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ON SHOCK WAVES IN ROCK CREATED BY SURFACE-AND NEAR-TO-SURFACE-D--ETC(U)

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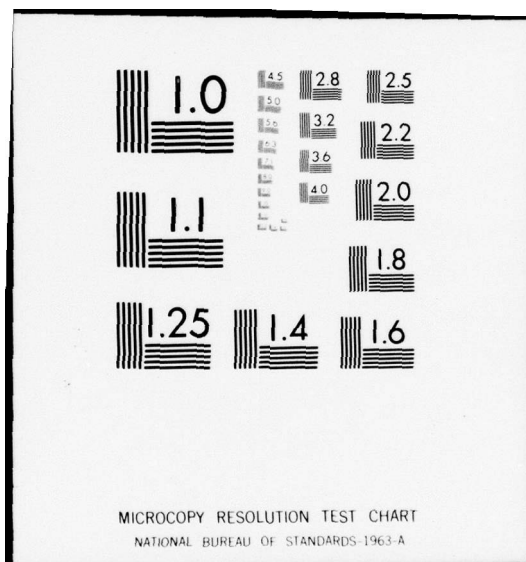
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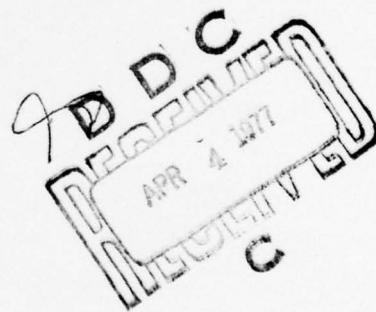
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A review is given of the research efforts sponsored by the German Defense Ministry to investigate the problem of coupling at surface bursts experi- mentally. Some results from the CENSE I experiments are also called to attention. The cratering process is connected to the evaluation of confined explosions.		

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On Shock Waves in Rock Created by Surface- or Near-to-Surface Detonations

by
Leif N. Persen

1. Introduction.

This presentation is aimed at giving a survey of the small scale experiments performed in Norway on behalf of the West-German Defense Ministry to start a research activity in the field covered by the title of this report. In addition the data from the CENSE experiments, which were obtained with much larger charges, are drawn upon to see if conclusions from the first set of data could be substantiated. The small scale experiments have been reported on in [1], the CENSE experiment is covered in [2], and the data from the latter have been obtained directly from the recordings. In addition results from some earlier experiments are drawn to attention. These have been treated separately in [3].

2. General remarks.

The general philosophy behind the small scale experiments referred to above can be outlined as follows. Usually the rock site of an installation has been tested by confined explosions. In this way the properties of the rock site as a transmitting medium may be considered known, for instance in the way described in [3]. Consequently the creation of a shock wave and its transmission through the rock may be said to be well known, provided the magnitude of the creating charge is known, and that it is detonated fully confined.

In the case of a shelter of some kind, the charge creating the shock wave is usually considered to be a surface charge of some sort. Detonation is supposed to take place above ground level, on the ground or at a certain penetration depth beneath the surface. The problem then arises how to make predictions for the propagation of the created shock wave based only on the

knowledge of the fully confined case. One way of answering this question is to perform experiments whereby the position of the charge above (or beneath) the surface is changed from one detonation to another, each time observing the created shock wave. This idea was more or less the basis for the CENSE experiments, and the result came out as diagrams of the "containment factors" for different quantities.

The small scale experiments were based on a somewhat more sophisticated philosophy. As shown in [3], pp.192-194, a possibility exists to draw direct conclusions for so-called "half buried" cases from knowledge of the fully contained case. It was therefore thought sufficient to relate cases with varying heights of the detonating charge above the surface to the "half buried" case. In this way the problem was split in two "stages", each stage being basically different from the other as the physics indicate. For positions of the charge on or close to but beneath the surface cratering becomes a problem. For positions of the charge above the surface cratering does not necessarily take place. It seems realistic to treat these two "stages" separately.

3.The experiment Vikersund.

A small scale experiment were performed in VIKERSUND, Norway. Two different geometries were used. The first one is shown in Fig.1 . A natural precipice with a rather un-eroded surface was located. In front of or at the vertical wall the charges were detonated at A. From the top of the precipice the holes 1 - 9 were drilled so that the pick-ups used for measuring strain or particle acceleration as the shock wave was transmitted could be positioned in the rock. All measuring devices were placed on the perpendicular to the surface at A. A separate hole was drilled so that a confined charge could be detonated in B. This made it possible to monitor the shock wave as it travelled in both directions between A and B, and thereby eventual systematical deviations could be detected. This part of the experiment was more or less a repetition of the experiment described in [3], pp 175-194.

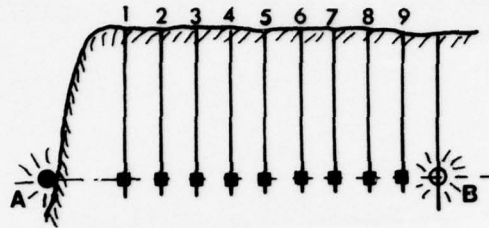


Fig.1. Geometry of the "row"-experiment at VIKERSUND, Norway.

In the second geometry used at VIKERSUND, the technique of fixing strain gauge directly to the rock was used. A hole was drilled normal to the surface of the rock as shown in Fig.2 . Strain gauges were fixed to the rock surface at different distances in the hole from the surface. The necessary wiring was led away in a sloping hole to prevent it from being broken by the explosion. The hole is then filled with concrete, and it was hoped that the signals would give a direct measurement of the strain in the rock during the passage of the shock wave. The shock wave was created

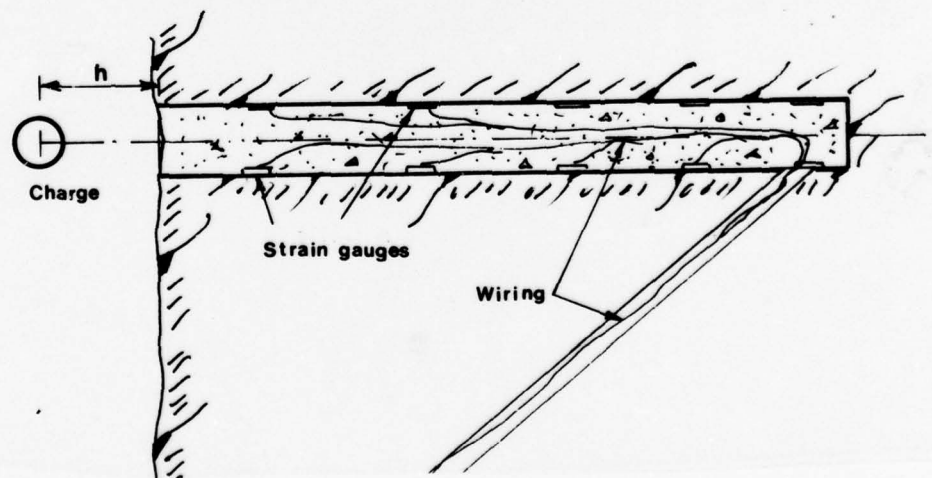


Fig.2. Geometry of the "hole"-experiment at VIKERSUND, Norway.

by letting a charge be detonated as shown, whereby the distance h and the charge magnitude W were varied from case to case. The results from these experiments will be treated separately.

4. The "row"-experiment, VIKERSUND.

In the "row"-experiment only charges in contact with the surface of the rock at A in Fig.1 were detonated. Consequently an increasing crater was developing at A as the experiment progressed. Because the magnitude W of the charge was increased gradually, one operated almost automatically with "half buried" charges.

The shots were numbered consecutively, and Table I shows how the charge magnitude was changed. The table also gives the maximum amplitude of the shock wave measured in [μ -strain] at each of the nine pickups. These details are given to illustrate the repeatability of the measurements. As shown the repeatability is not as good as one could wish, and each signal from each pickup was therefore scrutinized for "misbehaviour" which might indicate decreased reliability. It was found that only the shots A4, A5, A6, A11, A12 and A14 could be used with some confidence. The fully con-

TABLE I			Maximum amplitude A_z [μ -strain] measured at pickup No:								
Shot		W [kg]									
in	No.		$z=1$	2	3	4	5	6	7	8	9
B	1	0,5	61	83	131	190	157	183	256	610	792
B	2	2,0	58	71	71	131	-	-	214	490	875
A	3	0,5	792	238	-	-	-	-	-	-	-
A	4	0,5	582	155	22	21	11	9	-	-	-
A	5	0,5	629	190	36	34	15	12	-	22	17
A	6	2,0	1780	547	155	131	45	42	21	(32)	29
A	7	2,0	1466	309	(27)	42	20	16	-	18	12
A	8	2,0	-	285	95	98	46	36	-	41	24
B	9	2,0	23	36	60	131	78	131	250	626	933
A	10	5,0	1982	1368	268	-	-	-	-	128	63
A	11	5,0	-	893	190	238	76	58	59	85	51
A	12	15,0	-	2320	690	547	218	204	140	321	168
A	13	15,0	-	2507	489	319	171	148	154	294	139
A	14	30,0	-	4160	1082	786	278	296	357	514	274
A	42	30,0	-	4047	1071	785	171	185	330	350	245

tained shot B1, B2 and B9 will be treated separately, as these are giving the reference frame for the wave propagation for this par-

ticular rock. (the norwegian "Gneis").

