MILITARY ASPECTS of BLAST & SHOCK

Links

- Sort by Presenter
- Sort by Program Order

MABS 19 Papers - Sorted Alphabetically by Presenter

ID #	Title	Speaker	Affiliation	Country
*	CHARACTERIZATION OF HIGH ENERGY TRANSIENT EVENTS	Aguilo, Miguel	ARA	USA
P030	NUMERICAL SIMULATIONS OF EXPLOSIVE WALL BREACHING BLAST ENVIRONMENTS	Akers, Stephen	Army ERDC	USA
P065	EXPERIMENTAL AND NUMERICAL STUDIES OF THE BEHAVIOR OF LAMINATED GLASS UNDER DYNAMIC LOADS	Anteby, I.	Ben-Gurion University of the Negev	ISR
P031	COUPLED CFD/CSD MODELING OF SCALED WEAPON DETONATION AND FRAGMENTATION	Baum, Joseph	SAIC	USA
P012	DYNAMICS OF STRESS WAVE PROPAGATION ALONG CHAINS OF PHOTOELASTIC DISCS IMPACTED BY A PLANAR SHOCK WAVE	Ben-Dor, Gabi	Ben-Gurion University of the Negev	ISR
P019	ATTENUATION OF SHOCK WAVES BY BARRIERS IN TUNNELS AND CORRIDOR TYPE GEOMETRIES	Ben-Dor, Gabi	Ben-Gurion University of the Negev	ISR
P072	TOWARDS A PARAMETRIC MODEL OF A PLANAR BLAST WAVE CREATED WITH DETONATING CORD	Borgers, Jody	Netherlands Defence Academy	NLD
*	USING FINITE ELEMENT METHOD TO PREDICT THE RESPONSE OF POLYMERIC FOAM TO BOTH SHOCK WAVE AND FREE-FIELD BLAST LOADINGS	Bouamoul, Amal	DRDC Valcartier	CAN
P064	BLAST EFFECTS ON MULTI LAYERED PROTECTIVE WINDOWS	Brill, Alon	RAFAEL	ISR
P073	EXPERIMENTAL SMALL-SCALE STUDY OF BLAST LOADS ON AMMUNITION MAGAZINES	Brill, Alon	RAFAEL	ISR
P014	PARAMETER STUDIES FOR EMBEDDED MUNITIONS	Brown, Mary	ARA	USA
P047	A NEW CONCEPT FOR BULLET PROTECTION AND DEBRIS CONTAINMENT WITH MODERN CHAIN MAIL AND HYBRIDS WITH PLASTIC/METALLIC RESINS	Burger, Uli	University of Ingolstadt	DEU
P005	DEVELOPMENT OF A MODEL TO PREDICT EFFECTIVENESS OF AIR-DELIVERED EMBEDDED MUNITIONS AGAINST HARDENED STRUCTURES	Cameron, Robert	Sentel Corporation	USA
P003	NEW LARGE HE TEST FACILITY FOR CONVENTIONAL DETONATIONS	Carl, Dietmar	WTD 52	DEU
P021	NUMERICAL INVESTIGATIONS OF THE INFLUENCE OF THE CHARGE GEOMETRY ON THE BLAST FORMATION	Carl, Dietmar	WTD 52	DEU
P041	BLAST LETHALITY PREDICTION USING NORMALIZED WORK	Chan, Philemon	L-3 Jaycor	USA
P054	COMPARISON OF INTEGRATION PROCUDURE FOR PROGRESSIVE COLLAPSE ANALYSIS OF BUILDING STRUCTURES	Choi, Hyung Jin	Karagozian & Case	USA
P040	BLAST VULNERABILITY OF PERSONNEL IN A CONTAINER BASED OBSERVATION POST	Christensen, Svein	NDEA	NOR
P039	UNDERSTANDING ENHANCED BLAST EXPLOSIVES: A MULTI-SCALE CHALLENGE	Cooper, Marcia	SNL	USA
P062	CABLE CATCHER SYSTEMS FOR IMPROVING BLAST RESISTANCE OF GLAZING FAÇADES	Crawford, John	Karagozian & Case	USA
P008	THE RANKINE-HUGONIOT EQUATIONS: THEIR EXTENSIONS AND INVERSIONS RELATED TO BLAST WAVES	Dewey, John	Dewey McMillan & Associates	CAN

P045	NEW MODEL FOR SURVIVABILITY PREDICTIONS FOR SIMULATED FREE FIELD BLAST	Dionne, J.P.	Med-Eng Systems	CAN
P026	THE NATURE OF HETEROGENEOUS BLAST EXPLOSIVES	Frost, David	McGill University	USA
P050	STUDIES ON THE RESISTANCE OF HIGH STRENGTH CONCRETE PANELS AGAINST BLAST LOAD	Fuchs, Maximilian and Keuser, Manfred	University of the Federal Armed Forces	DEU
P078	RESPONSE OF BURIED STRUCTURES UNDER SHOCK LOADING: NUMERICAL SIMULATIONS AND EXPERIMENTAL TESTS	Gardou, Michel	DGA/DET/CEG	FRA
P063	BLAST SAFETY OF GLASS-MEMBRANE-FACADES AND THEIR INTERACTION WITH BUILDINGS	Gebbeken, Norbert	University of the Federal Armed Forces	DEU
P002	INTEGRATED MODELING AND TESTING FOR BLAST SIMULATIONS	Giltrud, Michael	DTRA	USA
P017	MASONRY CUBE STRUCTURE BENCHMARK TESTS - HYDROCODE SIMULATIONS	Glanville, Jon	Century Dynamics	GBR
P084	PROTECTIVE CONTAINER SOLUTIONS FOR TODAY'S MENACES	Glombek, Reinhard	Drehtainer	DEU
P055	LOCAL AND GLOBAL APPROACHES TO THE BLAST RESPONSE OF STRUCTURES	Haering, Ivo	Ernst-Mach Institut	DEU
P009	BLAST LOADS OF NON-SPHERICAL CHARGES IN FREE AIR	Held, Manfred	TDW/EADS	DEU
P020	IMPULSIVE LOADS ON MODELLED SCALED TARGETS	Held, Manfred	TDW/EADS	DEU
P027	APPLICATION OF MILITARY BLAST EFFECTS EXPERT SYSTEM TO MODERN FORCE PROTECTION STRUCTURES	Hlady, Sheri	DRDC Suffield	CAN
P061	OPTIMIZING THE CANADIAN FORCES BATTLE TRENCH FOR IMPROVED BLAST PROTECTION	Hlady, Sheri	DRDC Suffield	CAN
P059	SUPPORT LOADING RESULTING FROM THE EXPLOSION OF MUNITIONS ABOVE A PROTECTIVE ROOF	Hulton, Frederick	QinetiQ	GBR
P051	BLAST TESTING OF STEEL FRAME MOMENT CONNECTION ASSEMBLIES	Karns, Jesse	Myers. Houghton & Partners	USA
P028	FIELD TESTING OF VULNERABILITY ASSESSMENT AND PROTECTION OPTION (VAPO) TOOL	Kathir, Nathan	DTRA	USA
P052	STEEL FRAME COMPONENTS SUBJECTED TO BLAST LOADS	Kersul, Audrey	DTRA	USA
P032	NUMERICAL SIMULATION OF STANDARDIZED THERMOBARICS TESTS IN A TWO-ROOM STRUCTURE	Kim, Kibong	DTRA	USA
P068	A FAST TEMPERATURE SENSOR FOR EXPLOSIVE ENVIRONMENTS	Kisters, Thomas	Ernst-Mach Institut	DEU
P049	MITIGATION OF BLAST AND IMPACT LOADS USING THIN WALLED TUBES	Kivity, Yosef	Ben-Gurion University of the Negev	ISR
P075	THE BLAST WAVE RESULTING FROM AN ACCIDENTAL EXPLOSION IN AN AMMUNITION MAGAZINE	Kivity, Yosef	Ben-Gurion University of the Negev	ISR
P015	VALIDATION OF COUPLED FLUID-STRUCTURE SIMULATION AGAINST EXPERIMENTS IN THE LARGE BLAST SIMULATOR LBS 501	Klomfass, Amo	Ernst-Mach Institut	DEU
P038	MODELING COMBUSTION OF ALUMINUM PARTICLES IN SHOCK-DISPERSED-FUEL EXPLOSIONS	Kuhl, Allen	LLNL	USA
P071	THE MEASUREMENT AND MODELING OF EARTH ELECTRIC POTENTIAL SIGNALS PRODUCED BY IMPACTS AND DETONATIONS	Lauten, William	DTRA	USA
P016	INITIAL MAZ DEVELOPMENT I: IMPLEMENTATION OF GROWING CRACKS ON MOVING BOUNDARY SURFACES	Lee, Binky	Weidlinger Associates	USA
P023	UNDERWATER FRAGMENTATION OF CYLINDERS	Lee, Julian	DRDC Suffield	CAN
P042	THE EFFECTS OF BTD ORIENTATION ON INJURY PREDICTIONS	Levine, Jeffrey	Med-Eng Systems	CAN
P079	HUMAN TRAVEL DISTANCE DUE TO AN EXPLOSIVE	Levine, Jeffrey	Med-Eng Systems	CAN
P029	COMPARISON OF BODY-FITTED AND EMBEDDED 3-D EULER PREDICTIONS FOR BLAST LOADS ON COLUMNS	Lohner, Rainald	Applied Simulations	USA
P044	RESPONSE OF THE HYBRID III DUMMY SUBJECTED TO FREE-FIELD BLASTS - FOCUSSING ON TERTIARY BLAST INJURIES	Manseau, Josee	DRDC Valcartier	CAN
P080	PROGRESSIVE COLLAPSE ASSESSMENT OF BUILDINGS FOR CONFORMANCE WITH "UFC 4-023-03, DESIGN OF BUILDINGS TO RESIST PROGRESSIVE COLLAPSE" (PC UFC)	McKay, Aldo	ARA	USA
P037	MODELLING OF ENHANCED BLAST AND HETEROGENEOUS EXPLOSIVES	Milne, Alec	FGE Ltd.	GBR

