1 of 2

E 8/93

**Approximation Functions for
Airblast Environments From Buried Charges**

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SUMMARY

In EMI report E 1/93, "Airblast Environments from Buried HE-Charges", fit functions were used for the compact description of blastwave parameters. The coefficients of these functions were approximated by means of second order polynomials versus DOB. In most cases, the agreement with the measured data was satisfactory; to reduce remaining noticeable deviations, an approximation by polygons (i.e., piecewise-linear approximation) was used instead of polynomials.

The present report describes the results of the polygon approximation and compares them to previous data. We conclude that the polygon representation leads to a better agreement with the measured data.

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SECTION 1

INTRODUCTION

In the Ernst-Mach-Institut report E 1/93 entitled "Airblast Environments from Buried HE Charges", fit functions in dependence of the ground range (GR) and the depth of burst (DOB) were given for the following airblast parameters: peak overpressure, overpressure impulse, arrival time, positive phase duration. For the measured data, y , approximations of the form

$$(Eq. 1) \quad \log y = \sum_{i=0}^3 K_i (\log GR)^i$$

were used while polynomials of the form

$$(Eq. 2) \quad K_i = \sum_{j=0}^3 k_{ji} DOB^j$$

were chosen for the coefficients K_i . Scaled values were used for GR as well as for DOB, i.e., $[GR] = m/kg^{1/3}$ and $[DOB] = m/kg^{1/3}$.

As an improvement, the following function has been chosen as approximation for the airblast parameter "arrival time" instead of equation (Eq 1):

$$(Eq. 3) \quad t_a = c_1 \cdot \log GR + c_2/GR + GR/c_0 + c_3,$$

where c_0 = sound velocity [m/s].

The approximation of the coefficients c_i ($i = 1, 2, 3$) was made by means of the polynomials defined in (Eq 2).

In general, this choice of fit functions leads to a satisfactory agreement with the measured data. Digressions, however, have been noticed that can have various causes, some of which are:

- (a) material-dependent dispersion of the characteristics of the soil material,
- (b) variations in the charge weight and of DOB,
- (c) limited accuracy of the measured values,
- (d) the degree of the approximation function is not sufficient,
- (e) the approximation of the coefficients in the form of polynoms is not sufficient.

The causes given in (a) - (c) are of experimental nature and cannot be changed later, whereas consequences on the propagation functions and DOB curves can be noticed when there is a change in the approximation.

To do this, another description of the coefficients according to (Eq 2) was made and the propagation functions and the DOB curves were re-evaluated. The aim was to evaluate whether the deviations were caused by the choice of approximations.

Details of the DOB experiments with 0.5-g Nitropenta charges in three different simulated soils and the kind of data may be found in the before-mentioned EMI report E 1/93.

SECTION 2

AIRBLAST FUNCTION

No changes were made to the form of the approximation function Eq 1, as a very exact approximation of the blast wave data could be observed at least in the blast wave region. Noticeable deviations, however, were found for the description of the coefficients K_i (Eq 2) as function of DOB by polynomials. Efforts were made to obtain a better approach by means of polygons, i.e., piecewise linear approximations.

2.1 PEAK OVERPRESSURE

2.1.1 Fit Functions

As fit functions for measured peak overpressure, expressions of the form

$$\begin{aligned} \text{(Eq. 4)} \quad \log p &= a_0 + a_1 \log (GR) + a_2 (\log (GR))^2 \\ 1 &\leq GR \text{ [m/kg}^{1/3}] \leq 10 \end{aligned}$$

were used.

The values of the coefficients a_i ($i = 0, 1, 2$) as function of DOB [cm] are shown in Figures 1 to 3. The coefficients obtained from the individual experiments are indicated (dots). For a comparison with the polygon approximation (solid lines), the corresponding polynomial curves (dotted lines) are also given.

The deviations of the experimental values from the polygon curves are lower than in the case of the polynomial approximation. The analytical description of the polygons for each coefficient is given in Table 1. The range of validity applies to the interval:

$$\begin{aligned} \text{(Eq. 5)} \quad -0.25 &\leq DOB \text{ [m/kg}^{1/3}] \leq 0.63 \\ -2 &\leq DOB \text{ [cm]} \leq 5.0 \end{aligned}$$

The corresponding data for the polynomial presentation are to be found in report E 1/93, page 17.