The arrival times for each signal at each pickup was used to determine the signal velocity in the rock. Because the positions of the pickups are known, the arrival times t_i may be

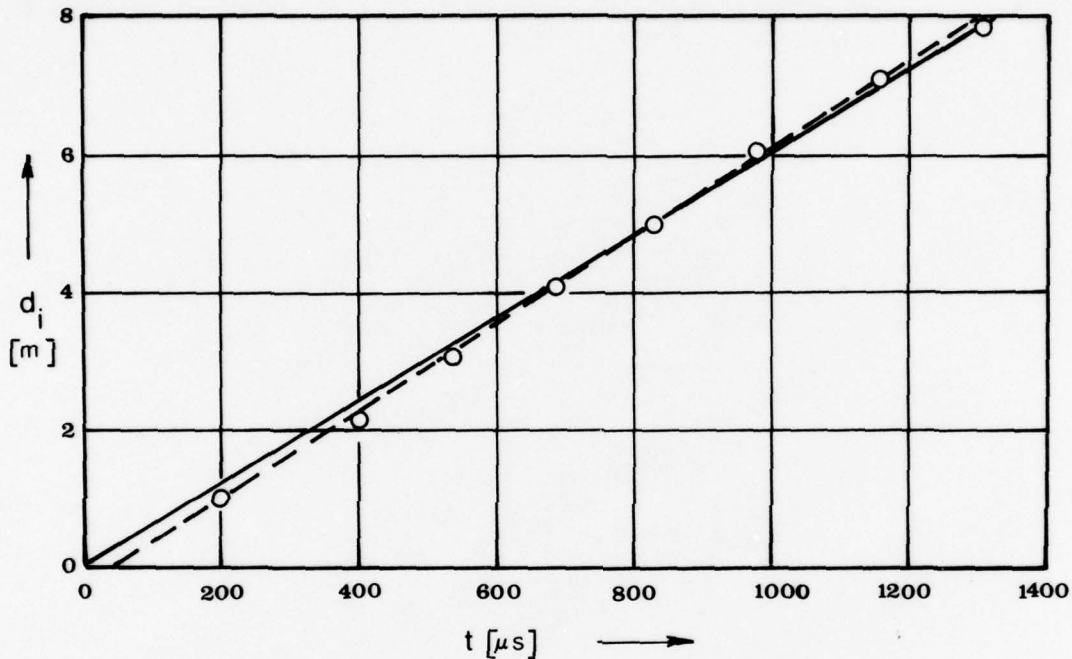


Fig.3. Arrival times t_i plotted as function of the distance d_i

plotted as a function of the distance d_i of each pickups from the point of detonation A, as shown in Fig. 3. The slope of the straight line through the points will then give the signal velocity c_s of the rock. Now there are two possibilities for defining this line:

$$\text{either: } d = d_0 + c_s t \quad (4.1)$$

$$\text{or: } d = c_s t \quad (4.2)$$

Linear regression gives:

$$\text{either: } c_s = 6327 \text{ [m/s] , } d_0 = 0.27 \text{ [m]} \quad (4.3)$$

$$\text{or: } c_s = 6030 \text{ [m/s]} \quad (4.4)$$

The two cases are illustrated in Fig.3 by a dashed line and a fully drawn line respectively. The difference between the two results amounts to 5%, and the absolute value of c_s is rather high. This rather trivial determination of the signal velocity has been given in detail here because it indicates the quality of the measurements.

The data for the "row"-experiment consists of the maximum amplitude A_i measured at pickup No. i , the dispersion C_i measured as the maximum slope of the signal in its first phase at each pickup, and the distance d_i from the explosion to the pickup. In addition the calibration constant k_i of each pickup may be considered as input data. These are now treated as shown in [3] to obtain the attenuation curves for the maximum amplitude and the dispersion. The whole procedure is given in Tables II and III, where the determination of the shot factors β , the corrected values of the non-dimensional distances $\xi_{i,corr}$ as well as of the characteristic lengths a for each shot are also shown. The dispersion data C_i have been made dimensionless using

$$c_s = 6250 \text{ [m/s]} \quad , \quad p_o = A_o^* \quad (4.5)$$

The attenuation curves will asymptotically be expressible as

$$A = A_o^* \xi^\lambda \quad (\text{for the max. ampl.}) \quad (4.6)$$

$$C = C_o^* \xi^\lambda a \quad (\text{for the dispersion}) \quad (4.7)$$

The evaluation delivers the values of A_o^* , C_o^* , λ and λ_a , with the added information of the standard deviation m given in percent of the measured values.

As mentioned some of the data obtained were rejected leaving only data from 6 of the shots to be considered. To make sure that one has not introduced any irrelevant regularity by this selection, the shots A12 and A14 with the larger charges were also

TABLE III

Shot No.	Pickup i	ξ_i corr	C_i [μ -str/ μ s]	k_i [μ -str/atm]	a [m]	$\frac{a \cdot 10^4}{A_0 C_i}$	$\frac{C_i}{P_0 C_i}$
A4	1	16.95	28.7	3.16151	.06607	2.54270	2.305-2
0.5 kg	2*	32.09	4.17	4.86875			2.178-2
	3*	49.64	0.50	3.21412			3.956-5
	4*	63.27	0.46	4.38324			2.568-5
	5*	78.86	0.22	3.33552			1.677-5
	6*	92.33	0.32	3.01506			(2.599-5)
	7			3.15001			
	8						
	9						
A5	1	14.37	31.0	3.16151	.07792	2.99859	2.940-3
0.5 kg	2*	27.21	6.55	4.86875			4.034-4
	3*	42.09	0.86	3.21412			8.024-5
	4*	53.65	0.86	4.38324			3.831-5
	5*	66.86	0.21	3.33552			1.888-5
	6*	78.29	0.32	3.01506			(2.877-5)
	7						
	8						
	9						
A6	1	8.07	73.3	3.16151	.13882	5.34232	1.259-2
2.0 kg	2*	15.27	19.2	4.86875			2.107-3
	3*	23.63	4.60	3.21412			7.646-4
	4*	30.11	2.96	4.38324			3.602-4
	5*	37.53	0.97	3.33552			1.554-4
	6*	43.94	1.76	3.01506			(3.119-4)
	7		0.74				
	8		1.05				
	9		0.48				
A11	1	12.52	26.0	3.16151	.16933	6.51652	3.480-3
5.0 kg	2*	19.37	4.39	4.86875			8.901-4
	3*	24.69	4.50	3.21412			6.590-4
	4*	30.77	1.14	4.38324			2.227-4
	5*	36.02	1.37	3.33552			(2.961-4)
	6*	42.34	0.63	3.01506			1.303-4
	7	48.49	0.56				
	8	53.03	0.46				
	9						
A12	1	7.59	80.0	3.16151	.27944	1.07541	
15.0 kg	2*	11.74	25.0	4.86875			1.767-2
	3*	14.96	15.4	3.21412			5.522-3
	4*	18.64	7.90	4.38324			3.775-3
	5*	21.83	7.79	3.33552			2.847-3
	6*	25.66	4.91	3.01506			(2.779-3)
	7	29.38	1.93	3.15001			1.676-3
	8	32.14					
	9						
A14	1	6.29	143.0	3.16151	.33685	1.29637	3.808-2
30.0 kg	2*	9.74	40.0	4.86875			1.613-2
	3*	12.41	18.2	3.21412			5.283-3
	4*	15.47	9.69	4.38324			3.374-3
	5*	18.11	8.36	3.33552			(3.594-3)
	6*	21.29	6.90	3.01506			2.840-3
	7	24.37	10.40	3.15001			
	8	26.66	3.92	2.89311			
	9						

TABLE II

Shot No.	Pickup i	d_i [m]	A_i [μ -strain]	k_i [μ -str/atm]	a [m]	ξ_i corr	A_i [atm]	β
A4	1	1.12	582	3.16151	.066	16.95	(184.09)	5.83987
0.5 kg	2*	2.12	155	4.86875		32.09	31.84	
	3*	3.28	22	3.21412		49.64	6.84	
	4*	4.18	21	4.38324		63.27	4.70	
	5*	5.21	11	3.33552		78.86	3.30	
	6*	6.10	9	3.01516		92.33	2.99	
	7	7.17	-	3.15001		-	-	
	8	8.21	-	3.22872		-	-	
	9	9.98	-	2.89311		-	-	
A5	1	1.12	629	3.16151	.078	14.37	(198.96)	4.09469
0.5 kg	2*	2.12	190	4.86875		27.21	39.02	
	3*	3.28	36	3.21412		42.09	11.20	
	4*	4.18	34	4.38324		53.65	7.76	
	5*	5.21	15	3.33552		66.86	4.50	
	6*	6.10	12	3.01516		78.29	3.98	
	7	7.17	-	3.15001		-	-	
	8	8.21	-	3.22872		-	(6.81)	
	9	9.98	-	2.89311		-	(5.88)	
A6	1	1.12	1780	3.16151	.139	8.07	(503.-)	1.18147
2.0 kg	2*	2.12	547	4.86875		15.27	112.3	
	3*	3.28	155	3.21412		23.63	48.2	
	4*	4.18	131	4.38324		30.11	29.9	
	5*	5.21	45	3.33552		37.53	13.5	
	6*	6.10	42	3.01516		43.94	13.9	
	7	7.17	21	3.15001		-	(6.7)	
	8	8.21	22	3.22872		-	-	
	9	9.98	29	2.89311		-	-	
A11	1	1.12	893	3.16151	.169	12.52	183.4	.77039
5.0 kg	2*	2.12	190	4.86875		19.37	59.1	
	3*	3.28	238	3.21412		24.69	54.3	
	4*	4.18	76	4.38324		30.77	22.8	
	5*	5.21	58	3.33552		36.02	19.2	
	6*	6.10	59	3.01516		-	(18.7)	
	7	7.17	59	3.15001		-	(26.3)	
	8	8.21	85	3.22872		-	(17.6)	
	9	9.98	51	2.89311		-	-	
A12	1	1.12	-	3.16151	.279	7.59	176.5	.26209
15.0 kg	2*	2.12	2320	4.86875		11.74	214.7	
	3*	3.28	690	3.21412		14.96	124.8	
	4*	4.18	547	4.38324		18.64	65.8	
	5*	5.21	218	3.33552		21.83	67.7	
	6*	6.10	204	3.01516		-	(44.4)	
	7	7.17	146	3.15001		-	(99.4)	
	8	8.21	321	3.22872		-	-	
	9	9.98	163	2.89311		-	(58.1)	
A14	1	1.12	-	3.16151	.337	6.29	854.4	.17530
30.0 kg	2*	2.12	1460	4.86875		9.74	336.6	
	3*	3.28	1032	3.21412		12.41	179.3	
	4*	4.18	766	4.38324		15.47	83.4	
	5*	5.21	278	3.33552		18.11	98.2	
	6*	6.10	296	3.01506		-	(113.3)	
	7	7.17	357	3.15001		-	(150.2)	
	8	8.21	414	3.22872		-	(94.7)	
	9	9.98	274	2.89311		-	-	