P056	FORCE PROTECTION AGAINST ENHANCED BLAST	Murray, Stephen	DRDC Suffield	CAN
P036	UPDATE ON THE STATUS OF NUMERICAL MODELING OF NON-IDEAL EXPLOSIVES	Needham, Charles	ARA	USA
P006	COMBUSTION OF SHOCK-DISPERSED ALUMINUM - SOME PARAMETRIC STUDIES	Neuwald, Peter	Ernst-Mach Institut	DEU
P034	DISTRIBUTED SDF-CHARGES IN A TUNNEL	Neuwald, Peter	Ernst-Mach Institute	DEU
P053	NUMERICAL ANALYSIS OF STEEL STUD BLAST WALL DESIGN	O'Daniel, James	Army ERDC	USA
P022	MEASURED AIRBLAST ENVIRONMENT FROM AN EXPLOSIVE CHARGE HAVING A SCORED METAL CASING	Ohrt, Alan	AFRL	USA
P066	ON THE USE OF DIFFERENTIAL PRESSURE GAGES FOR LOW PRESSURE BLAST MEASUREMENTS	Reinke, Robert	DTRA	USA
P057	NL RESEARCH PROGRAMME ON PROTECTION OF FIELD STRUCTURES AGAINST THE EFFECTS OF ENHANCED BLAST WEAPONS	Rhijnsburger, Marnix	TNO	NLD
P060	RESULTS OF CLOSE-IN EFFECTS OF ENHANCED BLAST WEAPONS, NUMERICAL SIMULATION OF BLAST AND RESPONSE OF FIELD STRUCTURES	Rhijnsburger, Marnix	TNO	NLD
P018	COUPLED CFD/CSD/DPM MODELING OF WALL RESPONSE TO BLAST LOADING	Rice, Darren	SAIC	USA
P067	EVALUATION OF LOWER-COST IN-TARGET STRESS MEASUREMENTS	Rickman, Denis	Army ERDC	USA
P004	DETONATION OF HEAVY ANFO USED IN LARGE HIGH EXPLOSIVE EXPERIMENTS	Rinehart, Eric	DTRA	USA
P025	BENEFITS TO THE WARFIGHTER FROM DTRA HARD TARGET DEFEAT AIR-DELIVERED WEAPON TESTING	Rinehart, Eric	DTRA	USA
P074	THE JANGLE EVENTS - THE FIRST NUCLEAR WEAPONS EFFECTS TESTS	Rinehart, Eric	DTRA	USA
P011	EXPLOSION PERFORMANCE OF ALUMINIZED TNT IN A CHAMBER	Ripley, Robert	Martec Ltd.	CAN
P058	BLAST RESPONSE OF HEMI-CYLINDRICAL TENTS	Ritzel, David	Dyn-FX	CAN
P069	NUMERICAL SIMULATIONS OF MEPPEN EXPERIMENTS : IMPACT OF SOFT PROJECTILES ON REINFORCED CONCRETE PLATES	Rouquand, Alain	DGA/DCE/CEG	FRA
P081	A MODEL FOR GEOLOGIC MATERIALS, PRESENTATION AND VALIDATION FOR A LARGE RANGE OF DYNAMIC LOADS	Rouquand, Alain	DGA/DCE/CEG	FRA
P024	PERFORATION OF METAL PLATES: LABORATORY EXPERIMENTS AND NUMERICAL SIMULATIONS	Schwer, Leonard	Schwer Engineering & Consulting Services	USA
P046	DESTRUCTIVE BLAST INHIBITING CONTAINER FOR BLAST PROTECTION ABOARD AN AIRCRAFT	Silnikov, Mikhail	NPO Special Materials	RUS
P070	INVESTIGATION ON NUCLEAR THERMAL RADIATION EFFECTS ON MILITARY PAINT LAYERS - A FRENCH-GERMAN COOPERATION	Simon, Klaus	WIS Munster	DEU
P010	PRESSURE LOADS ON SIMPLE GEOMETRIES	Sochet, Isabelle	ENSI Bourges	FRA
P035	HIGH SPEED SPECTROSCOPY OF EXPLOSIONS OF METALIZED EXPLOSIVES	Sturtzer, Michel-Olivier	ISL	FRA
P076	IMPROVEMENT OF THE SMALL SCALE BLAST TEST	Tournemine, Didier	CEG	FRA
P043	INJURY ASSESSMENT FOR BLAST OVERPRESSURE EFFECTS: EXPERIMENTAL APPROACH	van Deursen, J.	TNO	NLD
P082	NEW FRAGMENT SAFETY DISTANCES FOR EOD OPERATIONS	van Deursen, J.	TNO	NLD
P001	DETONICS AND BLAST R&D AT DRDC SUFFIELD	Weikert, Chris	DRDC Suffield	CAN
P077	MODERNIZATION OF THE PROCESS CONTROL FOR THE FREE FIELD THERMAL RADIATION SIMULATOR TRS-4	Wenig, Paul	University of the Federal Armed Forces	DEU
P083	IMPROVEMENTS TO HIGH EXPLOSIVE FREE AIR CODE (HEFAC)	Wofford, Thomas	ARA	USA
P033	CONFINED HETEROGENEOUS BLAST	Zhang, Fan	DRDC Suffield	CAN
P013	PARALLEL COMPUTATION SYSTEMS IN CFD SIMULATION AND VISUALIZATION	Zibarov, Alexey	GDT	RUS

* Indicates paper was accepted but not presented.

Note: Papers outstanding at the submission deadline are listed but are not available on this CD-ROM.