Aerated Grout (dry YTONG)					
A0	=	1.3469 + 0.1016 * DOB	-0.25	<= DOB <	-0.04
	=	1.0423 - 6.8060 * DOB	-0.04	<= DOB <	+0.15
	=	0.4697 - 3.0184 * DOB	+0.15	<= DOB <	+0.63
A1	=	- 3.3272 - 2.1747 * DOB	-0.25	<= DOB <	-0.04
	=	- 2.6681 + 2.7706 * DOB	-0.04	<= DOB <	+0.15
	=	- 0.7358 - 0.0102 * DOB	+0.15	<= DOB <	+0.63
A2	=	1.1827 + 1.9152 * DOB	-0.25	<= DOB <	-0.04
	=	0.7881 - 7.0330 * DOB	-0.04	<= DOB <	+0.15
	=	- 0.3182 + 0.2841 * DOB	+0.15	<= DOB <	+0.63

Water Saturated Grout (wet YTONG)					
A0	=	1.4473 + 0.4429 * DOB	-0.25	<= DOB <	-0.08
	=	0.8340 - 7.6695 * DOB	-0.08	<= DOB <	+0.16
	=	0.0338 - 2.7843 * DOB	+0.16	<= DOB <	+0.63
A1	=	- 3.3473 - 2.2962 * DOB	-0.25	<= DOB <	-0.08
	=	- 2.3183 + 1.3158 * DOB	-0.08	<= DOB <	+0.16
	=	- 0.4856 + 0.1262 * DOB	+0.16	<= DOB <	+0.63
A2	=	1.1350 + 1.8731 * DOB	-0.25	<= DOB <	-0.08
	=	0.5712 - 5.5845 * DOB	-0.08	<= DOB <	+0.16
	=	- 0.3366 - 0.0421 * DOB	+0.16	<= DOB <	+0.63

Clay/Loam					
A0	=	1.3050 - 0.3969 * DOB	-0.25	<= DOB <	-0.09
	=	0.6046 - 8.3307 * DOB	-0.09	<= DOB <	+0.13
	=	- 0.1763 - 2.1279 * DOB	+0.13	<= DOB <	+0.63
A1	=	- 2.9136 + 0.1484 * DOB	-0.25	<= DOB <	-0.09
	=	- 1.8388 + 2.3357 * DOB	-0.09	<= DOB <	+0.13
	=	- 0.0442 - 1.9081 * DOB	+0.13	<= DOB <	+0.63
A2	=	0.8448 + 0.2254 * DOB	-0.25	<= DOB <	-0.09
	=	0.3162 - 5.7686 * DOB	-0.09	<= DOB <	+0.13
	=	- 0.5459 + 1.0739 * DOB	+0.13	<= DOB <	+0.63

Table 1. Coefficients of approximation functions for *peak overpressure* vs *ground range*. DOB dependency described by polygon curves.
[DOB] = m/kg^{1/3}

2.1.2 Overpressure-Range Curves

The functions presented in Chapter 2.1.1 (Eq. 4 and Table 1) allow to calculate the overpressure-range curves for any DOB in the given interval (Eq. 5). In Figures 4 to 6, some curves for different DOBs are presented not only for polygon but also for polynomial approximation. The curves valid for HOB experiments are shown in color.

It can be noticed that the deviations of the peak overpressures vs ground range curves that are obtained in the described way are within acceptable limits.

2.1.3 Estimation of Energy Absorption by Cratering Processes

The estimation of the energy absorption was made according to the schematic in Table 2. The following result can be found:

$$(Eq. 6) \quad \Delta W/W = 1 - 0.5 (GR/R)^3$$

$$\text{where } p(GR) = p(R)$$

GR = ground range (DOB test)

$p(GR)$ = peak overpressure at GR

R = free air distance

$p(R)$ = peak overpressure at R

The function of the free-air overpressure curve is given by

$$(Eq. 7) \quad \begin{aligned} \log p &= 1.047 - 2.289 * \log R && \text{for } 0.9 < R \leq 2.45 \\ &= 0.954 - 2.253 * \log R + 0.427 * (\log R)^2 && \text{for } 2.45 < R \leq 9.8 \end{aligned}$$

$$\text{where } [R] = m/kg^{1/3}$$

The fit functions for peak overpressure at DOB tests are defined by Eq. 4 and Table 1.

The percentage of energy losses vs ground range are presented in Figures 7 to 9 for the different soil materials. The results based on polygon approximation are shown in Figures 7a, 8a, 9a, whereas Figures 7b, 8b, 9b give the evaluations based on polynomial approximation.

Table 2

**Evaluation of Energy Absorption
by Cratering Processes**

I Free Air Pressure-Range Function

$$p_f = f(R/w^{1/3})$$

p_f = peak overpressure
R = distance from charge center
w = charge weight

II DOB Pressure-Range Function

$$p_s = g_i(GR/w^{1/3}; DOB/w^{1/3})$$

GR = ground range
DOB = depth of burst

III 2W-Assumption for Ideal Surface Bursts

$$p_{s0} = g_0(GR_0/w^{1/3}; 0) = f(R_2/(2w)^{1/3}) \quad \text{where } GR_0 = R_2$$

Conclusion: from I: $p_f = \text{const}$
 $R_2/(2w)^{1/3} = R/w^{1/3}$

if $R/W_{1/3} = \text{const}$, or
 $R = R_2/2^{1/3} = GR_0/2^{1/3}$

IV Equivalent Surface Burst Assumption

$$p_s = g_i(GR/w^{1/3}; DOB/w^{1/3}) = g_0(GR_0/(w-\Delta w)^{1/3}; 0) \quad \text{where } GR = GR_0$$

V Evaluation of Energy Absorption

(Cranz-Hopkinson Similarity Law)

$$R : w^{1/3} = GR_0/2^{1/3} : (w - \Delta w)^{1/3} \quad \text{where } p_f = p_s$$

$$\text{Conclusion: } GR^3/2R^3 = 1 - \Delta w/w$$

$$\underline{\underline{\Delta w/w = 1 - 0.5 \cdot (GR/R)^3}} \quad \text{where } p(GR) = p(R)$$

Table 2. Evaluation of energy absorption by cratering processes.