TABLE V

Shot No.	i	C_i [μ-str/μs]	k_i [μ-str/atm]	a [m]	$\frac{a \cdot 10^4}{A \cdot C_i}$	ξ_i corr	$\frac{C_i \cdot a}{F \cdot C_i \cdot k_i}$
A4 0.5 kg	1	28.7	3.16151	.06635	2.55364	31.95	2.318·10 ⁻³
	2	4.17	4.86875			49.43	2.187·10 ⁻⁴
	3	.50	3.21412			62.99	3.373·10 ⁻⁵
	4	.46	4.38324			78.52	2.660·10 ⁻⁵
	5	.22	3.33552			91.93	1.684·10 ⁻⁵
	6	.32	3.01506				(2.710·10 ⁻⁵)
	7		3.15001				
	8						
	9						
A5 0.5 kg	1	31.0	3.16151	.07817	3.00817	27.12	2.350·10 ⁻³
	2	6.55	4.86875			41.96	4.047·10 ⁻⁴
	3	.86	3.21412			53.48	8.048·10 ⁻⁵
	4	.56	4.38324			66.65	3.843·10 ⁻⁵
	5	.21	3.33552			78.04	1.894·10 ⁻⁵
	6	.32	3.01506				(3.193·10 ⁻⁵)
	7		3.15001				
	8						
	9						
A6 2.0 kg	1	73.3	3.16151	.13870	5.33797	15.28	1.238·10 ⁻²
	2	19.2	4.86875			23.65	2.105·10 ⁻³
	3	4.60	3.21412			30.14	7.640·10 ⁻⁴
	4	2.96	4.38324			37.56	3.605·10 ⁻⁴
	5	.97	3.33552			43.98	1.552·10 ⁻⁴
	6	1.76	3.01506				(3.116·10 ⁻⁴)
	7	.74	3.15001				
	8	1.05					
	9	.48					
A11 5.0 kg	1	26.0	3.16151	.16896	6.50234	12.55	3.472·10 ⁻³
	2	4.39	4.86875			19.41	8.881·10 ⁻⁴
	3	4.50	3.21412			24.74	6.676·10 ⁻⁴
	4	1.14	4.38324			30.84	2.222·10 ⁻⁴
	5	1.37	3.33552			36.10	(2.355·10 ⁻⁴)
	6	.63	3.01506				
	7	.56	3.15001				
	8	.46					
	9						

TABLE IV

Shot No.	i	d_i [m]	A_i [μ-str]	k_i [μ-str/atm]	a [m]	ξ_i corr	A_i [atm]
A4 0.5 kg	1	1.12	590	3.16151	.06635	31.95	31.84
	2	2.12	155	4.86875		49.43	6.84
	3	3.38	22	3.21412		62.99	4.79
	4	4.18	21	4.38324		78.52	3.30
	5	5.21	11	3.33552		91.93	2.99
	6	6.10	9	3.01506			
	7	7.17	-	3.15001			
	8	8.21	-	3.22872			
	9	9.99	-	2.89311			
A5 0.5 kg	1	1.12	629	3.16151	.07817	27.12	39.02
	2	2.12	190	4.86875		41.96	11.20
	3	3.38	36	3.21412		53.48	7.76
	4	4.18	34	4.38324		66.65	4.50
	5	5.21	15	3.33552		78.04	3.98
	6	6.10	12	3.01506			
	7	7.17	-	3.15001			
	8	8.21	22	3.22872			
	9	9.99	17	2.89311			
A6 2.0 kg	1	1.12	1780	3.16151	.13870	15.28	112.3
	2	2.12	547	4.86875		23.65	48.2
	3	3.38	155	3.21412		30.14	29.9
	4	4.18	131	4.38324		37.56	13.5
	5	5.21	45	3.33552		43.98	13.9
	6	6.10	42	3.01506			
	7	7.17	21	3.15001			
	8	8.21	(32)	3.22872			
	9	9.99	29	2.89311			
A11 5.0 kg	1	1.12	-	3.16151	.16896	12.55	183.4
	2	2.12	893	4.86875		19.41	59.1
	3	3.38	190	3.21412		24.74	34.3
	4	4.18	238	4.38324		30.84	22.8
	5	5.21	76	3.33552		36.10	19.2
	6	6.10	58	3.01506			
	7	7.17	59	3.15001			
	8	8.21	85	3.22872			
	9	9.99	51	2.89311			

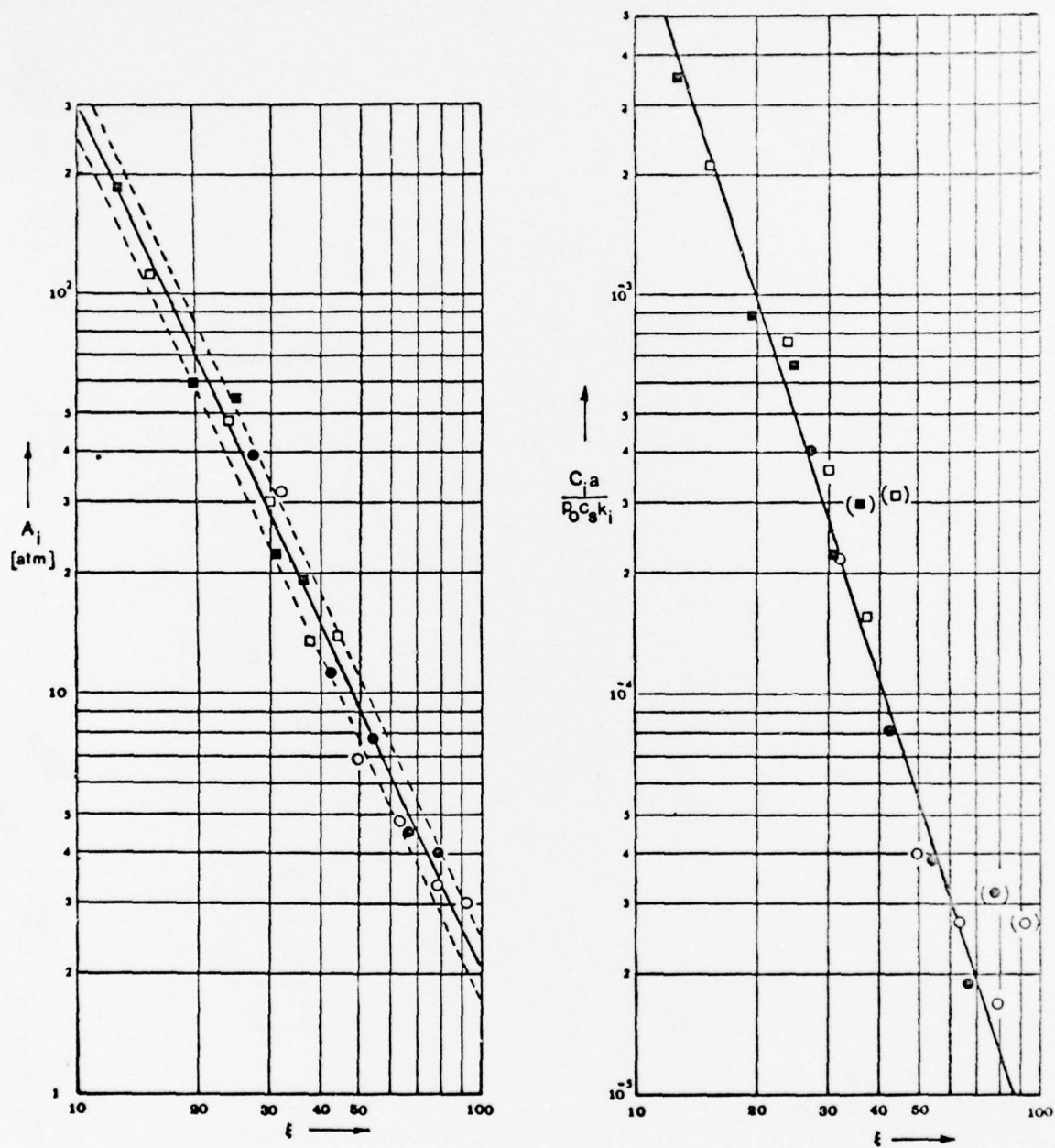


Fig.4. The resulting attenuation curves for the maximum amplitude A_i and for the non-dimensional "dispersion" $C_i a / p_0 c_s k_i$ (Half buried charges)

neglected and the evaluation repeated as shown in the Tables IV and V. Inspection of the data reveals that only data from the pickups No.2,3,4,5 and 6 can be relied upon. Those data are marked with a star (*) in the tables.

The results for the six shots as well as for the four shots are as follows:

For the 6 shots:
(Tables II and III)

$$\begin{aligned} A_O^* &= 41576 \text{ [atm]} \\ \lambda &= -2.15234 \\ m &= \pm 17.8\% \end{aligned}$$

$$\begin{aligned} C_O &= 10.88044 \\ \lambda_a &= -3.11369 \\ m &= \pm 24.7\% \end{aligned}$$

For the 4 shots:
(Tables IV and V)

$$\begin{aligned} A_O^* &= 43765 \text{ [atm]} \\ \lambda &= -2.16719 \\ m &= \pm 18.5\% \end{aligned} \quad (4.8)$$

$$\begin{aligned} C_O &= 11.83964 \\ \lambda_a &= -3.14128 \\ m &= \pm 23.6\% \end{aligned} \quad (4.9)$$

For all practical purposes these results may be considered as identical.

Tables IV and V show the legend used when the result is plotted in Fig.4 .

Unfortunately the data from the fully confined charges detonated in B in Fig.1 are not reliable. The reason for rejecting data from the pickups No.7,8 and 9 in the evaluation of the surface charges was, that the signals showed a behaviour which could be interpreted as caused by a major crack in the rock between pickups No.6 and 7. In this case the shock wave travels in the opposite direction, and one would expect only data from the pickups No. 9,8, and 7 to be relevant. The data are plotted in Fig.5 and it is observed that the wave from the 0.5 kg charge is damped less than the wave from the 2.0 kg charge. Consequently the smaller charge creates a larger maximum amplitude in the shock wave after a certain distance than the larger one, a result which must be rejected on physical grounds.