TOWARDS A PARAMETRIC MODEL OF A PLANAR BLAST WAVE CREATED WITH DETONATING CORD

J.B.W. Borgers[1], J. Vantomme[2]

[1] *Netherlands Defense Academy*
PO Box 90.002, 4800 PA Breda, Netherlands
[2] *Royal Military Academy*
Renaissancelaan 30, B-1000 Brussel, Belgium

ABSTRACT

A shock wave originating from a point source will expand spherically. At large distances the area of impact from this sphere is considered to be plane. For a test scenario this implicates a major problem: either the donor explosion has to be very large to generate a significant pressure at large distances or the blast wave is still spherical.
To overcome this problem researchers use multiple point sources, or a curtain of detonating cord instead of the single point source. Both these options introduce a different problem: the generated pressures and other blast parameters are hard to predict. These are measured and with iterative trial and error the desired parameters are realized.

This paper describes the first steps towards the generation of a model for predicting the blast wave parameters of a planar wave. The blast wave parameters are determined using AUTODYN, for the full range of the scaled distance Z.
First, the results of the spherical (1D) calculations are compared to several models described in literature. The generally accepted Kingery-Bulmash relations, implemented in CONWEP, are used as reference. An overall good similarity is found, as well as some specific deviations.
Next, AUTODYN is used to determine the blast wave parameters generated with a line explosion (2D) using detonating cord. These calculations are compared to the results of experiments, with special attention to the point of initiation. Based on these results, a parametric model of a line explosion is formulated.
The ultimate aim of the modeling will be the expansion of both the point and line models to a model of a plane detonation, being a set of in-plane cords, generating a plane blast wave.

INTRODUCTION

A variety of methods can be used to create a planar blast wave. The first is to simply assume a small area of a (hemi-) spherical shock front to be plane. The second is to create a Mach stem using several point sources at specific distances. The third is to use a curtain of detonating cord, with the advantage of the low total detonating weight. The third method in particular can be applied in both open air and in a shock tube. In both point and line source methods the interaction of several shock waves makes the resulting shock wave and its parameters hard to predict. In this paper the first steps towards a model for predicting the blast parameters of a planar blast wave are described.

An extensive comparison of blast wave parameters is performed to validate both the AUTODYN calculations and the measurement technique. After validations these two methods were also used to obtain the blast wave parameters of a line detonation.

AUTODYN CALCULATIONS

AUTODYN [1] is a computer modeling program for non-linear transient dynamic analysis of effects including shock, contact, impact, explosions and dynamic structural response. For the spherical detonation a 1D model is used, so a high number of cells can be used. Still, the far field values take a long time to calculate due to the small time steps when fine meshes are used. Some tricks are used to save calculation time. One trick is to delete the part of the model with the smallest cells: the detonation itself after the shockwave has properly developed. This way the timestep increases after resuming the calculations, due to the fact that the smallest cell size in the model has increased. Another method is to map an accurately calculated detonation solution on a new mesh using the remap option. An important aspect of AUTODYN calculations is to insert the correct internal energy of air, being the reference of atmospheric conditions (altitude and temperature). In these calculations the internal energy 2.068e5 μJ/mg is used. Furthermore, AUTODYN calculates absolute pressures, so the peak overpressure has to be calculated. A series of gauge points was used to export pressure-time results to a file. This file is imported into MATLAB to derive the actual shock wave parameters like positive phase duration, time of arrival and positive phase impulse.

The detonating material in the simulations is always TNT, in order to have no mistake in TNT equivalency.

SPHERICAL DETONATION

Models from literature

In literature many persons have proposed models for calculating the blast wave parameters, mainly for the peak incident pressure. These models are either based on theoretical analysis, numerical calculations or on a large number of experimental results. Some of these historical models are used in this paper to show their respective accuracy. In the last 20 years the Kingery-Bulmash [8] model (implemented in CONWEP [5]) has been accepted as being accurate, therefore CONWEP is used in this paper as reference. With the computer program CONWEP several effects of a wide range of weapons can be calculated, for example the blast wave parameters of a bare charge, for which the Kingery-Bulmash model is used. In detail (far-field pressure), some adjustments to this model were proposed to better fit the increasing number of experimental results. The best known is the modification from Kingery [12] , implemented in BEC [3] . The models, as listed in table 1, are compared mutually for the full range of the scaled distance Z ($=R/W^{1/3}$, where R is the range [m] and W is the TNT equivalent explosive weight [kg]).

Table 1 *Several models from literature for the peak incident pressure P_s*

Model	year	Equation p_s [bar] (Z in [m/kg$^{1/3}$])	range
Brode [4]	1955	$\frac{6.7}{Z^3}+1$ $\frac{0.975}{Z}+\frac{1.455}{Z^2}+\frac{5.85}{Z^3}-0.019$	$10 < p_s$ $0.1 \le p_s \le 10$
Henrych [6]	1979	$\frac{14.072}{Z}+\frac{5.540}{Z^2}-\frac{0.357}{Z^3}+\frac{0.00625}{Z^4}$ $\frac{6.1938}{Z}-\frac{0.3262}{Z^2}+\frac{2.1324}{Z^3}$ $\frac{0.662}{Z}+\frac{4.05}{Z^2}+\frac{3.288}{Z^3}$	$0.05 \le Z \le 0.3$ $0.3 \le Z \le 1$ $1 \le Z \le 10$
Naumenko & Petrovskyi [9] Sadovskyi [10]	1956 1952	$\frac{10.7}{Z^3}-1$ $\frac{0.76}{Z}+\frac{2.55}{Z^2}+\frac{6.5}{Z^3}$	$Z \le 1$ $1 \le Z \le 15$
Kinney & Graham [7]	1985	$\frac{p_s}{p_0}=\frac{808(1+(Z/4.5)^2)}{\sqrt{1+(Z/0.048)^2}\sqrt{1+(Z/0.32)^2}\sqrt{1+(Z/1.35)^2}}$	
Kingery Bulmash [8] / CONWEP [5]	1984	(defined and used in CONWEP)	
modified KB / DoD [12]	1998	*A* *B* *C* *D* *E* 7.2106 -2.1069 -0.3229 0.1117 0.0685 7.5938 -3.0523 0.40977 0.0261 -0.01267 6.0636 -1.4066 0 0 0 $\exp(A+B\ln(Z)+C\ln(Z)^2+D\ln(Z)^3+E\ln(Z)^4)$ (p_s in [kPa])	$0.2 < Z < 2.9$ $2.9 < Z < 23.8$ $23.8 < Z < 198.5$

Figure 1 shows the standard double logarithmic plot of the peak incident overpressure (p_s) versus the scaled distance Z. In this plot all models seem to give similar results, but this is partially because of the logarithmic scale used. Therefore the second plot in figure 2 gives the relative deviation from the CONWEP pressure versus the same scaled distance Z. The following conclusions can be drawn from these plots:

- In the range 1<Z<10 all models give similar results, except for BEC (and the "modified DoD", which is identical). BEC results in a better fit to experimental values of p_s, as will be shown in this paper, but these values are almost always 40% higher then CONWEP.

- In near field (Z<1), all models diverge strongly. Mind that several models have been extended to Z = 0.1, which is close to the outer radius of the explosive.

- Henrych [6] proposed 3 equations, based on experiments. The deviation, especially from the middle equation (also discussed by Smith and Hetherington [11]) is awkward, since simply adjusting the ranges from the 1st and 3rd equation to fill in the gap would lead to a more accurate solution.

- The far-field solution from Brode [4] , starting at p_s<10 kPa is deviating rapidly due to the limited range of the equation (10 kPa = 0.1 bar ≤ p_s).

- The old Russian model from Sadovskyi [10] gives results very close to CONWEP, but is only valid for the medium to far-field range: 1 < Z < 15. The other part of this curve (from [9] is based on nuclear explosions, resulting in evident different blast parameters than chemical explosions.

- The first AUTODYN results from a mediate fine mesh already give satisfactory results.