The general statements made in report E 1/93 are confirmed. The energy loss based on the peak blast wave pressure is not constant, it varies with ground range. This indicates that, in the DOB tests, the peak pressure at a constant distance from ground zero is not uniformly distributed in space.

It is obvious as demonstrated by Figures 7 to 9 that the estimated energy losses due to cratering processes depends very sensitively on small errors of the approximatively calculated peak overpressures, $p(\text{GR})$, especially in the HOB region. To estimate $\Delta w/w$, the third power of the corresponding distances, R , are to insert in equation, Eq. 6. Therefore, small variations in R give rise to big changes of the energy losses.

Because the polygon approximation is more accurate than the polynomial one - as we know - the diagrams for polygon approximation are more trustworthy. Some negative $\Delta w/w$ -values, found for polynomial approximation in the HOB region, are criticized for that reason as questionable.

For different ground range positions, the percentage of energy losses is given as function of DOB in Figures 10 to 12. For each soil material, two diagrams are shown, based on polygon and polynomial approximations of the overpressure-range curves.

For reasons discussed before, negative $\Delta w/w$ -values at polynomial approximation, Figures 10b to 12b, are believed to be questionable.

2.1.4 Isobaric DOB Curves

In Figures 13 - 15, isobaric curves for the different soil materials are given in the intermediate-pressure regime. For comparison reasons, the isobaric curves in Figure 13a are shown as spline functions of the values derived from the measured overpressure-ground range curves. In Figure 13b, the isobaric DOB curves are presented as a result of the polygonal approximation whereas Figure 13c gives the result of the polynomial approximation. The same sequence is used also for the following isobaric curves. The diagrams in the low-pressure regime are presented in Figures 16 to 18.

In comparison to the diagrams with spline functions, the DOB curves were smoothed by the applied coefficient approximations, as expected. The polygonal approximation causes also the appearance of kinks in the DOB curves. Nevertheless, this approximation leads to a result

that seems more trustworthy than the polynomial approximation. The restriction has to be made here as well (compare E 1/93, page 20) that the isobaric DOB curves are, strictly speaking, only valid in the blast wave regime.

2.2 OVERPRESSURE IMPULSES

2.2.1 Fit Functions

As fit functions for the recorded overpressure impulses, relations of the form

$$\begin{aligned} \text{(Eq. 8)} \quad \log I+ &= b_0 + b_1 * \log GR + b_2 * (\log GR)^2 \\ &1 \leq GR [m/kg^{1/3}] \leq 10 \end{aligned}$$

were used.

The values of the coefficients b_i ($i = 0, 1, 2$) as function of DOB [cm] are shown in Figures 19 to 21. In addition to the data derived from each experiment (dots), the polygon (solid lines) and the polynomial (dotted lines) approximations are given. The analytical description for polygon curves can be found in Table 3. The range of validity applies to the interval:

$$\begin{aligned} \text{(Eq. 9)} \quad &- 0.25 \leq DOB [m/kg^{1/3}] \leq 0.63 \\ &- 2.0 \leq DOB [cm] \leq 5.0 \end{aligned}$$

The corresponding data for the polynomial presentation are given in report E 1/93, page 21.

2.2.2 Impulse-Range Curves

The functions presented in Chapter 2.2.1 (Eq. 8 and Table 3) allow to calculate the overpressure-impulse vs ground-range curves for any DOB in the given interval (Eq. 9). In Figures 22 to 24, some curves for different DOBs are plotted not only for polygon but also for polynomial approximations.

The deviation of the two sets of diagrams for the different soil materials remains in an acceptable range and exceeds 25 % only in a few cases.