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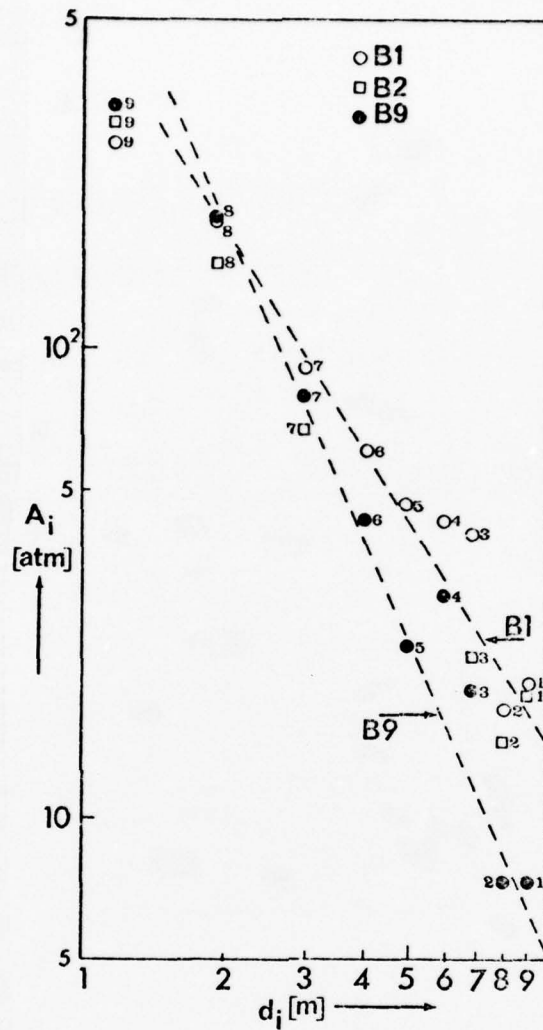


Fig. 5. Data from shots B1, B2 and B9 with the attenuation curves derived from the data of B1 and B9 separately.

Difficulties occurred with the charge in shot B2. The data from this shot are therefore neglected. The dashed lines in Fig. 5 show the attenuation curves given by the two shots B1 and B9 separately. The deviation is so great that further attempts at drawing meaningful conclusions from these data are thought futile. This means that the previously established correlation between the effect of a half buried charge as compared with a fully contained charge could not be checked.

[illegible]

the surface. The maximum amplitudes of the shock waves measured in [μ -strain] at each strain gauge as well as the specifications of each shot (distance above the surface h and charge magnitude W) are given in TABLE VI.

It is observed that the instrumentation of this experiment is different from the one used in the "row"-experiment. The question of whether or not the type of instrumentation influences the data such that conclusions drawn on the physical behaviour really reflects instrument-induced errors becomes important. It is therefore imperative somehow to connect the results from this experiment with that of the "row"-experiment. This occurs first through the determination of the signal velocity of the rock. In Fig.7 are the arrival times t_a of the signals at the different pickups and the distance d travelled plotted against each other for the shots 16, 18, 20, 37 and 38. The data exhibit a comparatively large scatter,

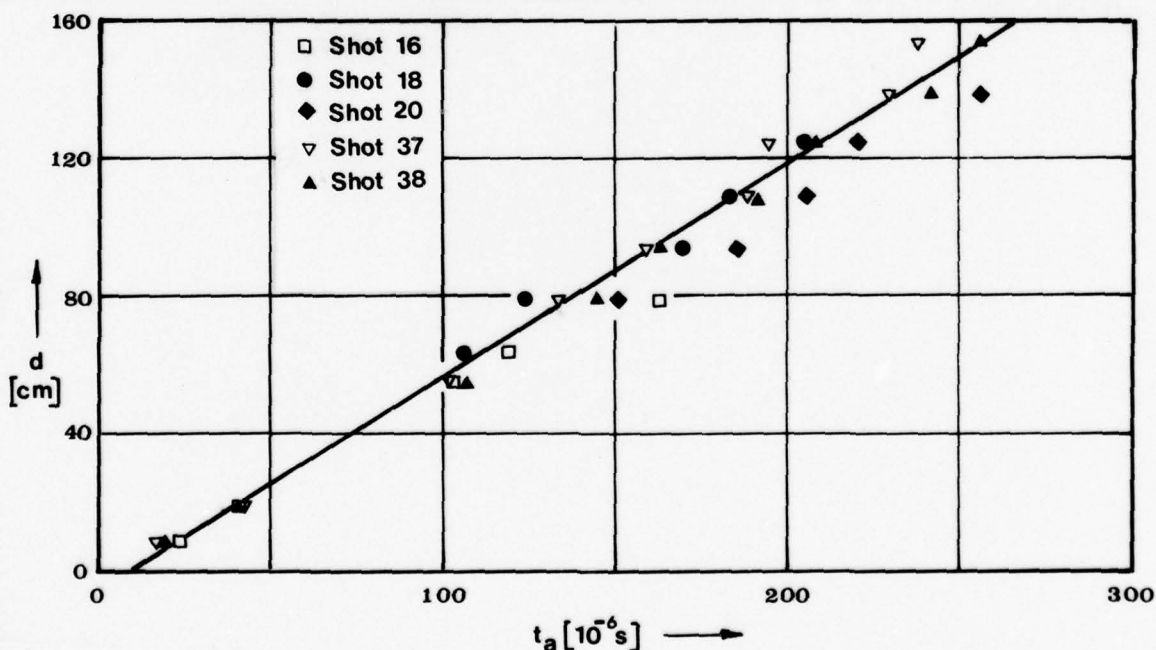


Fig.7 . Arrival time t_a of the shock wave at the pickups related to the distance d travelled. "Hole"-experiment, VIKERSUND:

but the straight line through these points, determined by linear regression, gives through its slope the signal velocity c_s as follows:

$$c_s = 6210 \text{ [m/s]}, \quad b = 5.18 \text{ [m]} \quad (5.1)$$

where b is the distance at which $t = 0$, leaving an impression of the accuracy of the measurements. The agreement between the results (4.3), (4.4) and (5.1) is satisfactory.

The only data in Table VI which may be compared to the results obtained in the "row"-experiment are the ones from the shots 40 and 41. Only in these two cases did one have the charges in contact with the rock's surface. The data are repeated in Table VII which also gives the legend for the points in Fig.8 .

TABLE VII

Shot No.	Pickup i	d_i [cm]	A_i [μ-str]
40 ◇	1	190	86
	2	175	87
	3	161	119
	4	145	140
	5	130	156
	6	130	180
	7	115	226
	8	100	256
	9	91	278
	10	80	-
	11	55	927
	12	55	943
41 ●	1	190	84
	2	175	81
	3	161	105
	4	145	125
	5	130	140
	6	130	164
	7	115	-
	8	100	-
	9	91	378

The straight line through the data points will have a slope λ which can be determined by linear regression:

$$\lambda = -1.9779 \quad (5.2)$$

This value should be compared with the values obtained in (4.8). A better idea of the agreement between the two cases is however obtained by comparing the results in an attenuation diagram. Fig.8 shows this where the fully drawn line represents the attenuation curve determined from the data shown, and the dashed line represents the attenuation curve obtained from the results of the

"row"-experiment with $\alpha = 0.06635 \text{ [m]}$

for a charge $W = 0.5 \text{ [kg]}$ and with a mean value of $k = 3.1 \text{ [μ-str/atm]}$

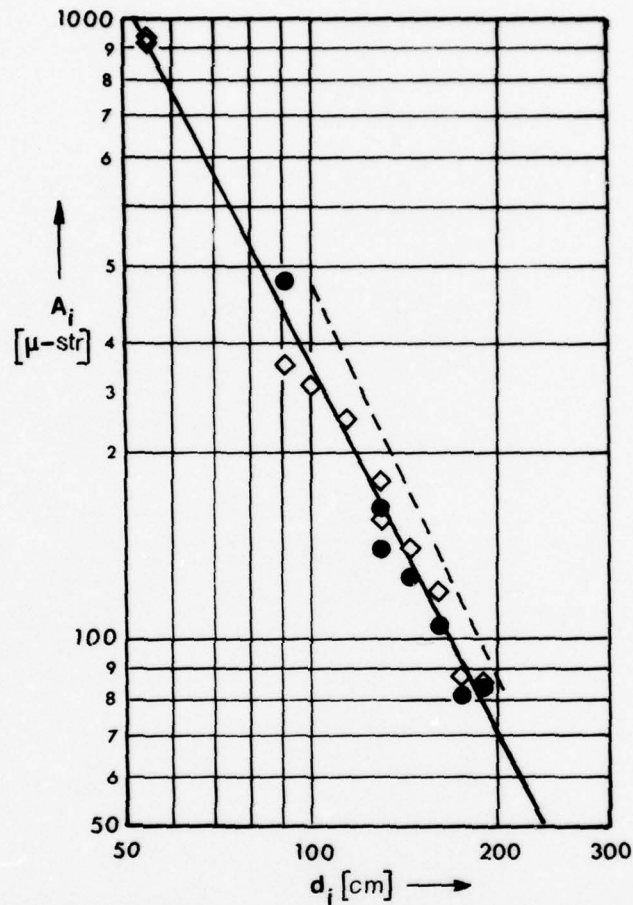


Fig.8 . Maximum amplitudes A_i ("hole"-experiment) by the shots 40 and 41.

for the calibration constant. Considering the fact that one is in this case comparing results from experiments with two entirely different types of pickups, the agreement must be considered very satisfactory.

So far the experiments have dealt with situations for which at least some sort of theoretical approach could be envisaged. For cases with charges detonated in the air above the surface, no theoretical method known to the author exists by means of which one can relate the shock wave induced in the ground to that which the same charge would have caused when detonated completely confined. The idea behind the experiments was to do this experimentally.

The free hanging charges will induce shock waves in the rock which will be influenced among other things by the distance h above the surface at which the charge is detonated. This distance may be made dimensionless by scaling it against the charge magnitude W , i.e. $h_* = h/\sqrt[3]{W}$. The experiment was planned such that the non-dimensional distance h_* was repeated for each charge magnitude. One observes that this means equivalence in the way in which distances are scaled in the rock as well as above its surface.

Before examining the experimental data one may contemplate what kind of relationship one may anticipate. If one uses the attenuation curve for the maximum amplitude of the shock wave in the case of fully contained explosions as a guide, one will expect an attenuation curve as shown in Fig.9, where the maxi-

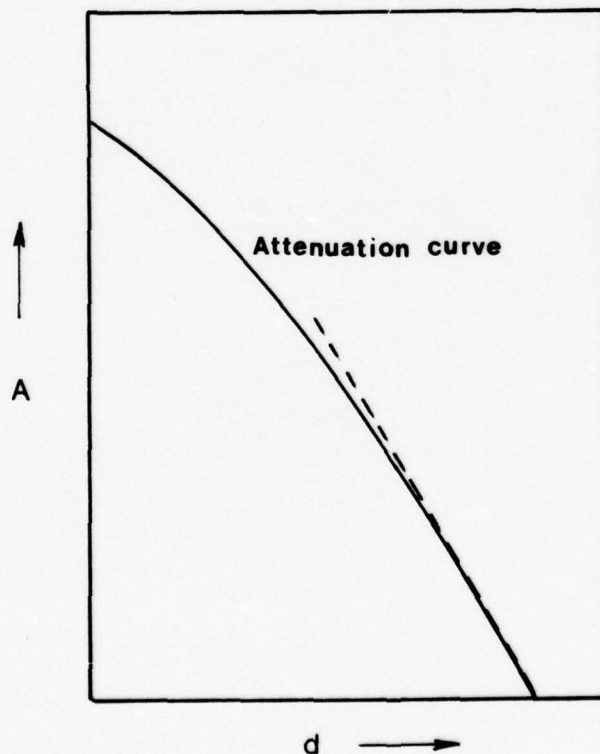


Fig.9 . Attenuation curve for the maximum amplitude A
maximum amplitude A is plotted as a function of the distance d travel-

led by the shock wave. The diagram is in doubly logarithmic scale and consequently the curve ought to exhibit an asymptotic behaviour as a straight line as shown by the dashed line.

