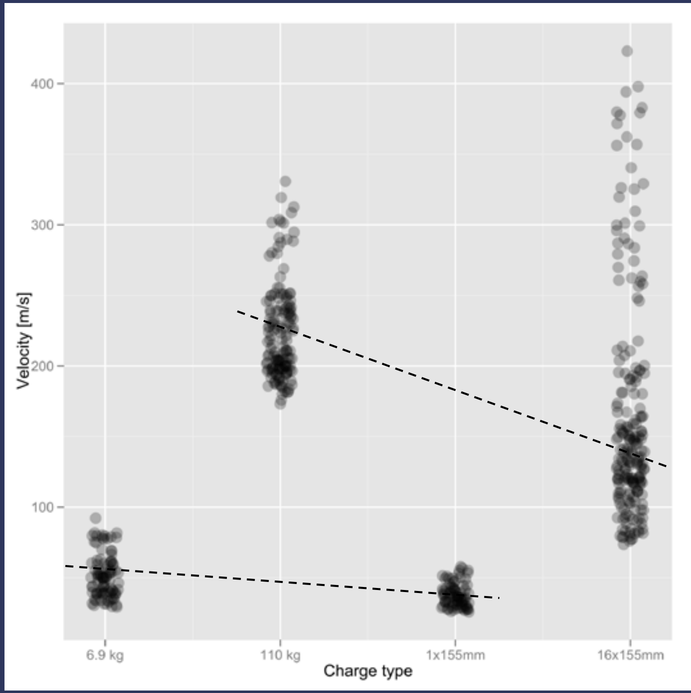
Open air equivalence factor – impulse density

Results – Initial breakup



110 kg uncased (left) and 16x155 mm shells (right)

Results - Concrete debris velocity



Test	Charge	*N*	Min. (m/s)	1st Quartile [m/s]	Median [m/s]	Mean [m/s	3rd Quartile [m/s]	Max. [m/s]
6	6.9 kg	92	29	39	50	52	61	92
8	1 shell	81	26	31	36	38	43	58
7	110 kg	150	173	198	216	224	241	331
10	16 shells	205	74	114	139	165	191	423

Results – Concrete mass characteristics

Recovered concrete debris masses

Charge	1st Quartile [10^{-3}kg]	Median [10^{-3}kg]	Mean [10^{-3}kg]	3rd Quartile [10^{-3}kg]	Max [10^{-3}kg]
6.9 kg	79	138	310	328	5600
1 shell	68	109	206	216	4399
4 shells	69	107	203	220	4400
110 kg	61	81	118	127	1106
16 shells	61	83	118	132	910

Results – Total number of fragments characteristics

Total number of fragments and total debris masses recovered

Charge	Concrete		Rebar		Casing	
	N	*m* [kg]	*N*	*m* [kg]	*N*	*m* [kg]
6.9 kg	6019	1864	114	260	-	-
1 shell	2054	424	24	64	22	0.6
4 shells	5957	1208	181	354	447	14.1
110 kg	2463	291	218	359	-	-
16 shells	1494	176	269	341	1876	66.6