Aerated Grout (dry YTONG)				
B0	=	0.4924 + 0.3445 * DOB	-0.25	<= DOB < -0.04
	=	0.2272 - 5.6710 * DOB	-0.04	<= DOB < +0.06
	=	- 0.0555 - 1.1834 * DOB	+0.06	<= DOB < +0.63
B1	=	- 1.3584 - 1.7787 * DOB	-0.25	<= DOB < -0.04
	=	- 0.7998 + 0.8943 * DOB	-0.04	<= DOB < +0.06
	=	- 0.0483 - 1.0318 * DOB	+0.06	<= DOB < +0.63
B2	=	0.3102 + 1.2437 * DOB	-0.25	<= DOB < -0.04
	=	- 0.0638 - 7.2393 * DOB	-0.04	<= DOB < +0.06
	=	- 0.5316 + 0.1857 * DOB	+0.06	<= DOB < +0.63

Water Saturated Grout (wet YTONG)				
B0	=	0.5397 + 0.3802 * DOB	-0.25	<= DOB < -0.08
	=	0.0966 - 5.4821 * DOB	-0.08	<= DOB < +0.10
	=	- 0.4328 - 0.2302 * DOB	+0.10	<= DOB < +0.63
B1	=	- 1.3122 - 1.5834 * DOB	-0.25	<= DOB < -0.06
	=	- 0.3806 + 3.3572 * DOB	-0.06	<= DOB < +0.03
	=	- 0.0179 - 1.0342 * DOB	+0.03	<= DOB < +0.63
B2	=	0.2740 + 1.1747 * DOB	-0.25	<= DOB < -0.06
	=	- 0.2764 - 7.5632 * DOB	-0.06	<= DOB < +0.03
	=	- 0.4689 + 0.0770 * DOB	+0.03	<= DOB < +0.63

Clay/Loam				
B0	=	0.5333 + 0.3548 * DOB	-0.25	<= DOB < -0.06
	=	- 0.0446 - 8.8204 * DOB	-0.06	<= DOB < +0.04
	=	- 0.3535 - 0.6492 * DOB	+0.04	<= DOB < +0.63
B1	=	- 1.1777 - 1.0580 * DOB	-0.25	<= DOB < -0.06
	=	0.0440 + 8.3345 * DOB	-0.06	<= DOB < 0.00
	=	0.0440 - 0.5294 * DOB	0.00	<= DOB < +0.63
B2	=	0.1773 + 0.7040 * DOB	-0.25	<= DOB < -0.06
	=	- 0.6000 - 1.6356 * DOB	-0.06	<= DOB < 0.00
	=	- 0.6000 + 0.1468 * DOB	0.00	<= DOB < +0.63

Table 3. Coefficients of approximation functions for *positive impulse vs ground range*. DOB dependency described by polygon curves.
[DOB] = m/kg^{1/3}

2.2.3 Iso-Impulse DOB Curves

In Figures 25 to 27, iso-impulse curves are given for the different soil materials. For comparison reasons, three sets of diagrams are shown, that is (a) spline function approximation, (b) polygon approximation and (c) polynomial approximation.

2.3 ARRIVAL TIMES

2.3.1 Fit Functions

For each set of arrival-time data, fit functions of the form

$$\begin{aligned} \text{(Eq. 10)} \quad t_a &= c_1 \cdot \log GR + c_2/GR + GR/c_0 + c_3 \\ &1 \leq GR \text{ [m/kg}^{1/3}\text{]} \leq 10 \end{aligned}$$

have been determined, where c_0 means sound speed in air and t_a and GR are given in cube-root scaled values.

The values of the coefficients c_i ($i = 1, 2, 3$) are shown in Figures 28 to 30. Besides the directly evaluated data from the experiments (dots), also the functions of the polygon (solid lines) and of the polynomial (dotted lines) approximations are plotted. The analytical description of the polygon curves can be found in Table 4. The range of validity applies to the interval:

$$\begin{aligned} \text{(Eq. 11)} \quad &- 0.25 \leq \text{DOB [m/kg}^{1/3}\text{]} \leq 0.63 \\ &- 2.0 \leq \text{DOB [cm]} \leq 5.0 \end{aligned}$$

The corresponding data for the polynomial presentation can be found in report E 1/93, pages 23 and 24.

2.3.2 Arrival-Time Range Curves

The function defined in Eq. 10 and Table 4 are used to calculate arrival-time vs ground-range curves. The results for polygon and polynomial approximations are presented in Figures 31 to 33.

Aerated Grout (dry YTONG)				
C1	=	-	4.1220 E-3 + 3.8812 E-3 * DOB	-0.25 <= DOB < +0.03
	=	-	4.4000 E-3 + 1.2699 E-2 * DOB	+0.03 <= DOB < +0.19
	=	-	3.3770 E-3 + 7.2862 E-3 * DOB	+0.19 <= DOB < +0.63
C2	=		2.0000 E-3 + 3.1748 E-3 * DOB	-0.25 <= DOB < -0.03
	=		1.3800 E-3 - 1.6509 E-2 * DOB	-0.03 <= DOB < +0.09
	=	-	2.0570 E-4 + 2.7224 E-4 * DOB	+0.09 <= DOB < +0.63
C3	=	-	4.2000 E-3 - 3.1748 E-3 * DOB	-0.25 <= DOB < -0.03
	=	-	3.5000 E-3 + 1.9049 E-2 * DOB	-0.03 <= DOB < +0.13
	=	-	2.0000 E-3 + 7.1433 E-3 * DOB	+0.13 <= DOB < +0.63