One may be more specific at this point. One cannot off-hand know how the attenuation curve is influenced by the rock type, the type of explosive used, the dimensionless duration τ_0 of the input pulse and/or the elevation h above the surface. One can however assume as a working hypothesis that

- a) the distances may be scaled with $\sqrt[3]{W}$,
- b) the dimensionless duration τ is the same in all cases; because among other things the same explosive is used,
- c) the data, which here consists of measured maximum amplitudes of the shock wave, will depend only on one parameter, say h_* .

Such a hypothesis corresponds to the expected behaviour of the attenuation curve for a contained explosion.

This hypothesis is now examined in the two Tables VIII and IX. First Table VIII is arranged in such a way that the three cases of constant h_* appear separately. One then computes the ratios between the measured maximum amplitudes at each pickup. [$A_{0.5}$, $A_{2.0}$ and $A_{5.0}$ are the maximum amplitudes measured with $W = 0.5[\text{kg}]$, $W = 2.0[\text{kg}]$ and $W = 5.0[\text{kg}]$ respectively.] It is observed that the ratios remain fairly constant for larger distances. The average value of the ratios neglecting those closest to the charge and appearing in paranthesis () in the table is given.

Secondly Table IX is arranged such that the three cases of different charge magnitudes appear separately. Again the ratios are computed and again the average values of the ratios are given for the pickups farthest away from the surface. This exercise indicates that the data should be subjected to a scaling procedure which is exhibited in Fig.10. On the transparent page 1 the data from the 0.5 kg-charges at different distances h are gathered. The scaling occurs vertically and is proportional to $1/h_*$. On page 2 the same has been done for the 2.0 kg-charges, but here a horizontal scaling occurs in accordance with point a) above. On

TABLE VIII

	$A_{0.5}$	$A_{2.0}$	$A_{5.0}$	$A_{0.5}/A_{2.0}$	$A_{0.5}/A_{5.0}$	Remarks
W	0.5 kg	2.0 kg	5.0 kg			
h/i	60 cm	90 cm	129 cm			
1	-	16 -	23.33			$(A_{0.5}/A_{2.0})_{Av.} = 0.6319 \pm 0.0631$ $(A_{0.5}/A_{5.0})_{Av.} = 0.4471 \pm 0.0274$ $h_* = 13.60$
2	-	14.-	23.-			
3	11.33	-	26.67		.4248	
4	14.67	21.-	30.67	.6986	.4783	
5	14.50	22.67	32.67	.6396	.4438	
6	-	-	-			
7	19.67	35.67	48.33	.5514	.4070	
8	25.33	37.-	55.33	.6846	.4578	
9	24.-	41.-	51.-	.5854	.4706	
10	40.33	49.50	61.67	(.8147)	(.6540)	
11	54.-	55.-	61.67	(.9818)	(.8756)	
12	-	-	-			
13	45.57	54.-	64.-	(.8439)	(.7120)	
14	394.67	555.33	595.-	(.7107)	(.6633)	
15	62.-	72.33	90.67	(.8572)	(.6838)	
16	96.-	117.33	104.33	(.8182)	(.9202)	
17	124.33	186.33	251.67	(.6673)	(.4940)	
h/i	40 cm	63.5 cm	86 cm			
1	11.33	26.-	35.33	.4358	.3207	$(A_{0.5}/A_{2.0})_{Av.} = 0.4752 \pm 0.036$ $(A_{0.5}/A_{5.0})_{Av.} = 0.3558 \pm 0.035$ $h_* = 9.09$
2	13.-	27.33	31.-	.4757	.4194	
3	12.67	27.50	38.67	.4607	.3276	
4	15.33	35.67	46.33	.4298	.3309	
5	17.-	31.67	48.33	.5368	.3517	
6	-	-	-			
7	25.-	52.-	74.33	.4808	.3363	
8	32.33	63.-	83.33	.5132	.3880	
9	28.-	59.67	75.33	.4692	.3717	
10	49.67	76.67	106.33	(.6391)	(.4671)	
11	57.-	98.67	132.33	(.5771)	(.4307)	
12	-	-	-			
13	63.33	93.-	136.-	(.6810)	(.4657)	
14	674.-	856.67	1083.33	(.7868)	(.6222)	
15	95.67	125.-	211.50	(.7654)	(.4523)	
16	137.-	193.67	265.33	(.7074)	(.5163)	
17	185.67	246.67	546.67	(.7527)	(.3396)	
h/i	20 cm	32 cm	43 cm			
1	15.67	47.-	67.-	.3334	.2339	$(A_{0.5}/A_{2.0})_{Av.} = 0.3389 \pm 0.0352$ $(A_{0.5}/A_{5.0})_{Av.} = .2335 \pm 0.0205$ $h_* = 4.54$
2	-	45.-	62.-			
3	16.33	55.50	79.-	.2942	.2067	
4	21.67	67.50	91.-	.3210	.2381	
5	20.67	61.-	95.-	.3389	.2176	
6	-	63.-	103.-			
7	32.67	95.-	131.-	.3439	.2494	
8	43.-	105.5	161.-	.4076	.2671	
9	35.-	113.5	158.-	.3084	.2215	
10	66.67	334.5	-	(.1993)		
11	64.33	407.-	460.-	(.1581)	(.1398)	
12	-	280.-	360.-			
13	78.33	272.-	-	(.2880)		
14	880.67	2418.50	5600.-	.3641	(.1573)	
15	440.33	-	-			
16	171.-	610.-	-	(.2803)		
17	1098.67	-	-			

page 3 the same procedure is repeated for the data from the 5.0 kg-charges. Because the pages are transparent the figure reveals how nicely the data seem to follow the scaling laws outlined above.

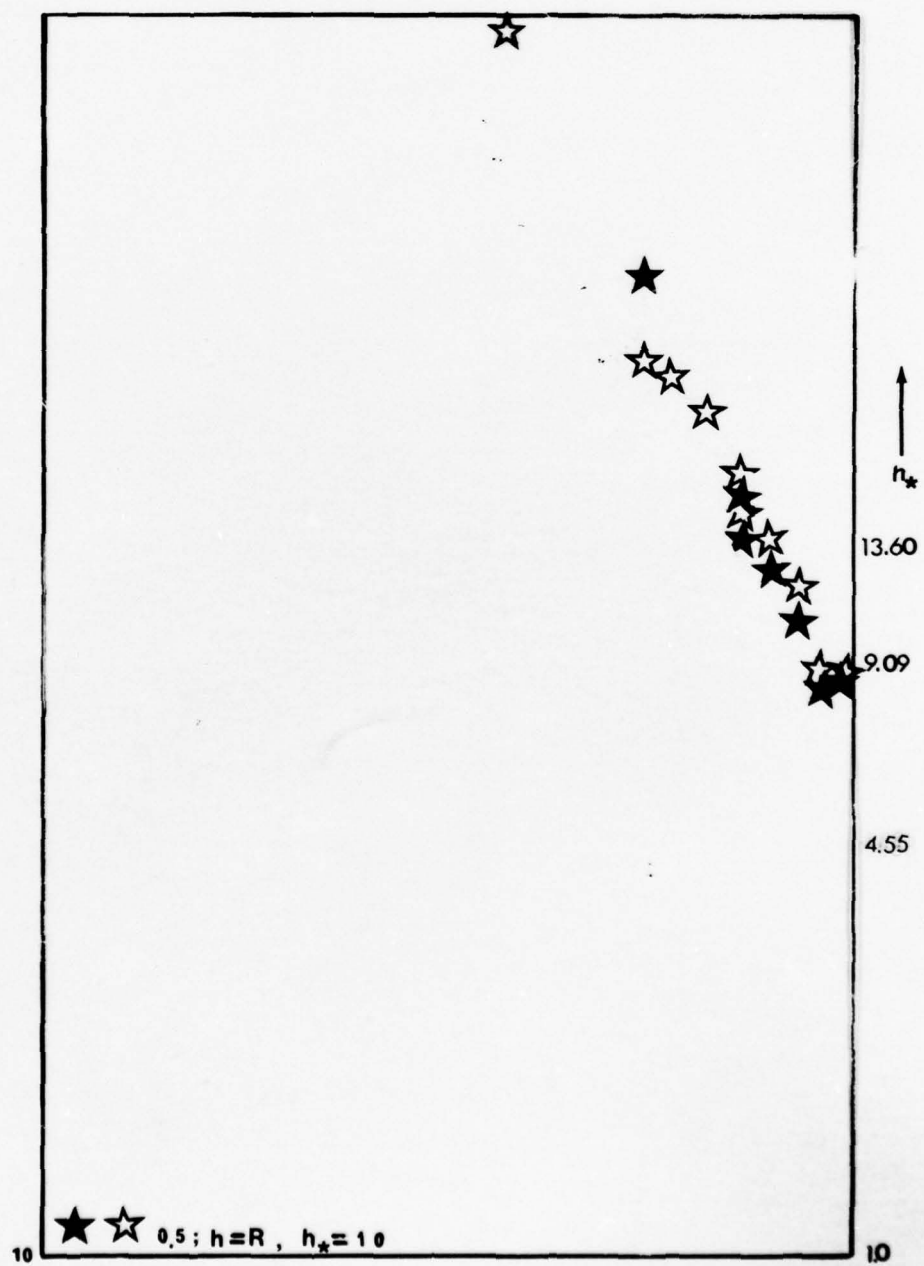
One should at this point add the following remarks:
The ratios computed may to some extent be independent of eventual