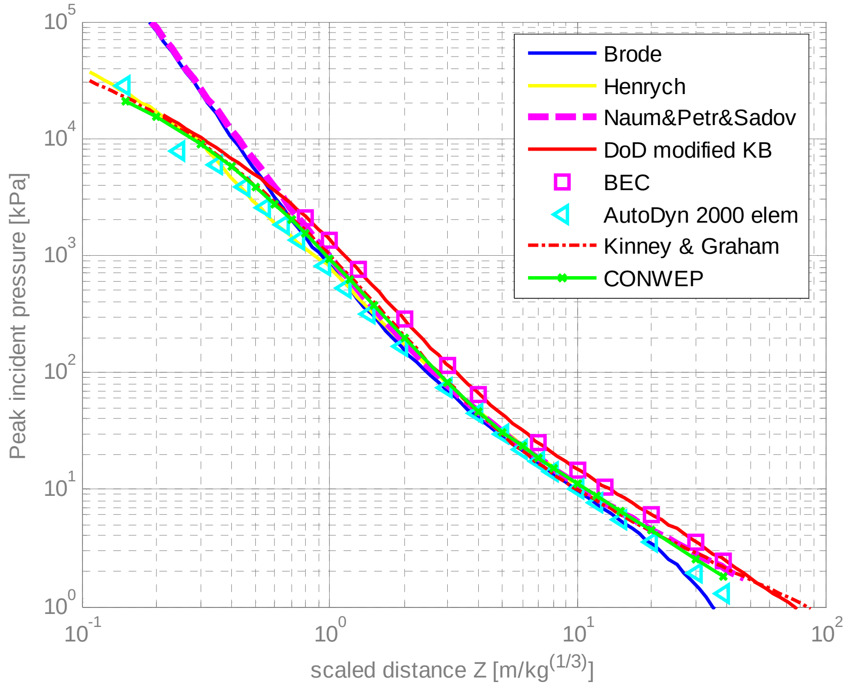

Figure 1 *Incident peak overpressure p_s versus scaled distance*

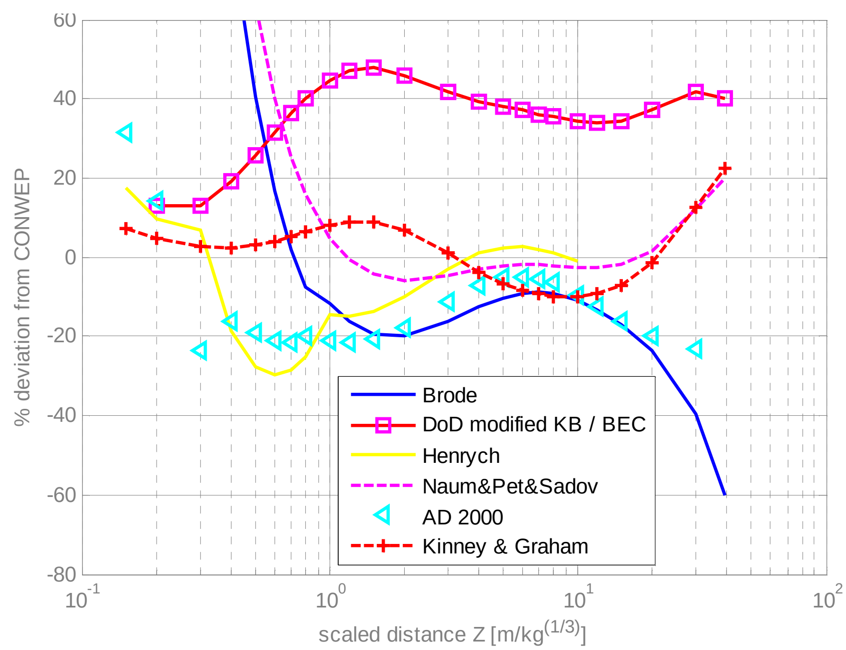

Figure 2 *Relative deviation from CONWEP of incident peak overpressure p_s versus scaled distance.*

Measurements

The Netherlands Defense Academy has acquired a set of 4 pressure sensors to measure the incident blast wave. This equipment was used in two small series of tests for validation purposes. Because of a lacking trigger signal at detonation the time of arrival could not be measured. Due to inaccuracies in the signal (noise, peak signal inaccuracies, and additional disturbing signals later on in time, possibly due to reflections) the blast wave parameters p_s and especially t_{pos} are sometimes hard to determine. Therefore each pressure-time signal was automatically curve-fitted using MATLAB, assuming each signal to be exponentially decaying. This shape, also called the Friedlander-curve ($p = p_s(1-t/t_p)e^{-\alpha t/t_p}$), is determined by three parameters: peak pressure (p_s), positive phase duration (t_p) and a wave form parameter (α).

The first series was obtained in Reek (NL), using spherical charges of 150 g pentriet (plastic explosives) for the spherical blast wave. For pentriet a TNT equivalence of 1.28 is used. The second series of measurements was obtained in Brasschaat (Be), using spherical charges of 1.493 kg M112 (plastic explosives, TNT-equivalence 1.34), resulting in a TNT equivalent spherical charge of 2.0 kg.

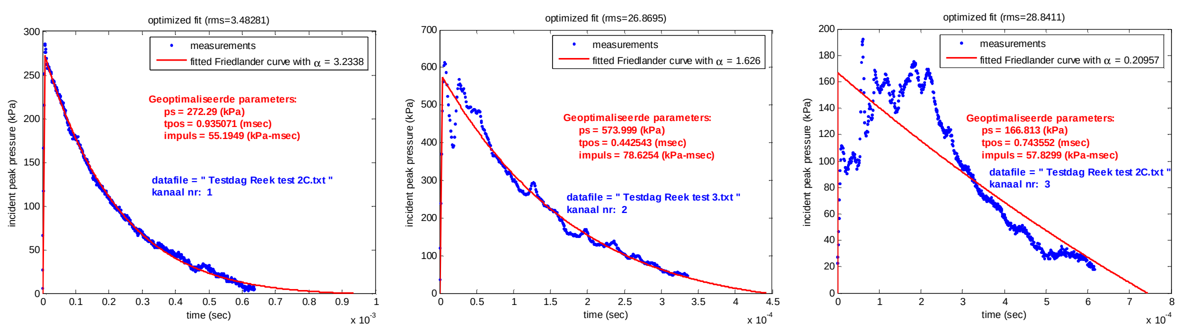

Figure 3 *Three examples of testdata fits with Friedlander curve (good, medium and bad signal)*

For consistency reasons no signals were skipped, although some signals gave a deviant shape (see figure 3), especially when measuring the near field values (Z<1). All four blast wave parameters obtained from AUTODYN simulations, measurements and three different models from literature are plotted in figure 4 to figure 7, which are similar to the graphs from side-on blast wave parameters as presented by Baker et al. [2] .