Water Saturated Grout (wet YTONG)				
C1	=	-	4.5572 E-3 + 1.3604 E-3 * DOB	-0.25 <= DOB < -0.03
	=	-	4.1457 E-3 + 1.4422 E-2 * DOB	-0.03 <= DOB < +0.19
	=	-	2.6436 E-3 + 6.4734 E-3 * DOB	+0.19 <= DOB < +0.63
C2	=		1.9546 E-3 + 2.5978 E-3 * DOB	-0.25 <= DOB < -0.04
	=		9.8350 E-4 - 1.9423 E-2 * DOB	-0.04 <= DOB < +0.06
	=	-	3.0270 E-4 + 9.9609 E-4 * DOB	+0.06 <= DOB < +0.63
C3	=	-	4.2561 E-3 - 2.4049 E-3 * DOB	-0.25 <= DOB < -0.04
	=	-	3.0741 E-3 + 2.4399 E-2 * DOB	-0.04 <= DOB < +0.13
	=	-	1.8000 E-4 + 1.4287 E-3 * DOB	+0.13 <= DOB < +0.63

Clay/Loam				
C1	=	-	4.5200 E-3 + 3.4923 E-3 * DOB	-0.25 <= DOB < +0.06
	=	-	5.5834 E-3 + 2.0372 E-2 * DOB	+0.06 <= DOB < +0.25
	=	-	7.7500 E-4 + 1.2898 E-3 * DOB	+0.25 <= DOB < +0.63
C2	=		1.7767 E-3 + 2.8041 E-3 * DOB	-0.25 <= DOB < -0.06
	=		5.5000 E-4 - 1.6668 E-2 * DOB	-0.06 <= DOB < +0.06
	=	-	5.6180 E-4 + 9.8101 E-4 * DOB	+0.06 <= DOB < +0.63
C3	=	-	4.2000 E-3 - 3.1748 E-3 * DOB	-0.25 <= DOB < -0.06
	=	-	2.8000 E-3 + 1.9049 E-2 * DOB	-0.06 <= DOB < +0.13
	=	-	3.4000 E-4 - 4.7622 E-4 * DOB	+0.13 <= DOB < +0.63

Table 4. Coefficients of approximation functions for *arrival time vs ground range*.
 DOB dependency described by polygon curves.
 [DOB] = m/kg^{1/3}

As could already be assumed from the deviations of the approximation values of the coefficients for the soil material clay/loam (Figure 30), considerable differences occur for this kind of soil in the arrival-time range curves (Figure 33). The polygonal approximation, however, corresponds more closely to reality.

2.3.3 Constant Arrival Time DOB Curves

In Figures 34 to 36, the iso-arrival time DOB curves are given for the different soil materials. For comparison reasons, three sets of diagrams are shown, i.e., (a) spline function approximation, (b) polygon approximation, (c) polynomial approximation, respectively.

2.4 POSITIVE PHASE DURATIONS

2.4.1 Fit Functions

For each set of positive phase duration data, fit functions of the form:

$$\begin{aligned} \text{(Eq. 12)} \quad \log t+ &= e_0 + e_1 \log GR + e_2 (\log GR)^2 \\ 1 &\leq GR [m/kg^{1/3}] \leq 10 \end{aligned}$$

have been determined. The values of the coefficients e_i ($i = 0, 1, 2$) are shown in Figures 37 to 39. Besides the directly evaluated data from the experiments (dots), also the functions of the polygonal (solid lines) and of the polynomial approximation (dotted lines) are plotted. The analytical description of the polygonal curves can be found in Table 5. The range of validity applies to the interval:

$$\begin{aligned} \text{(Eq. 13)} \quad &- 0.25 \leq DOB [m/kg^{1/3}] \leq 0.63 \\ &- 2.0 \leq DOB [cm] \leq 5.0 \end{aligned}$$

Aerated Grout (dry YTONG)					
E0	=	- 2.8800 + 1.1112 * DOB	-0.25	<= DOB <	0.00
	=	- 2.8800 - 7.3020 * DOB	0.00	<= DOB <	+0.03
	=	- 3.1639 + 1.7120 * DOB	+0.03	<= DOB <	+0.63
E1	=	0.6200 - 2.0636 * DOB	-0.25	<= DOB <	0.00
	=	0.6200 + 3.1761 * DOB	0.00	<= DOB <	+0.03
	=	1.4822 - 4.1979 * DOB	+0.03	<= DOB <	+0.31
	=	- 0.2257 + 1.2247 * DOB	+0.31	<= DOB <	+0.63
E2	=	0.0000 + 1.3493 * DOB	-0.25	<= DOB <	0.00
	=	0.0000 - 9.6838 * DOB	0.00	<= DOB <	+0.03
	=	- 0.6833 + 2.0104 * DOB	+0.03	<= DOB <	+0.31
	=	0.5429 - 1.8819 * DOB	+0.31	<= DOB <	+0.63