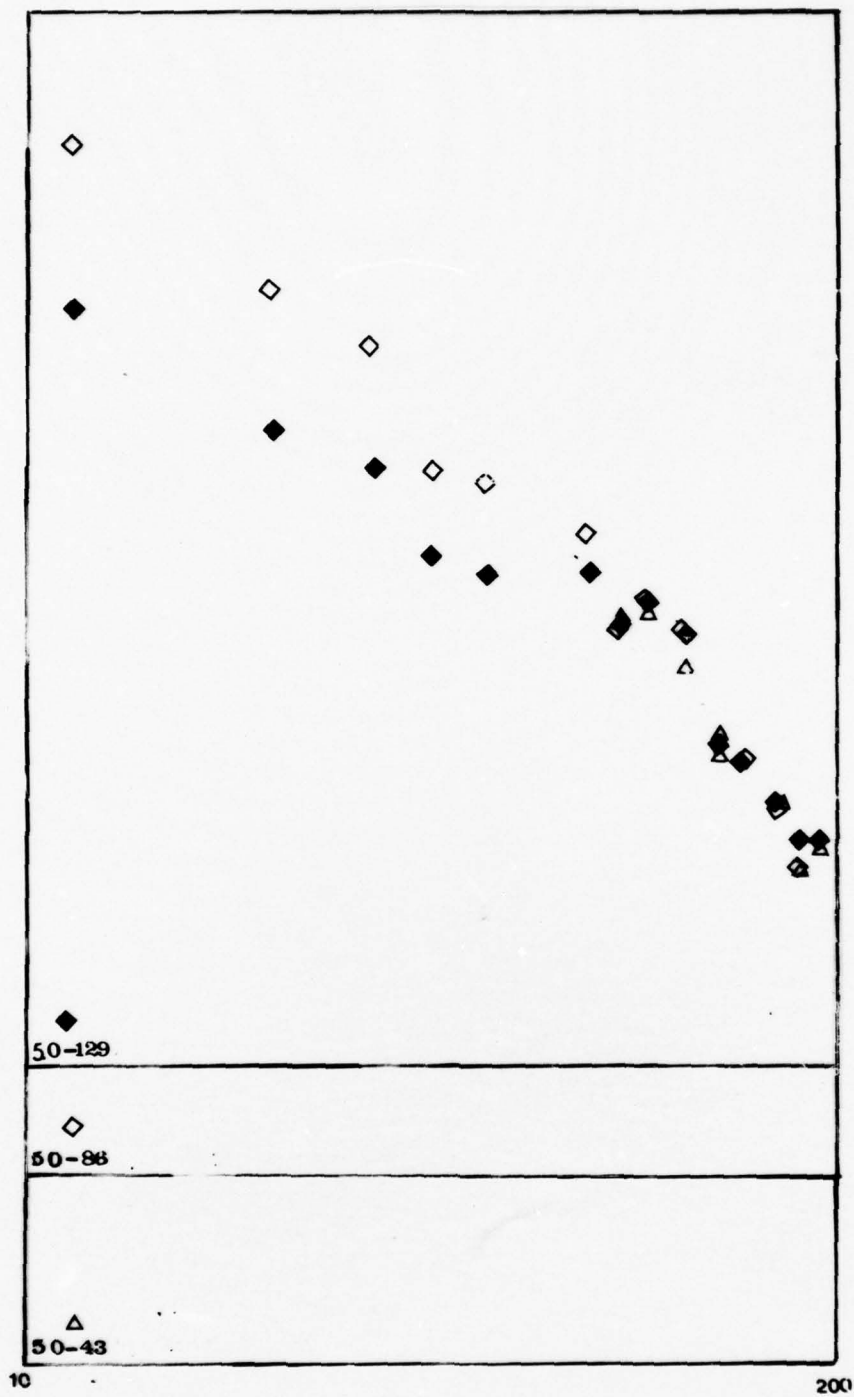
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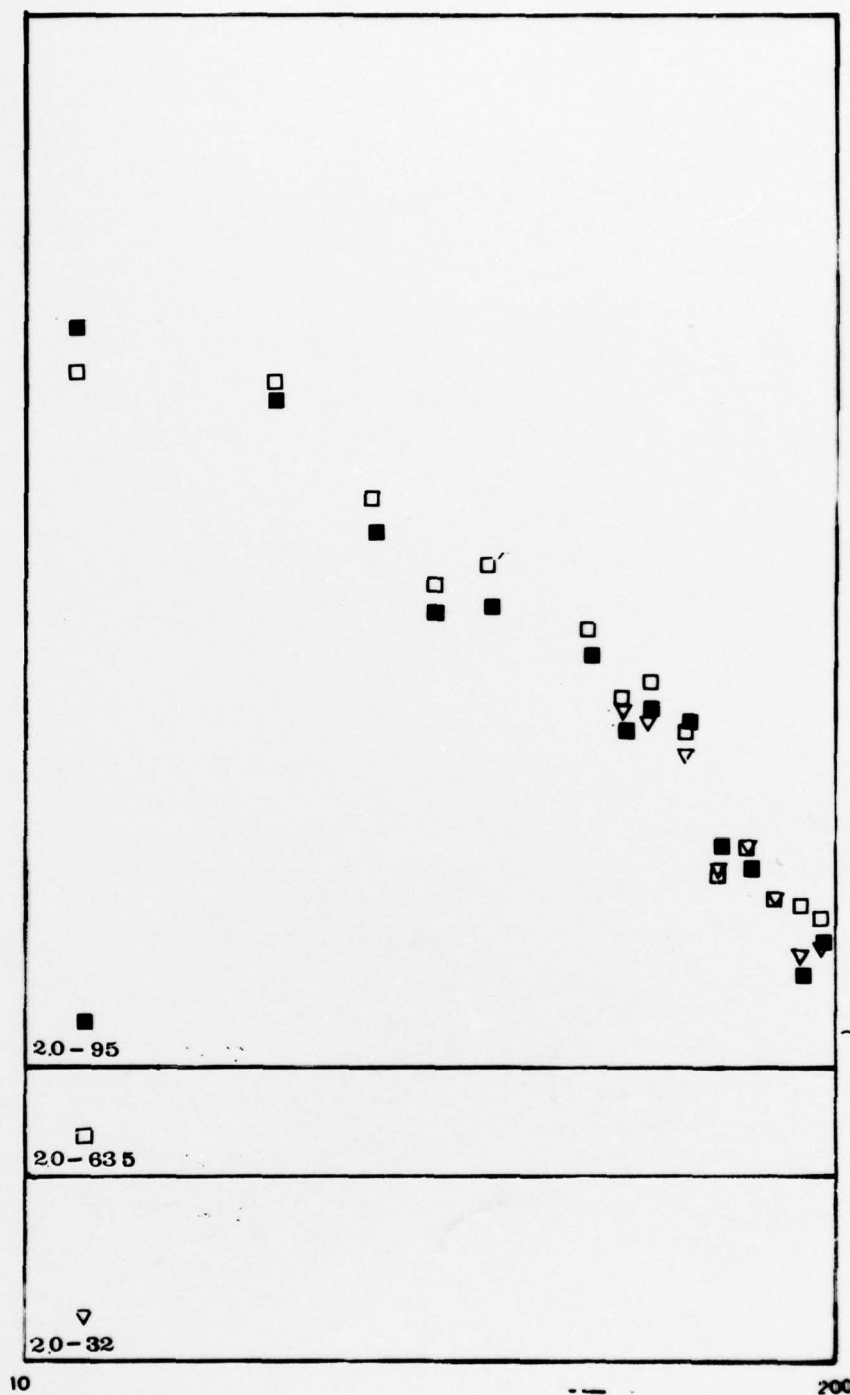
TABLE IX

			h_1	h_2	h_3			
W	i	d_i	A_{1i}	A_{2i}	A_{3i}	A_{1i}/A_{2i}	A_{1i}/A_{3i}	Remarks
0.5 kg	1	190	-	11.33	15.67			$A_{1i}/A_{2i}=0.8554\pm0.066$
	2	175	-	13.-	-			
	3	161	11.33	12.67	16.33	.8942	.6938	$A_{1i}/A_{3i}=0.6511\pm0.052$
	4	145	14.67	15.33	21.67	.9569	.6770	
	5	130	14.50	17.-	20.67	.8529	.7015	
	6	130						
	7	115	19.67	25.-	32.67	.7868	.6021	$h_1 = 60cm$
	8	100	25.33	32.33	43.-	.7835	.5891	$h_2 = 40cm$
	9	91	24.-	28.-	35.-	.8571	.6857	$h_3 = 20cm$
	10	80	40.33	49.67	66.67	(.8120)	(.6049)	
	11	55	54.-	57.-	64.33	(.9474)	(.8394)	
	12	55						
	13	45	45.57	63.33	78.33	(.7196)	(.5818)	
	14	36	394.67	674.-	880.67	(.5856)	(.4481)	
	15	36	62.-	95.67	440.33	(.6481)	(.1408)	
	16	25	96.-	137.-	171.-	(.7007)	(.5614)	
	17	12	124.33	185.67	1098.67	(.6696)	(.1132)	
2.0 kg	1	190	16.-	26.-	47.-	.6154	.3404	$A_{1i}/A_{2i}=0.6275\pm0.072$
	2	175	14.-	27.33	45.-	.5123	.3111	
	3	161	-	27.50	55.50	-	-	$A_{1i}/A_{3i}=0.3460\pm0.027$
	4	145	21.-	35.67	67.50	.5887	.3111	
	5	130	22.67	31.67	61.-	.7158	.3716	
	6	130			63.-	-	-	
	7	115	35.67	52.-	95.-	.6860	.3755	$h_1 = 90cm$
	8	100	37.-	63.-	105.50	.5873	.3507	$h_2 = 63.5cm$
	9	91	41.-	59.67	113.50	.6871	.3612	$h_3 = 32cm$
	10	80	49.50	76.67	334.50	(.6456)	(.1480)	
	11	55	55.-	98.67	407.-	(.5574)	(.1351)	
	12	55			280.-	-	-	
	13	45	54.-	93.-	272.-	(.5806)	(.1985)	
	14	36	555.33	856.67	2418.50	(.6482)	(.2296)	
	15	36	72.33	125.-	-	(.5786)	-	
	16	25	117.33	193.67	610.-	(.6058)	(.1923)	
	17	12	186.33	246.67	-	(.7554)	-	
5.0 kg	1	190	23.33	35.33	67.-	.6603	.3482	$A_{1i}/A_{2i}=0.6776\pm0.029$
	2	175	23.-	31.-	62.-	.7419	.3710	
	3	161	26.67	38.67	79.-	.6897	.3376	$A_{1i}/A_{3i}=0.3466\pm0.016$
	4	145	30.67	46.33	91.-	.6620	.3370	
	5	130	32.67	48.33	95.-	.6760	.3439	
	6	130			103.-	-	-	
	7	115	48.33	74.33	131.-	.6502	.3689	$h_1 = 129cm$
	8	100	55.33	83.33	161.-	.6640	.3437	$h_2 = 86cm$
	9	91	51.-	75.33	158.-	.6770	.3228	$h_3 = 43cm$
	10	80	61.67	106.33	-	(.5800)	-	
	11	55	61.67	132.33	460.-	(.4660)	(.1341)	
	12	55			360.-	-	-	
	13	45	64.-	136.-	-	(.4706)	-	
	14	36	595.-	1083.33	5600.-	(.5492)	(.1063)	
	15	36	90.67	211.50	-	(.4287)	-	
	16	25	104.33	265.33	-	(.3932)	-	
	17	12	251.67	546.67	-	(.4604)	-	

systematic errors in the data. An example is the data from pick-up no. 14 which evidently are erroneous. Still the ratio computed from them is not unrealistic. This means further that even though the data give ratios with fair degree of accuracy (<10%) they may still exhibit a rather large scatter. Fig.10 shows how this is the case for data obtained close to the surface.