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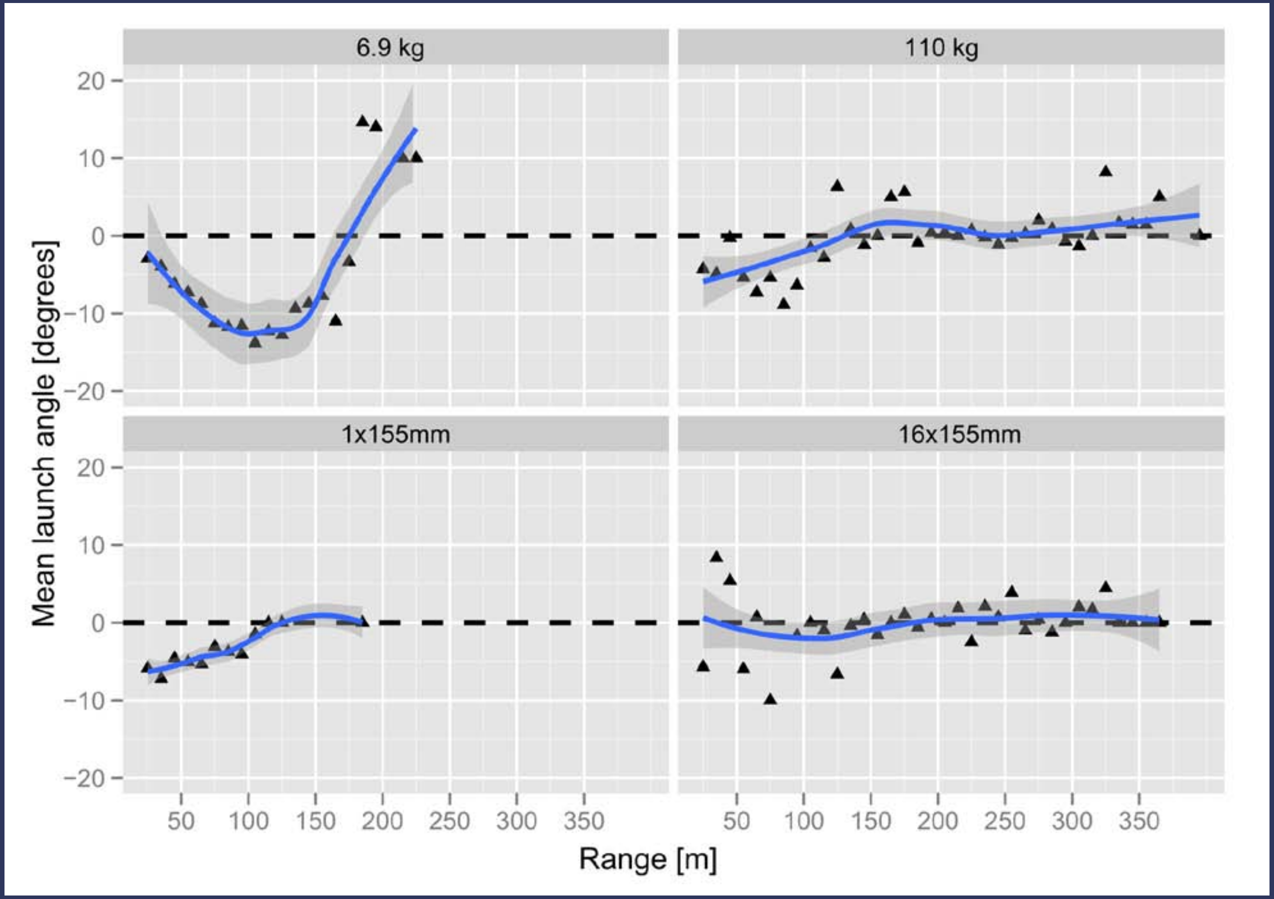
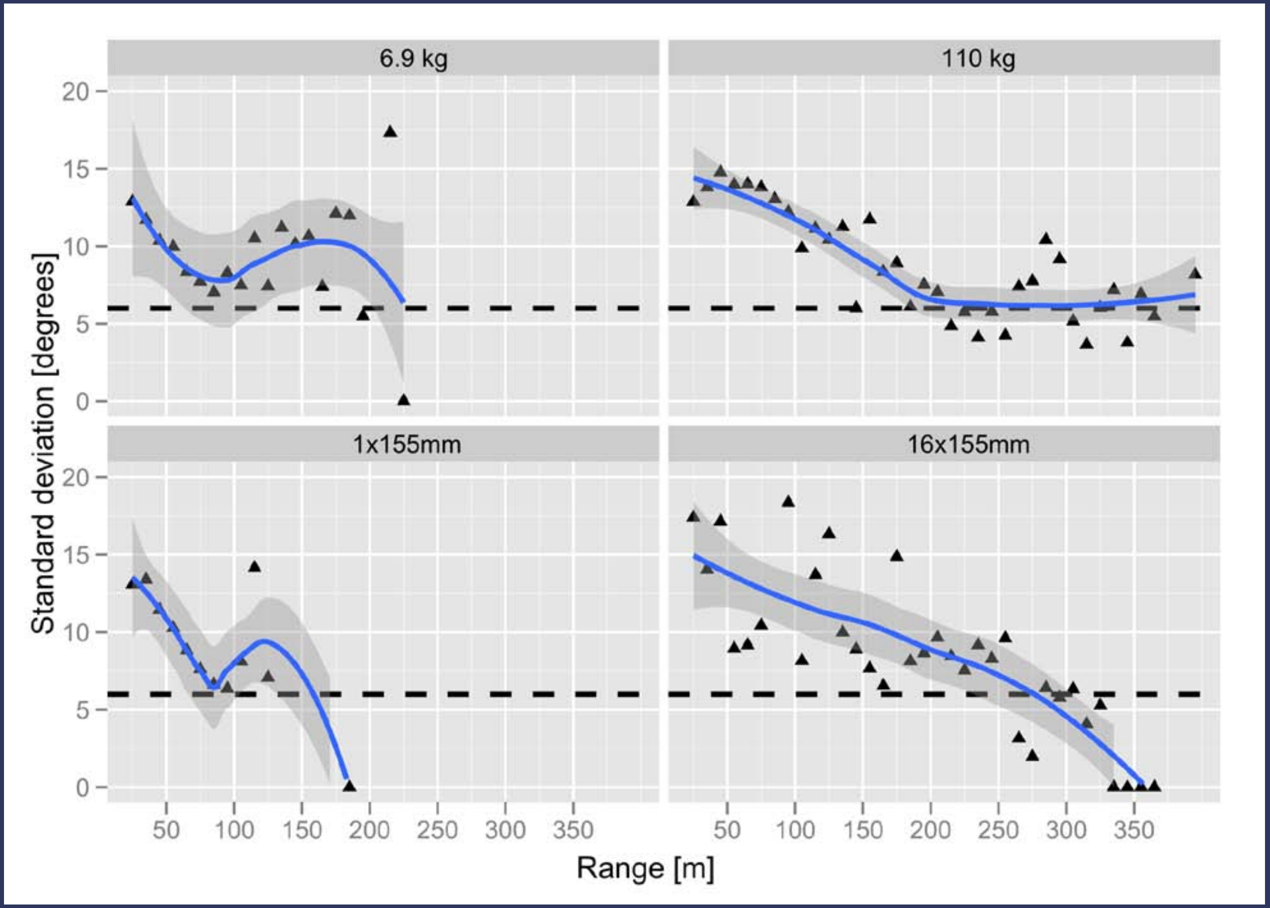
Results – Horizontal launch angle