Water Saturated Grout (wet YTONG)					
E0	=	- 2.8300 + 1.1112 * DOB	-0.25	<= DOB <	-0.06
	=	- 3.7400 - 3.3342 * DOB	-0.06	<= DOB <	-0.03
	=	- 3.2368 + 2.6414 * DOB	-0.03	<= DOB <	+0.63
E1	=	0.6033 - 1.9311 * DOB	-0.25	<= DOB <	-0.06
	=	3.0150 + 6.3515 * DOB	-0.06	<= DOB <	-0.03
	=	1.5567 - 9.9474 * DOB	-0.03	<= DOB <	+0.06
	=	1.0618 - 2.0922 * DOB	+0.06	<= DOB <	+0.63
E2	=	0.1033 + 1.6406 * DOB	-0.25	<= DOB <	-0.06
	=	- 1.8200 - 8.8907 * DOB	-0.06	<= DOB <	-0.03
	=	- 0.7267 + 5.8202 * DOB	-0.03	<= DOB <	+0.06
	=	- 0.3998 + 0.6318 * DOB	+0.06	<= DOB <	+0.63

Clay/Loam					
E0	=	- 2.7633 + 1.3755 * DOB	-0.25	<= DOB <	-0.06
	=	- 3.2400 - 6.1909 * DOB	-0.06	<= DOB <	0.00
	=	- 3.2400 + 3.6113 * DOB	0.00	<= DOB <	+0.25
	=	- 2.4850 + 0.6151 * DOB	+0.25	<= DOB <	+0.63
E1	=	0.2633 - 3.2804 * DOB	-0.25	<= DOB <	-0.06
	=	1.3200 + 3.4929 * DOB	-0.06	<= DOB <	0.00
	=	1.3200 - 4.4169 * DOB	0.00	<= DOB <	+0.25
	=	- 0.3245 + 2.1097 * DOB	+0.25	<= DOB <	+0.63
E2	=	0.0933 + 1.4818 * DOB	-0.25	<= DOB <	-0.06
	=	- 0.4660 - 7.3973 * DOB	-0.06	<= DOB <	0.00
	=	- 0.4171 + 0.8334 * DOB	0.00	<= DOB <	+0.25
	=	- 0.1160 - 0.3611 * DOB	+0.25	<= DOB <	+0.63

Table 5. Coefficients of approximation functions for *positive peak duration vs ground range*. DOB dependency described by polygon curves.
[DOB] = m/kg^{1/3}

The corresponding data for the polynomial presentation can be found in report E 1/93, pages 25 and 26.

2.4.2 Duration Range Curves

The functions defined in Eq. 12 and Table 5 are used to calculate positive-phase duration vs ground-range curves. The results for polygon and polynomial approximations are presented in Figures 40 to 42. The deviations remain in the ordinary course. It should be pointed out that it is difficult to measure the positive phase duration and also that open points exist as to what is the correct value in porched shock fronts or compressions waves situations.

2.4.3 Constant Duration DOB Curves

In Figures 43 to 45, the DOB curves for constant positive phase duration are given. As for the other blastwave parameters, three sets of diagrams are shown, i.e., (a) spline functions approximation, (b) polygon approximation, (c) polynomial approximation, respectively.

SECTION 3

CONCLUSIONS

The second-order approximation for the coefficients of the propagation functions of the different blastwave parameters did not lead to a satisfactory description of the processes in all cases. An improvement was achieved by means of polygon approximation, although the DOB curves sometimes showed kinks at the interval boundaries. However, the achievement was made that in the experimentally investigated interval

$$- 0.25 \leq \text{DOB} [\text{m/kg}^{1/3}] \leq 0.63$$

a very simple analytical description of the blastwave parameters for any depth of burst is now available.

At the same time, the approximations used also show distinctly that the DOB curves depend strongly on small deviations in the used sets of data.

On the whole, however, it can be stated that the range of deviations is still tolerable, since -- in contrast to the usual DOB/HOB curves -- the results were presented in a very distorted scale. Apart from that, an experimentally verified transition from HOB to DOB for different blastwave parameters has been made available by the help of the consistent data material described here.