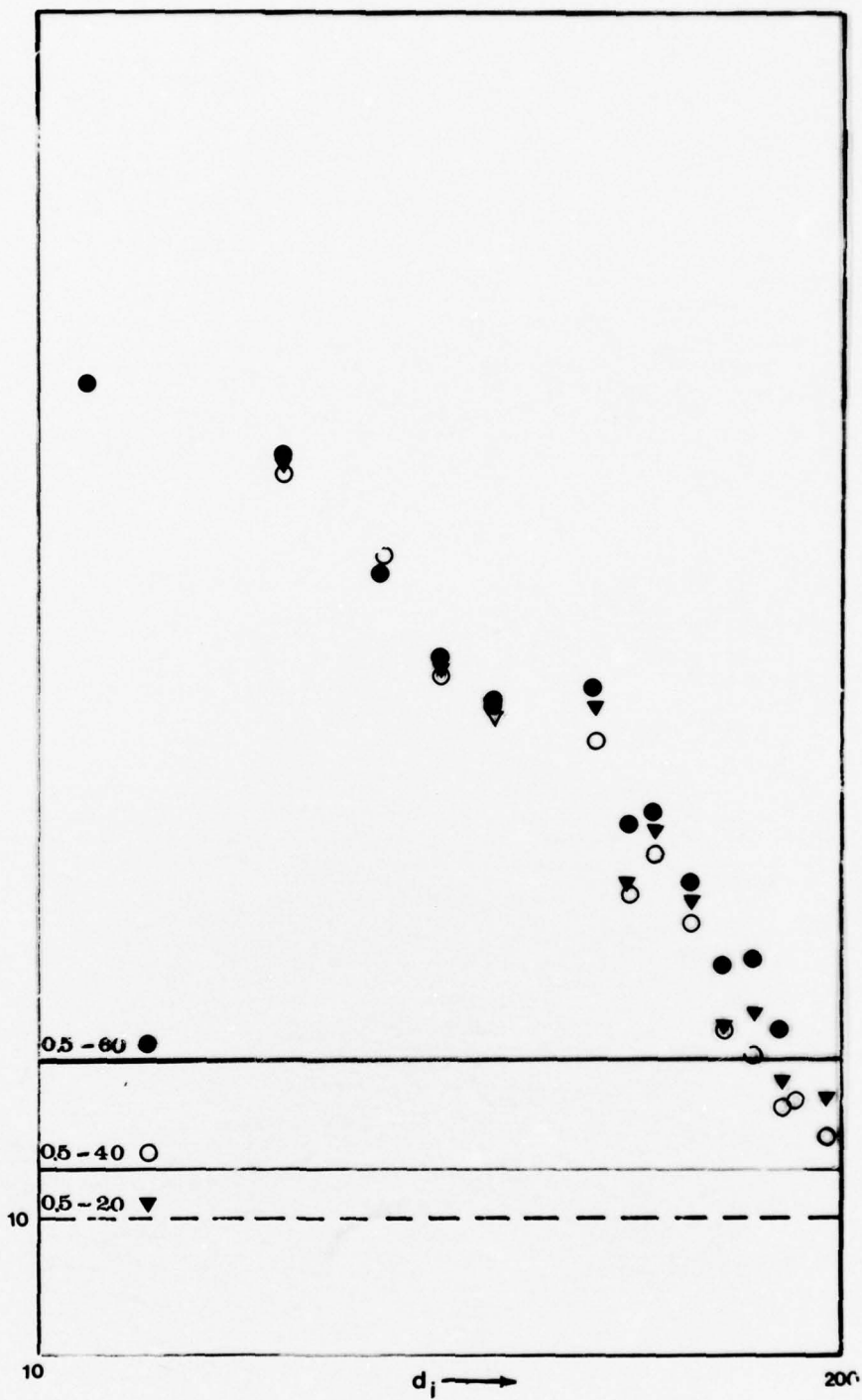


$\uparrow$
 A_i

10

10

10



*Fig. 10. Correlation of all measured
maximum amplitudes A_i .*

It must be remarked that the data for the case of $W = 0.5 \text{ kg}$ and $h = 20 \text{ cm}$ do not seem to fit in with the proposed scaling procedure. It is therefore plotted in with its base line dashed.

Finally it should be remarked that the exercise so far has only given a scaling procedure for cases of free hanging charges. If it is extended to the case of the charge in contact with the surface, ($h_* = 1$), one would have been able to connect the present result to the case of half buried charges and thus, through the results of [3], also to the case of a confined charge. In Fig.10 the data from shots 40 and 41 are plotted on page 4 realizing that these data may be regarded as a case for which $h_* = 1$, whereas the other cases give values of this parameter as shown in Table VIII. The fact that these data fit in so nicely with the rest may be taken as a very strong indication that the scaling procedure outlined here may be acceptable.

6. Conclusions from the VIKERSUND experiments.

It is not easy to draw general conclusions from experiments within a limited range. Keeping this in mind one is however encouraged by the apparent consistency in the data and an attempt may be made to generalize the results as follows:

- ① When comparing two cases I and II where the charges W_I and W_{II} are being detonated in the same distance h_* above the surface of the rock, one will find that the same maximum amplitude in the shock wave is created at distances d_I and d_{II} respectively, whereby

$$d_I = d_{II} \sqrt[3]{\frac{W_I}{W_{II}}} \quad (6.1)$$

(Maximum amplitude measured in [μ -strain])

This is to be considered the first part of a "scaling law" or a "model law". The non-dimensional distance h_* used here is defined

as

$$h_* = h/R \quad , \quad R = \sqrt[3]{3W/4\pi\rho} \quad (6.2)$$

where h is the elevation above the surface where the detonation takes place, and R is the radius of the equivalent spherical charge with ρ as the density of the explosive..

The second part of the "scaling law" may be formulated as follows:

② When comparing two cases I and II where the same charge W is detonated at the non-dimensional elevations $h_{*,I}$ and $h_{*,II}$ respectively, one will find that in the same non-dimensional distance from the surface the shock wave will exhibit maximum amplitudes S_I and S_{II} respectively which will be related to each other through

$$S_I = S_{II} \frac{h_{*,II}}{h_{*,I}} \quad (6.3)$$

If this result can be substantiated and confirmed by further experimental evidence, one has succeeded in relating at least one important case of air blast induced shock waves in rock to the case of a confined explosion. For cases where crater building is a major factor in the process, reference is being made to the handling of this problem in [3] .

7. The CENSE experiments.

In connection with the VIKERSUND experiments, which were conducted on a small scale, it may be of interest to examine the results of the CENSE experiments. These were conducted with charges which were orders of magnitude greater. The results from these experiments are discussed in [2] and the lay-out of the experiments is shown in Fig.11 . The numbers indicate the 7

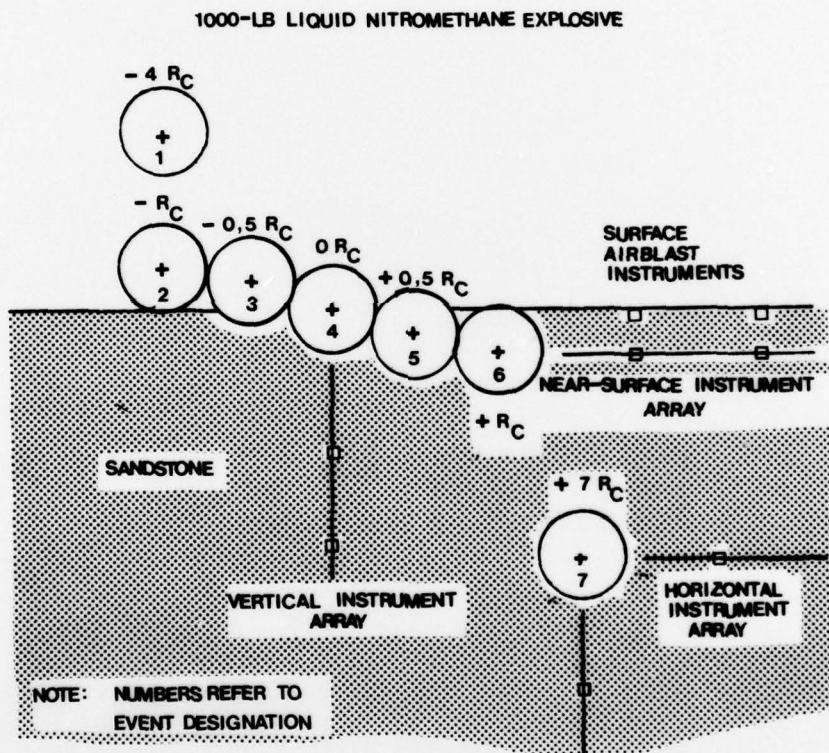


Fig.11. The experimental lay-out of the CENSE experiments.

different events, where for each event the position of the detonating charge is changed. In this way one covers the whole range of positions above, on, near to and below the surface. For each event recordings of the induced shock wave in the rock were made

on a vertical ray through the center of the charge as indicated through the vertical instrument array. In case 7 also a horizontal instrument array was in operation. Other measurements were also made, but these are so far of marginal interest in the present context.