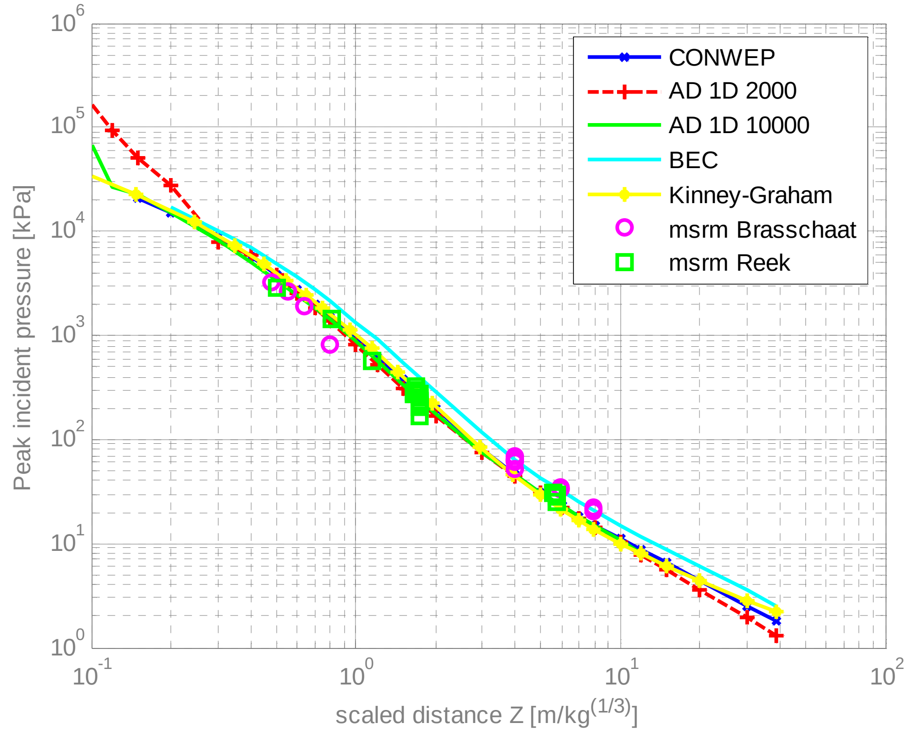

Figure 4 *Peak incident overpressure of spherical detonation (point source)*

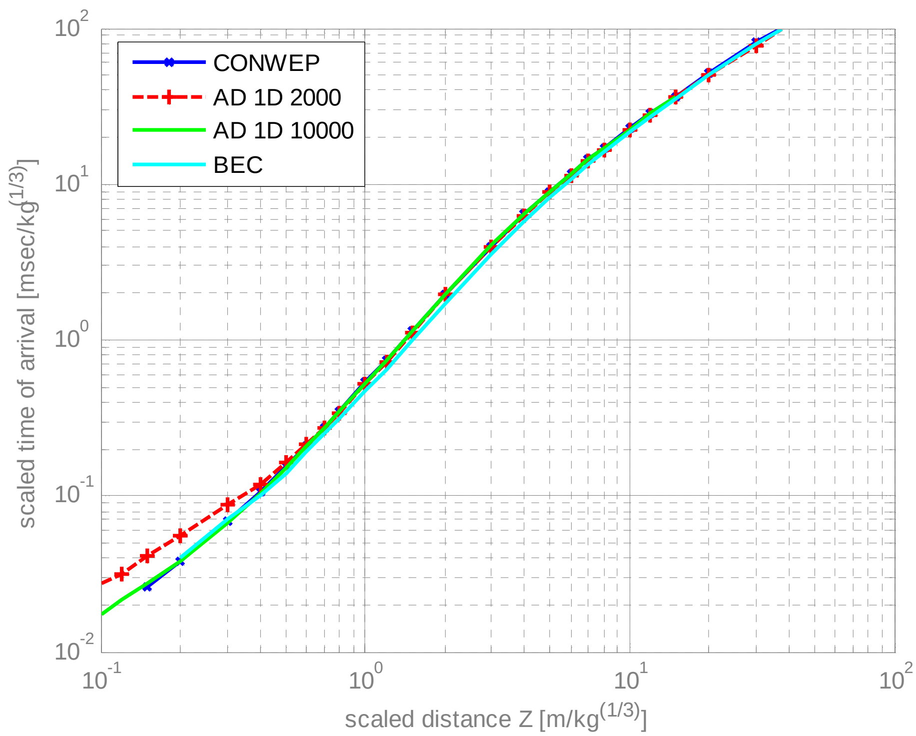

Figure 5 *Time of arrival of spherical detonation (point source)*

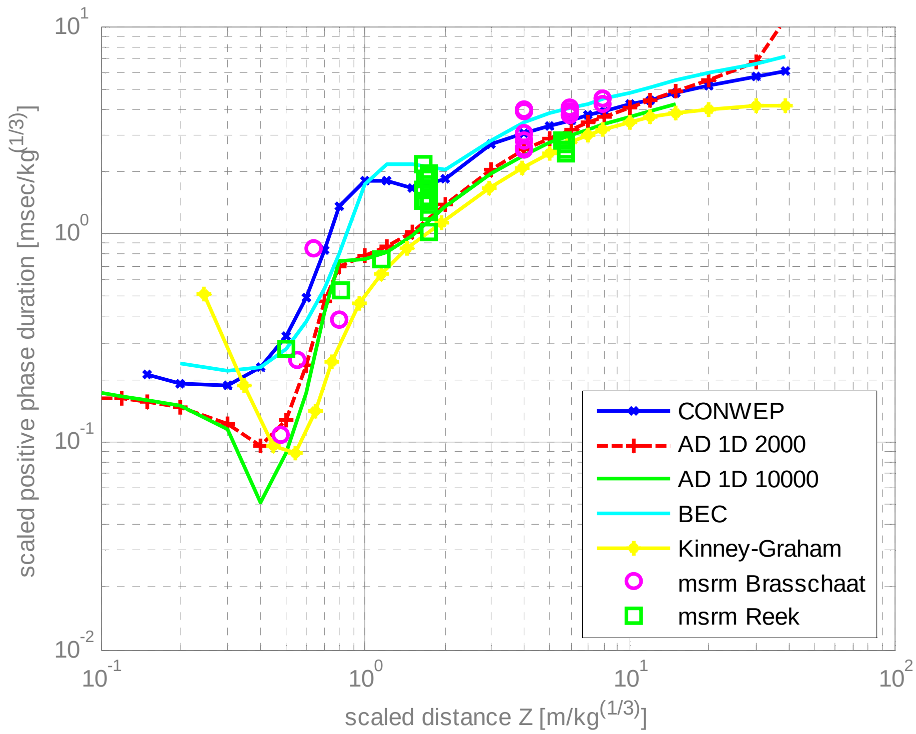

Figure 6 *Positive phase duration of spherical detonation (point source)*

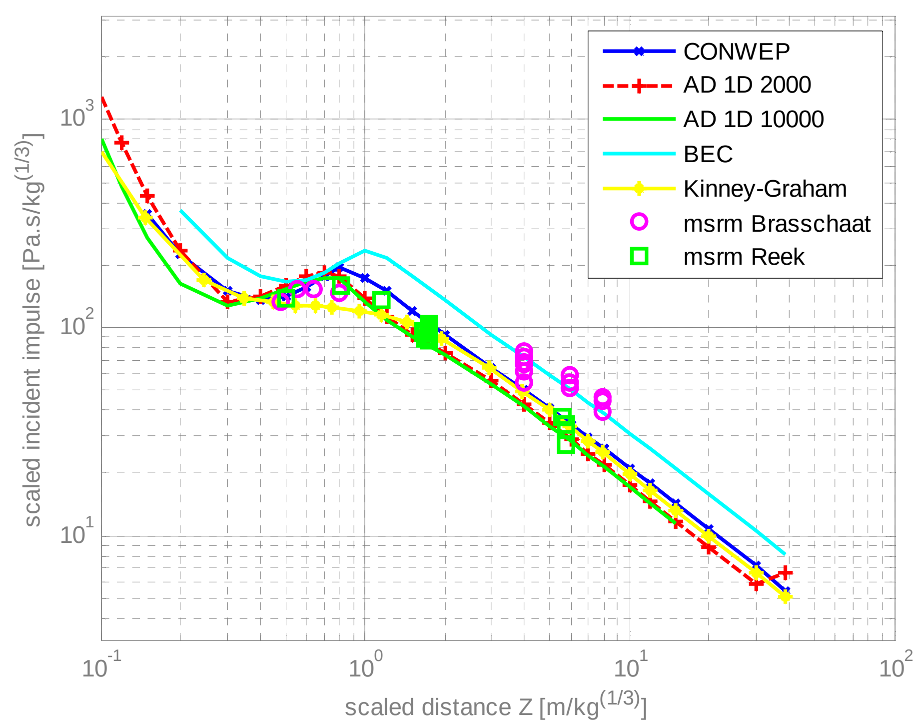

Figure 7 *Incident positive phase impulse of spherical detonation (point source)*

From figures 4-7 the following can be concluded, based on comparison with CONWEP.

- The peak incident pressures are accurately measured as well as simulated.

- The time of arrival is accurately simulated, because the curves concur with both CONWEP and BEC.