Figure 1. Coefficients of approximation functions for *peak overpressure vs ground range* at different DOB.
Aerated grout (dry YTONG)
 polynomial and polygon approximation

Figure 2. Coefficients of approximation functions for *peak overpressure vs ground range* at different DOB.
Water-saturated grout (wet YTONG)
 polynomial and polygon approximation

Figure 3. Coefficients of approximation functions for *peak overpressure vs ground range* at different DOB.
Wet clay/loam
 polynomial and polygon approximation

Figure 4. Peak overpressure vs ground range curves for different DOB
Aerated grout (dry YTONG)
 (a) polygon approximation (b) polynomial approximation

Figure 5. Peak overpressure vs ground range curves for different DOB
Water-saturated grout (wet YTONG)
 (a) polygon approximation (b) polynomial approximation

Figure 6. Peak overpressure vs ground range curves for different DOB
Wet clay/loam
 (a) polygon approximation (b) polynomial approximation

Figure 7a. Percentage of energy losses vs ground range
 Soil material: *dry aerated grout (dry YTONG)*
 Polygon approximation

Figure 7b. Percentage of energy losses vs ground range
 Soil material: *dry aerated grout (dry YTONG)*
Polynomial approximation

Figure 8a. Percentage of energy losses vs ground range
 Soil material: water-saturated grout (wet YTONG)
 Polygon approximation

Figure 8b. Percentage of energy losses vs ground range
 Soil material: water-saturated grout (wet YTONG)
 Polynomial approximation

Figure 9a.

Soil material: clay/loam
Polygon approximation

Figure 9b. Percentage of energy losses vs ground range
 Soil material: *clay/loam*
 Polynomial approximation

Figure 10a. Percentage of energy losses vs DOB at $GR = 2 [m/kg^{1/3}]$
Polygon approximation

Figure 10b. Percentage of energy losses vs DOB at $GR = 2$ [m/kg^{1/3}]
Polynomial approximation

Figure 11a. Percentage of energy losses vs DOB at $GR = 6 [m/kg^{1/3}]$
Polygon approximation

Figure 11b. Percentage of energy losses vs DOB at $GR = 6 [m/kg^{1/3}]$
Polynomial approximation

Figure 12a. Percentage of energy losses vs DOB at $GR = 10 [\text{m/kg}^{1/3}]$
Polygon approximation

Figure 12b. Percentage of energy losses vs DOB at $GR = 10 [m/kg^{1/3}]$
Polynomial approximation

Figure 13a. Isobaric DOB curves for dry aerated grout (dry YTONG) in the intermediate-pressure regime. Spline function approximation.

Figure 13b. Isobaric DOB curves for *dry aerated grout (dry YTONG)* in the intermediate-pressure regime. *Polygon approximation.*

Figure 13c. Isobaric DOB curves for *dry aerated grout (dry YTONG)* in the intermediate-pressure regime. *Polynomial approximation.*

Figure 14a. Isobaric DOB curves for water-saturated grout (wet YTONG) in the intermediate-pressure regime. Spline function approximation.

Figure 14b. Isobaric DOB curves for *water-saturated grout (wet YTONG)* in the intermediate-pressure regime. *Polygon approximation.*

Figure 14c. Isobaric DOB curves for water-saturated grout (wet YTONG) in the intermediate-pressure regime. Polynomial approximation.

Figure 15a. Isobaric DOB curves for *wet clay/loam* in the intermediate-pressure regime. Spline function approximation.

Figure 15b. Isobaric DOB curves for *wet clay/loam* in the intermediate-pressure regime. Polygon approximation.

Figure 15c. Isobaric DOB curves for *wet clay/loam* in the intermediate-pressure regime. *Polynomial approximation.*

Figure 16a. Isobaric DOB curves for *dry aerated grout (dry YTONG)* in the low-pressure regime. *Spline function approximation.*

Figure 16b. Isobaric DOB curves for *dry aerated grout (dry YTONG)* in the low-pressure regime. *Polygon approximation.*

Figure 16c. Isobaric DOB curves for *dry aerated grout (dry YTONG)* in the low-pressure regime. *Polynomial approximation.*

Figure 17a. Isobaric DOB curves for water-saturated grout (wet YTONG) in the low-pressure regime. Spline function approximation.

Figure 17b. Isobaric DOB curves for water-saturated grout (wet YTONG) in the low-pressure regime. Polygon approximation.

Figure 17c. Isobaric DOB curves for water-saturated grout (wet YTONG) in the low-pressure regime. Polynomial approximation.

Figure 18a. Isobaric DOB curves for wet clay/loam in the low-pressure regime. *Spline function approximation.*

Figure 18b. Isobaric DOB curves for wet clay/loam in the low-pressure regime. *Polygon approximation.*

Figure 18c. Isobaric DOB curves for *wet clay/loam* in the low-pressure regime. Polynomial approximation.

Figure 19. Coefficients of approximation functions for *overpressure impulse vs ground range* at different DOB.
Aerated grout (dry YTONG); polynomial and polygon approximation

Figure 20. Coefficients of approximation functions for *overpressure impulse vs ground range* at different DOB.
Water-saturated grout (wet YTONG); polynomial and polygon approximation

Figure 21. Coefficients of approximation functions for *overpressure impulse vs ground range* at different DOB.
Wet clay/loam; polynomial and polygon approximation

Figure 22. Overpressure-impulse vs ground-range curves for different DOB.
Aerated grout (dry YTONG)
 (a) polygon approximation (b) polynomial approximation

Figure 23. Overpressure-impulse vs ground-range curves for different DOB.
Water-saturated grow (wet YTONG)
 (a) polygon approximation (b) polynomial approximation