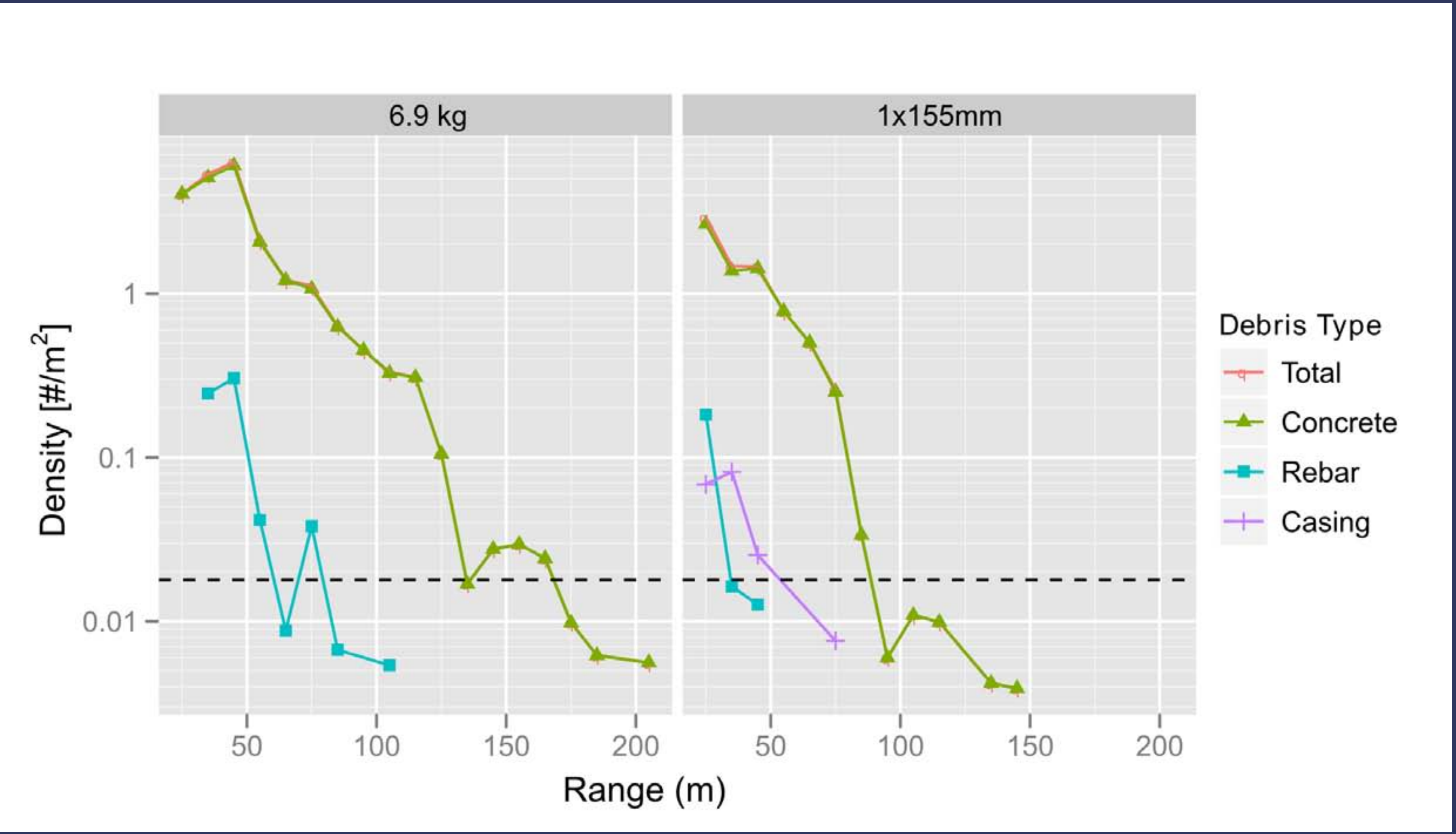
Horizontal mean launch angle (concrete debris, side wall)