- The positive phase duration shows a 50% lower value for the simulations compared to CONWEP, especially for the lower range of Z, however the Kinney & Graham model [7] results in even lower values. These large differences can be explained by the difficulties determining the actual end of the positive phase. The pressure decays exponentially, so the gradient is the smallest at the zero crossing. Furthermore measurement noise and possible disturbing signals from reflections mask the exact zero transitions. This results in the strong variation in the measurement results for positive-phase-duration, plotted in the figure 6. These problems are universal and because the reference models are based on fits through experimental results, some deviation can be expected. The main explanation however can be found looking at the actual shape of the blast wave, obtained from the AUTODYN simulations. The non-linearity in figures 6 and 7 (Z<1) indicates a transition. Analyzing the blast wave from the simulation it is clear that it does not decay exponentially. Figure 8 shows the discrepancy for Z = 0.1 and Z = 0.3.

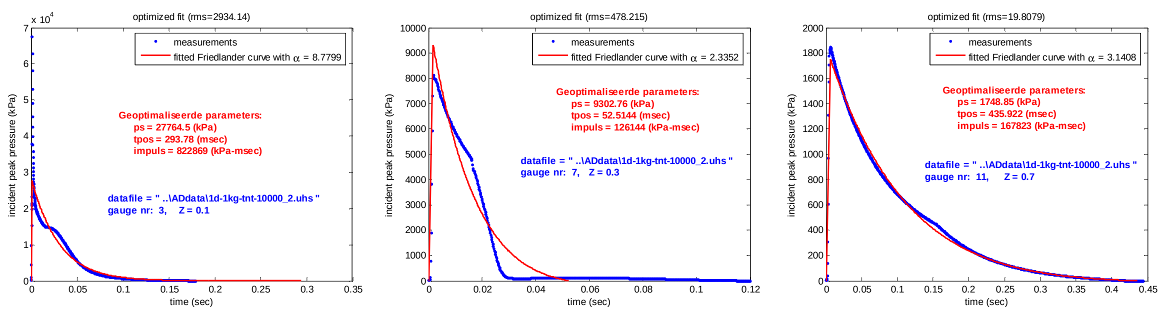

Figure 8 *Discrepancy in application of Friedlander curve for near field pressure-time response.*

The strong non-linear part of figure 6 must be considered as a transition phase and only for higher values of Z the Friedlander curve can be used to describe the blast wave shape. CONWEP however assumes the exponential shape for the full range of Z. Furthermore the measurements in the near-field region also give lower values than CONWEP.

- The impulse of the positive phase shows fairly good results, although the AUTODYN results are consistently smaller than both the models and measurements.

The AUTODYN simulations using 2000 cells are reasonably accurate, but the 10.000 cells model matches even better with CONWEP. The deviations between both AUTODYN models increase mainly in near-field, which indicates that extreme fine meshing is needed near and in the detonation.

The measurement results are within the variation of the several models and therefore acceptable. An important point of attention here is the TNT equivalency used in plotting the results, because no distinction is made between pressure- or impulse equivalency. This could explain the fit differences in figure 7: the pentriet (Reek) detonation fits better to CONWEP, where the M112 (Brasschaat) detonation fits better to BEC.

Looking at all four parameters we conclude that the simulations give a fairly good, but slightly low estimate of the actual values.

CYLINDRICAL DETONATION

The results from the spherical detonation show that AUTODYN can be used to model a detonation accurately, so we can now use AUTODYN to generate blast wave parameters for a two dimensional blast wave originating from a detonating cord. The results are verified by comparing several AUTODYN simulations, with mesh refinement and with different explosive charge weights. Additionally some measurements have been performed to validate these simulations.

<u>AUTODYN calculations</u>

The calculations for a line detonation were performed using the same wedge model is for the spherical detonation, but this time a 2D model instead of 1D model is used. Again, the detonating material in the simulations is TNT, in order to have no mistake in TNT equivalency. The radius of the detonator is much smaller (1.534 mm for 12 g/m), resulting in smaller cells, because in order to represent the detonation phase of an explosion with an acceptable degree of accuracy it is desirable to have at least 10 cells within the explosive charge [1] , in this paper 15 to 100 cells in the detonating material are used. In the simulations only the bare explosive charge is modelled, the actual confinement of detonating cord is not modelled, since this will hardly influence the results, or will cause the results to depend on the modelling of the confinement.

<u>Measurements</u>

In both measurement series (in Reek and Brasschaat) pentriet detonating cord was used. According to the specifications the (Dutch) detonating cord contains a minimum of 11 g/m, but the total roll with 30m contains 500g. Therefore an average of 16 g/m pentriet (TNT-equivalency 1.28) is used. The Belgian detonating cord contained 10 g/m pentriet, with no further details know, but for consistency reasons the same 16 g/m is assumed.

The blast pencils were positioned on different locations over the length of 6 m detonating cord, in order to determine whether the shock wave is still cylindrical. At a distance of 1 m this showed to be the case, so all measurements between 1 and 5 meter can be used. Two tests were performed twice to demonstrate reproducibility; three parameters from one sensor in 4 identical tests all varied within 3%.

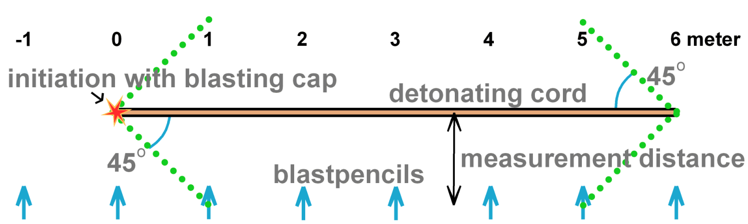

Figure 9 *Location of blast pencils in tests with detonating cord.*

The measured pressure-time plots again were curve-fitted to obtain the most reliable results. Due to the fitting routine, slight differences with the actually measured maximum pressure occured, the impulse remained constant (since the fitting-routine was actually based on the complete positive phase of the blast wave), but especially the positive phase duration obtained from the fitting procedure can be up to 100% different, because the exact location of the zero transition of the pressure is hard to recognize from the measurement signal, as was discussed in the spherical detonation section.

During the tests in Brasschaat a high speed camera recorded the detonations. The detonating proces is clearly visible and a constant detonating velocity of 6,3 km/s was derived from all the tests. One frame from a test, initiated on both sides is shown in figure 10. In a region with contrasting background (trees, not vissible in figure 10) the shock wave can be recognized. From these images the time of arrival can be determined, which was not possible from the pressure signal due to the lack of a trigger signal at detonation. These results are plotted in figure 12.

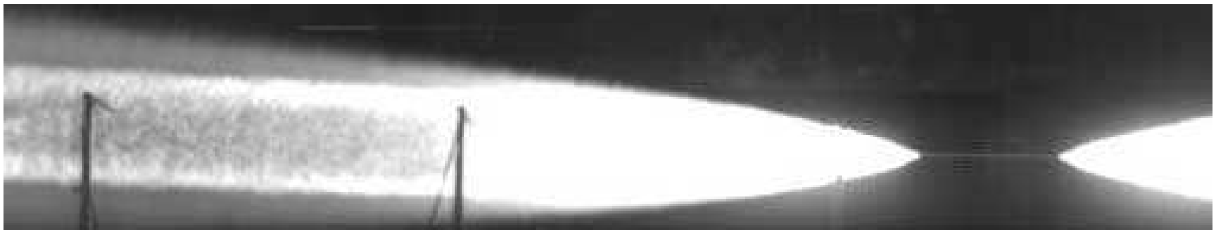

Figure 10 *High speed image of detonating cord, initiated on both sides.*

New model for line detonations

The results from both the simulations and the measurements are plotted in figures 11 to 14, where the horizontal axis indicates the square-root scaled distance $Z = R / W^{1/2}$, where the unit of W is [kg/m], so the unit of Z becomes [$m^{3/2}/kg^{1/2}$]. Except for the peak pressure all parameters are scaled as well, by dividing the parameter by the square–root of weight per meter $(kg/m)^{1/2}$. The AUTODYN simulations with three entirely different weights per meter coincide because of this scaling.