Figure 24. Overpressure-impulse vs ground-range curves for different DOB.
Wet clay/loam
 (a) polygon approximation (b) polynomial approximation

Figure 25a. Iso-impulse DOB curves for *dry aerated grout (dry YTONG)*.
Spline function approximation

Figure 25b. Iso-impulse DOB curves for *dry aerated grout (dry YTONG)*.
Polygon approximation

Figure 25c. Iso-impulse DOB curves for *dry aerated grout (dry YTONG)*.
Polynomial approximation

Figure 26a. Iso-impulse DOB curves for water-saturated grout (wet YTONG)
Spline function approximation

Figure 26b. Iso-impulse DOB curves for water-saturated grout (wet YTONG)
Polygon approximation

Figure 26c. Iso-impulse DOB curves for water-saturated grout (wet YTONG)
Polynomial approximation

Figure 27a. Iso-impulse DOB curves for wet clay/loam.
 Spline function approximation

Figure 27b. Iso-impulse DOB curves for wet clay/loam.
Polygon approximation

Figure 27c. Iso-impulse DOB curves for wet clay/loam.
Polynomial approximation

Figure 28. Coefficients of approximation functions for *arrival time vs ground range* at different DOB.
Aerated grout (dry YTONG); polynomial and polygon approximation

Figure 29. Coefficients of approximation functions for *arrival time vs ground range* at different DOB.
Water-saturated grout (wet YTONG); polynomial and polygon approximation

Figure 30. Coefficients of approximation functions for *arrival time vs ground range* at different DOB.
Wet clay/loam; polynomial and polygon approximation

Figure 31. Arrival-time vs ground-range curves for different DOB.
Aerated grow (dry YTONG)
 (a) polygon approximation (b) polynomial approximation

Figure 32. Arrival-time vs ground-range curves for different DOB.
Water-saturated grout (wet YTONG)
 (a) polygon approximation (b) polynomial approximation

Figure 33. Arrival-time vs ground-range curves for different DOB.
Wet clay/loam
 (a) polygon approximation (b) polynomial approximation

Figure 34a. Constant arrival time DOB curves for *dry aerated grout* (dry YTONG)
Spline function approximation

Figure 34b. Constant arrival time DOB curves for *dry aerated grout* (dry YTONG)
Polygon approximation

Figure 34c. Constant arrival time DOB curves for *dry aerated grout* (dry YTONG)
Polynomial approximation

Figure 35a. Constant arrival time DOB curves for water-saturated grout (wet YTONG)
 Spline function approximation

Figure 35b. Constant arrival time DOB curves for water-saturated grout (wet YTONG)
Polygon approximation

Figure 35c. Constant arrival time DOB curves for water-saturated grout (wet YTONG)
Polynomial approximation

Figure 36a. Constant arrival time DOB curves for *wet clay/loam*
Spline function approximation

Figure 36b. Constant arrival time DOB curves for *wet clay/loam*
Polygon approximation

Figure 36c. Constant arrival time DOB curves for wet clay/loam
Polynomial approximation

Figure 37. Coefficients of approximation functions for *positive phase duration vs ground range* at different DOB.
Aerated grout (dry YTONG); polynomial and polygon approximation

Figure 38. Coefficients of approximation functions for *positive phase duration vs ground range* at different DOB. *Water-saturated grout (wet YTONG); polynomial and polygon approximation*

Figure 39. Coefficients of approximation functions for *positive phase duration vs ground range* at different DOB.
Wet clay/loam; polynomial and polygon approximation

Figure 40. Positive phase duration vs ground range curves for different DOB.
Aerated grow (dry YTONG)
 (a) polygon approximation (b) polynomial approximation

Figure 41. Positive phase duration vs ground range curves for different DOB.
Water-saturated grout (wet YTONG)
 (a) polygon approximation (b) polynomial approximation

2 of 2

Figure 42. Positive phase duration vs ground range curves for different DOB.
Wet clay/loam
 (a) polygon approximation (b) polynomial approximation

Figure 43a. Constant duration DOB curves for dry aerated grout (dry YTONG)
Spline function approximation

Figure 43b. Constant duration DOB curves for *dry aerated grout (dry YTONG)*
Polygon approximation

Figure 43c. Constant duration DOB curves for *dry aerated grout (dry YTONG)*
Polynomial approximation

Figure 44a. Constant duration DOB curves for water-saturated grout (wet YTONG)
Spline function approximation

Figure 44b. Constant duration DOB curves for *water-saturated grout (wet YTONG)*
Polygon approximation

Figure 44c. Constant duration DOB curves for water-saturated grout (wet YTONG)
Polynomial approximation

Figure 45a. Constant duration DOB curves for clay/loam
Spline function approximation

Figure 45b. Constant duration DOB curves for *clay/loam*
Polygon approximation

Figure 45c. Constant duration DOB curves for clay/loam
Polynomial approximation

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