Results – Horizontal launch angle



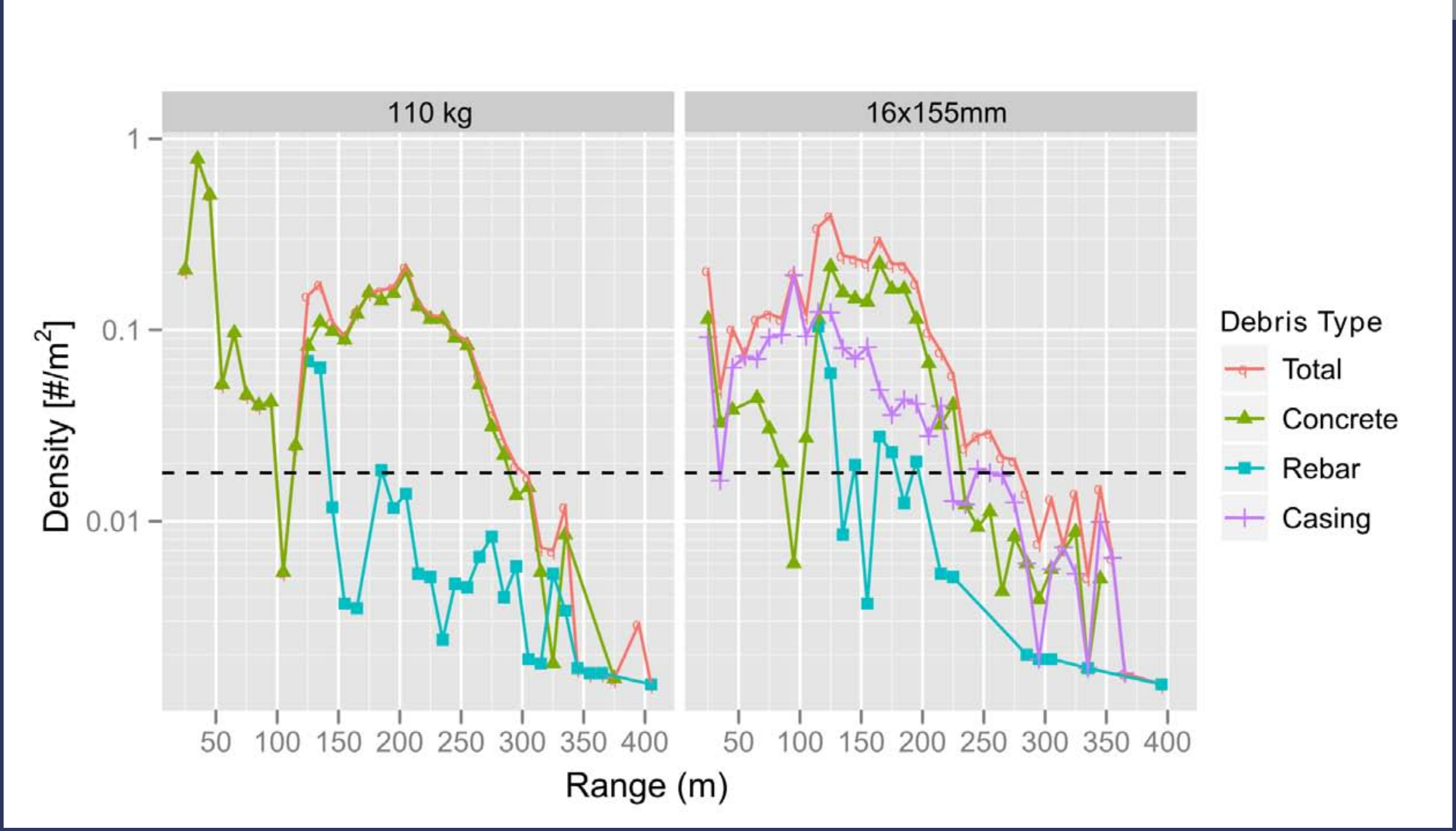
Horizontal launch angle standard deviation (concrete debris, side wall)