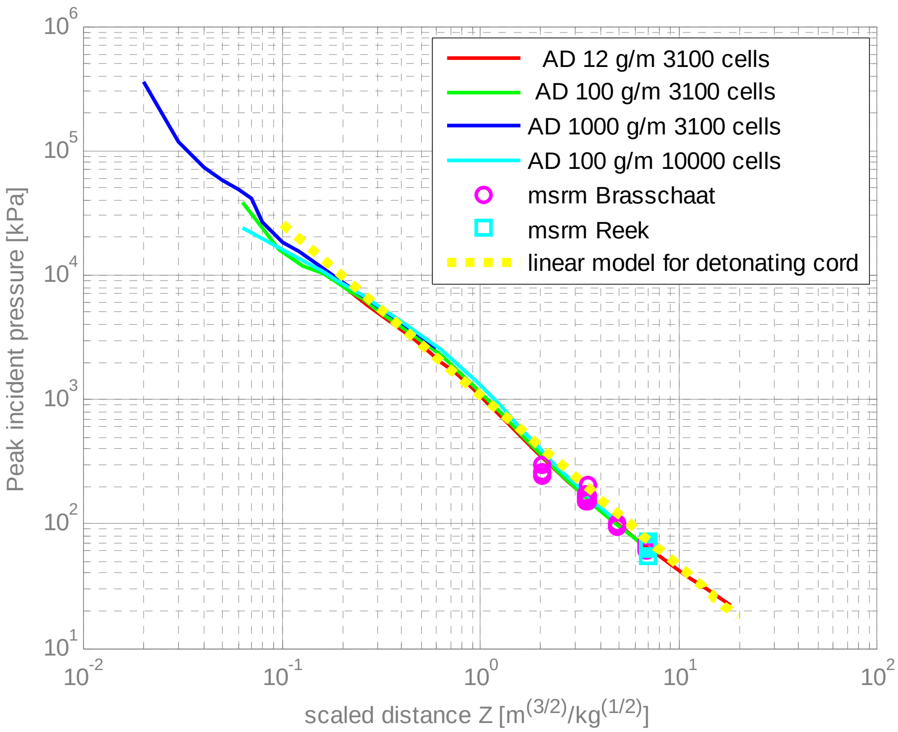

Figure 11 *Peak incident overpressure of cylindrical detonation (line source)*

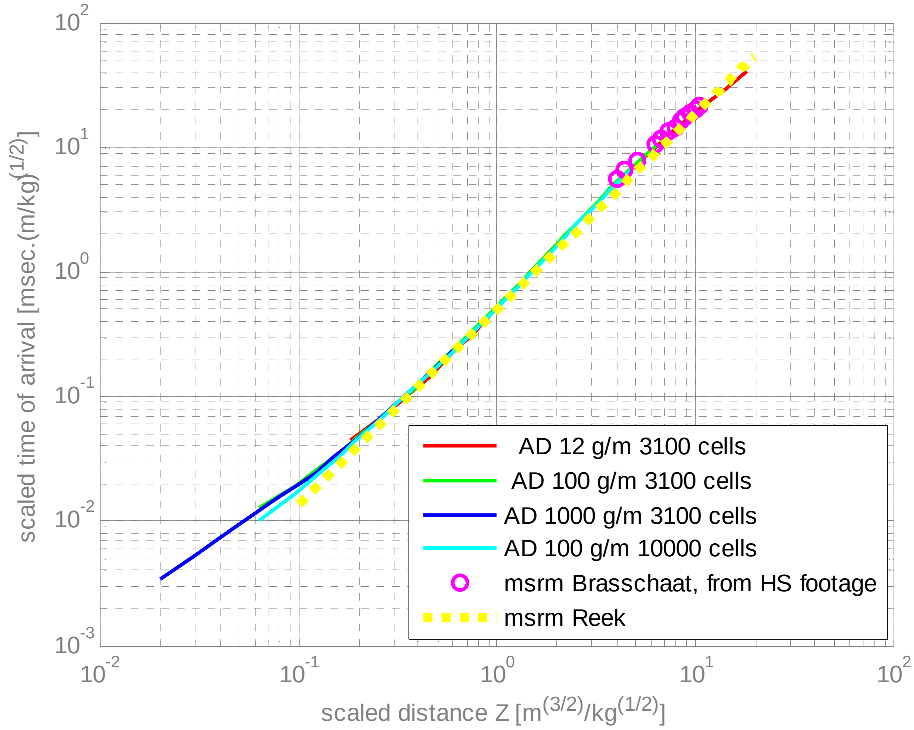

Figure 12 *Time of arrival of cylindrical detonation (line source)*

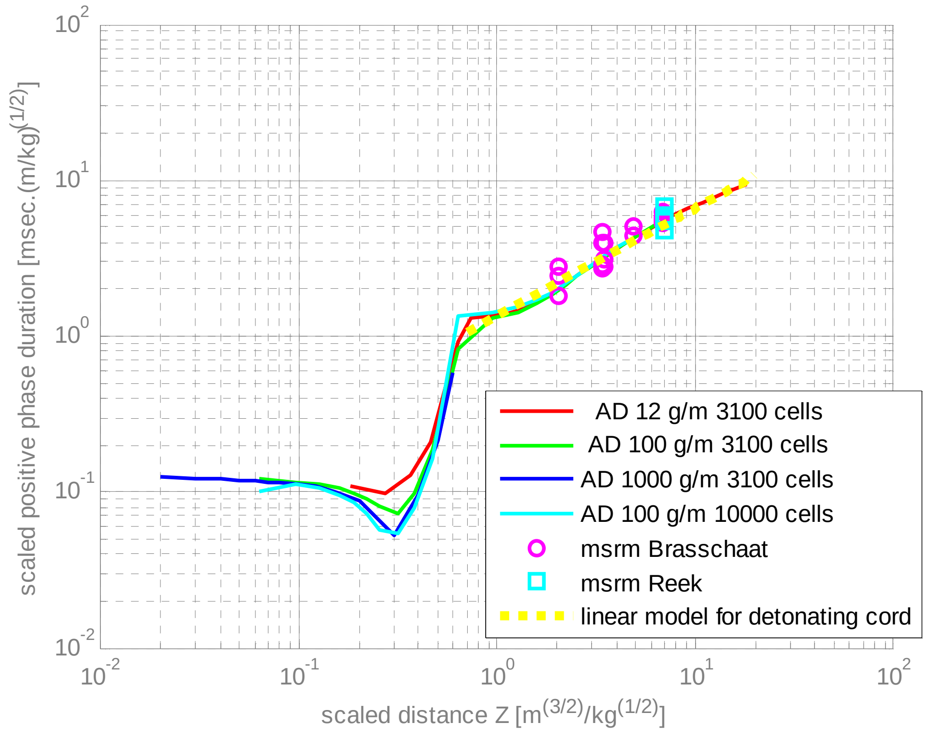

Figure 13 *Positive phase duration of cylindrical detonation (line source)*

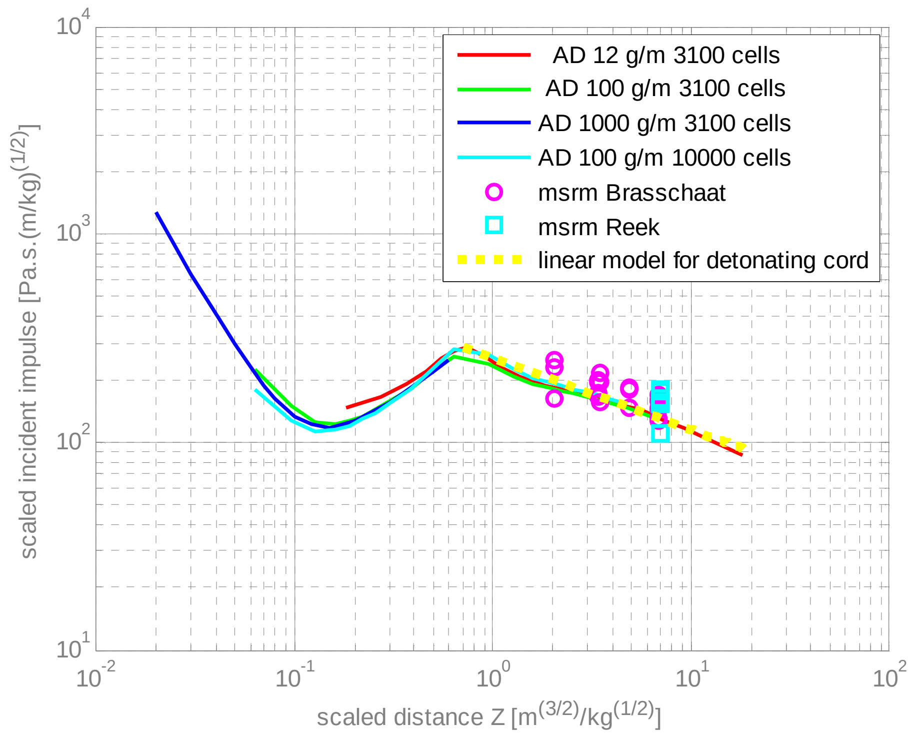

Figure 14 *Incident positive phase impulse of cylindrical detonation (line source)*

A remarkable feature in figures 13 and 14 is the non-linear behaviour in the near-field region, which is similar to the parameter plots for spherical detonation (figures 6 and 7). All four plots show a good correspondance, between the mutual AUTODYN simulations as well as between the simulations and measurements. Therefore based on these results the following models for obtaining the blast parameters are proposed for a line detonation. These models are plotted as well.

Incident peak pressure	$p_s^{wire} = 10^{-1.38\log(Z)+3.033}$	kPa	$[0.1 < Z < 20]$	*(1)*
Time of arrival	$t_{arrival}^{wire} = 10^{1.57\log(Z)-0.295}$	msec.(m/kg)$^{1/2}$	$[0.1 < Z < 20]$	*(2)*
Positive phase duration	$t_{pos}^{wire} = 10^{0.69\log(Z)+0.136}$	msec.(m/kg)$^{1/2}$	$[0.7 < Z < 20]$	*(3)*
Positive phase impulse	$I_{pos}^{wire} = 10^{-0.35\log(Z)+2.41}$	Pa.s.(m/kg)$^{1/2}$	$[0.7 < Z < 20]$	*(4)*

In these equations is $Z = R / W^{1/2}$, with R in [m] and W in [kg/m]. Mind that apart from the incident peak pressure all blast wave parameters are scaled with $W^{1/2}$. These models are relatively simple (linear in double log plot), but in the given ranges accurately fitting both the simulations as well as the measurements.

The lower limit for the positive-phase-duration and impulse models (Z = 0.7), is no disadvantage, since the application of this model is in the generation of a blast wave at a distance, since the expansion to a planar wave implies a combination of blast waves from several detonating cords in a curtain construction. The near field parameters however can be obtained from the figures 13 and 14 as we used to do for spherical detonations using the blast parameter plot (for example from Baker [2]). As in the spherical models one can apply the weight correction factor 2 for surface detonations.

The upper limit (Z = 20) could perhaps be extended since all plots show linear behaviour in this region, but this is not necessary needed because at large distances, the original cilindrical (or the future planar) blast wave transforms to a spherical shape, so the application of these models is limited. The tests showed that within a 45^o angle the blast wave can be considered cilindrical (plane), see the dotted lines in figure 9. Using a single wire (16 g/m pentriet), the upper limit of Z corresponds with a distance of almost 3 m, so in our test set-up with 6 m detonating cord only the centre blast pencil would be measuring a cylindrical wave. Assuming detonation and measuring height were sufficient to prevent ground reflection interference. This example indicates the redundancy of expanding the model to larger distances.

The simulations were performed in 2D, meaning that the detonation was initiated over the full length of the detonating cord instantaniously. In the measurements however, two types of initiation were used: single (one-sided) or double (both-sided). All parameters showed to be independent of the initiation type, however the time of arrival would vary if measured from initiation time, because of the detonation velocity in the cord and the measurement position along the cord. For this reason the actual cilindrical wave was not plane, but slightly cone-shaped. Towards a model for a planar blast wave the initiation method is a major point of concern, as will be the curtain shape (braiding), due to the interaction of individual blast waves.

Application example of the new model

Suppose detonation cord is used to force an entry in a house. A line of 4 strings, 2 meters long is used to open a door at its hinges. What would be the safety distance for the special forces, considering ear drum rupture at 35 kPa.

This must be considered as a surface explosion. Assuming the 16g/m cord as was used in our test, the detonating weight would be $W = 2.4.16.10^{-3}$ kg/m. From equation ***(1)*** one can work out the corresponding $Z = 12$, which results in a minimum distance of 4,3 m. The other equations can now be used to obtain the other shock wave parameters.

However, at this distance the blast wave will no longer be cylindrical (due to the 45^o angle, the maximum validity range of the cylindrical equations for 2 m. detonating cord is 1 m.) and the detonation must probably be considered spherical, concentrating all detonating mass into a sphere. The comparison of both models will be studied in future work.

CONCLUSION

In the validation proces of the AUTODYN simulations generally good similarity was found with both measurements and models from literature for the spherical blast parameters. On the other hand some specific differences with CONWEP were shown and discussed, especially in the positive phase duration.

The first step toward a parametric model of a planar blast wave has been set by defining equations of four blast wave parameters of a cilyndrical blast wave: the peak incident pressure, the time of arrival, the positive phase duration and the positive phase impuls. This model, listed in equations ***(1)*** to ***(4)***, is based on a curve fit of both numerical simulations and experimental results, which were shown to concur. The model can be applied for any kind of line detonation, restricted for the validity range of *Z*. A second restriction is the transformation from a cylindrical to a spherical blast wave shape for a line source with finite length, so the model can only be applied to a distance of half this line length. In the scaled distance *Z* the square-root of the explosive charge weight per length is used.

REFERENCES

[1] AUTODYN®, software for non-linear dynamics, proprietary to Century Dynamics. (1985-2006).

[2] Baker W.E., Cox P.A., Westine P.S., Kulesz J.J., Strehlow R.A., *Explosion hazards and evaluation*. Elsevier (1983)

[3] BEC (software), Swisdak, M.M, *The DDESB Blast Effects Computer, Version 4.0*, (2000)

[4] Brode H.L., *Numerical solution of spherical blast waves*. Journal of Applied Physics, No. 6, (June 1955).

[5] CONWEP (software), Hyde D.W., *Conventional Weapon Effects*. US Army Engineering Waterways Experimental Station, based on [13] (1992)

[6] Henrych J., *The dynamics of explosion and its use*. Elsevier (1979)

[7] Kinney G.F., Graham K.J., *Explosive Shocks in Air.* (2nd Edition) Springer-Verlag, New York (1985)

[8] Kingery C.N., Bulmash G. *Airblast Parameters from TNT Spherical Air Burst and Hemispherical Surface Burst*. US Army Armament Research and Development Center, Ballistics Research Lab., Aberdeen Proving Ground, Maryland. Tech. Report ARBRL-TR-02555 (1984)

[9] Naumenko I.A., Petrovski I.G., *The Shock Wave of a Nuclear Explosion*. Moskau (1956)

[10] Sadovskyi M.A., *Mechanical Effects of Air Shock Waves from Explosions According to Experiments*. Moskau (1952)

[11] Smith P.D., Hetherington J.G., *Blast and ballistic loading of structures*. Butterworth-Heinemann Ltd (1994)

[12] TB 700-2; NAVSEAINST 8020.8B; TO 11A-1-47; DLAR 8220.1, *Department of defense Ammunition and explosives hazard classification procedures*, (jan 1998)

[13] TM 5-855-1, *Fundamentals of protective design for conventional weapons*, US department of the Army, (1987)