Results – Debris number density, IBD



Perpendicular to rear wall (Dotted line = 1/56m^2)

Results – Debris number density, IBD

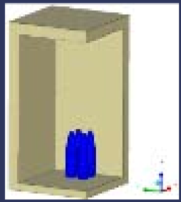


Perpendicular to rear wall (Dotted line = 1/56m^2)

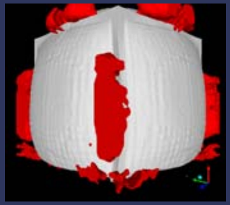
Conclusions

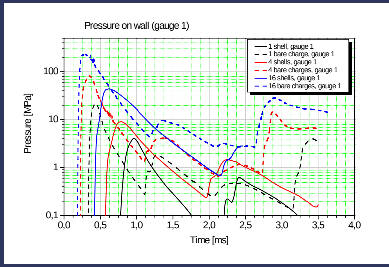
- Different break up patterns from uncased and cased charges
- Reduction of TNT equivalence factor compared to open air for confined charges and especially for cased confined charges
- Median concrete debris velocity decreased with cased charges
- Smaller concrete debris masses with increasing loading density (and also with cased charges compared with uncased charges – one shell test)
- Horizontal launch angle standard deviations slightly higher than 6 deg. (assumed for KG-ET); no clear picture of differences with uncased and cased charges
- Debris number density is dominated by concrete debris (but less dominant for high loading densities with cased charges)

Computational support to KASUN Trials



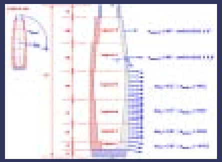
- Aims:
  - Insight differences loading and response for bare and cased charges
  - Support data analysis and design future tests

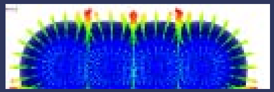




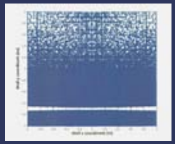
Status 2010

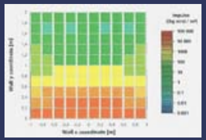
- Three step strategy:
  - Blast loading (fully coupled Eulerian-Lagrange)
    - Bare and cased; including venting





  - Shell fragmentation (semi empirical)
    - Masses, velocities and trajectories
    - Hit conditions and hit probability on structure/segment





  - Response calculation for:
    - Blast load + fragment impulse
    - Blast load + fragment impulse + penetration/perforation