It should be mentioned that the results of these experiments, as they appear in [2], are given in terms of coupling factors. As an example: the ground shock factor F_u is defined as

$$F_u = \frac{\text{peak horizontal particle velocity}}{\text{peak radial velocity for full containment (DoB = } 7R_c)} \quad (7.1)$$

It is stressed that the ground shock factor is determined from measurements along the near surface instrument radial, and that data from the measurements directly beneath the explosive are not included in the analysis. This is in contrast to the present examination, where only the data from the vertical instrument array will be used. (In event 7 also the horizontal array will be considered.)

8. Peak velocity data from the CENSE I experiment.

The data from CENSE I are presented in the form of recorded particle velocity as function of time as exemplified in Fig.12 . The peak particle velocity is rather

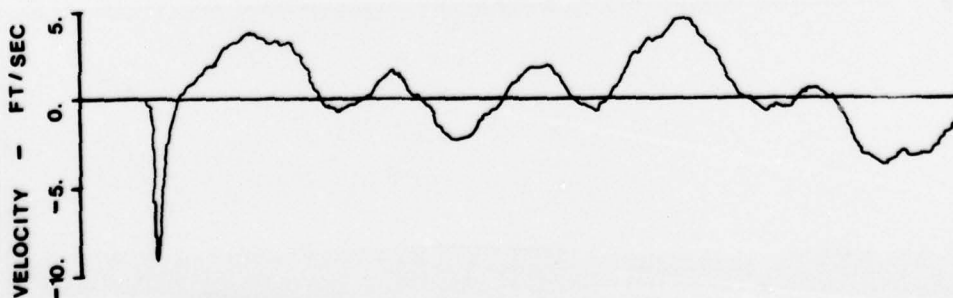


Fig. 12. Recorded particle velocity at a distance of 20 feet in Event 3.

easily picked out from such recordings, and this quantity is used to characterize the shock waves as done also in the first report [2]. These data are listed in Table X as the maximum amplitude A_i measured at pickup no. i in a distance d_i from the explosion.

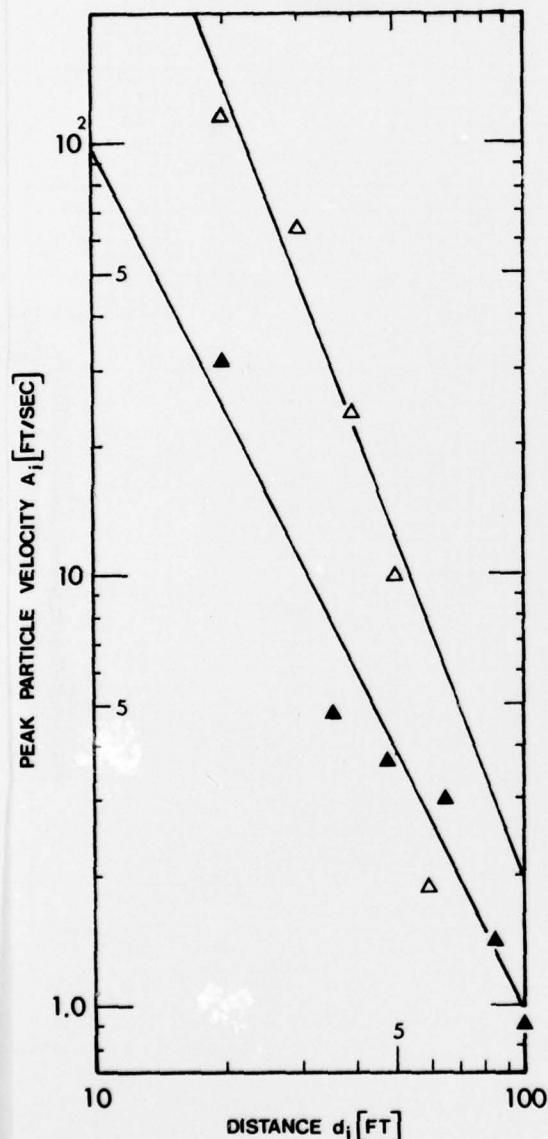


Fig. 12. Data from event 7.

One may start examining these data by looking at the fully contained case, event 7. This is to be a reference case and it is imperative that this case is well established. If the data are plotted as done in Fig.12, it becomes however apparent that the attenuation of the maximum amplitude of the shock wave is much greater in the vertical than in the horizontal direction. This may indicate that the rock (sandstone) exhibits different properties as a wave-transmitting medium in the two directions, i.e. the sandstone is "layered". Or it may reflect the fact that one or more of the pickups used exhibit systematic errors. Because repeated experiments were not undertaken, and no other information is available, the question of which of the two possibilities is really the case must remain unresolved.

Both data from the horizontal and from the vertical array in event 7 record what may be assumed to be a spherical wave. The idea behind the handling of the data from

TABLE X

Event No.	Pickup i	d_i [ft]	A_i [ft/sec]	F_u	F_u^*	Remarks
1 ○	3	40	.463	.019	.359	Vertical array
	4	50	.219	.022	.264	
	5	60	.147	.079	.352	
2 ●	1	20	1.767	.015	.078	Vertical array
	2	30	.514	.008	.101	
	3	40	(.432)	(.018)	(.335)	
	4	50	.170	.017	.205	
	5	60	.112	.060	.268	
3 □	1	20	9.32	.080	.412	Vertical array
	2	30	3.184	.051	.624	
	3	40	.844	.035	.654	
	4	50	.192	.019	.232	
	5	60	.156	.084	.373	
4 ■	1	20	12.85	.110	.568	Vertical array
	2	30	6.077	.096	1.192	
	3	40	.836	.035	.648	
	4	50	.620	.062	.749	
	5	60	.200	.107	.478	
5 ◇	1	20	22.64	.194	1.0	Vertical array
	2	30	5.10	.081	1.0	
	3	40	1.29	.054	1.0	
	4	50	.828	.083	1.0	
	5	60	.418	.224	1.0	
6 ◆	1	20	131.-	1.122		Vertical array
	2	30	15.5	.246		
	3	40	2.203	.092		
	4	50	2.452	.245		
	5	60	.722	.388		
7 △ ▲	1	20	116.75	1.0		Vertical array
	2	30	63.05	1.0		
	3	40	24.04	1.0		
	4	50	10.-	1.0		
	5	60	1.863	1.0		
	6	20	31.78			Horizontal array
	7	36	4.726			
	8	48	3.688			
	9	65	2.955			
	10	85	1.411			
	11	100	.891			

the charges placed on or near to the surface is to assume that the situation on the vertical through the charge can be compared with the confined case. Now, the confined case appears to give ambiguous informations, and the reference case thus becomes uncertain.

In [2] the ground shock factor F_u is defined in accordance with (7.1) where the data from the horizontal array are used for the reference case. If a straight line is fitted through the data points ($\blacktriangle$) from the horizontal array in Fig.12, an approximation to the attenuation curve is obtained which may be expressed as

$$A = 10752 d_z^{-2.03053} \text{ [ft/sec]} \quad (8.1)$$

where A is the peak particle velocity of the shock wave. The mean deviation of the data points from this line is $\pm 35.7\%$.

The slope λ of the attenuation curve determined from the data of the horizontal array above is equal to the exponent -2.03053 in the expression (8.1). The corresponding slope determined from the data of the vertical array (Δ) in Fig.12 is much greater. Even if the point originating from pickup no.5 is neglected as a stray point, the value of the slope would be

$$\lambda = -2.66817 \quad (8.2)$$

and the mean deviation of the points from the straight line shown in Fig.12 would be $\pm 32.6\%$. The difference in magnitude of the slopes as well as the vertical position of the straight lines representing the attenuation curves in Fig.12 is clearly brought out by the plot. One has however a possibility to check this result by drawing Fig.3 of the report [2] to attention. This figure is reproduced in Fig.13 with the original figure caption. It is seen that the different cases give lines of approximately the same slope $\lambda \approx -1.55$. This indicates that the present investigation may be based on data which differ from

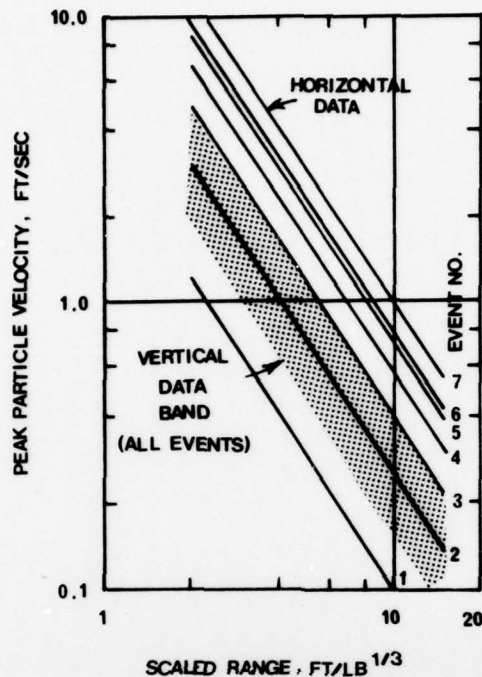


Fig.13. Replot of Fig.3 in reference [2] with the caption: "Peak particle velocity versus scaled range as a function of charge containment".

those used in reference [2]. It should however be noted, that the magnitude of the slope in Fig.13 corresponds well to the slope $\lambda = -1.65$ suggested by Fred M. Sauer in Nuclear Geoplosics [4] for the so-called composite attenuation curve, and that the slopes obtained from the present data in (8.1) and (8.2) seem unusually high by comparison.

In spite of the discrepancy which seem to have been discovered, it may well be that the data give adequate results for the ground shock factor F_u as defined in (7.1). This factor is therefore computed for each shot and each distance in Table X. Also the factor F_u^* with the data from event 5 as reference has been calculated in the same table. Both cases reveal that no obvious trend can be found in these results.

TABLE XI

Event j	i	d_i [ft]	A_i [ft/sec]	β_j	$\beta_j A_i$ [ft/sec]
1 ○	3	40	.463	1.82616	.846
	4	50	.219		.400
	5	60	.147		.268
2 ●	1	20	1.767	2.22640	3.934
	2	30	.514		1.144
	3	40	(.432)		.962
	4	50	.170		.378
	5	60	.112		.249
3 □	1	20	9.32	1.53131	14.27
	2	30	3.184		4.876
	3	40	.844		1.292
	4	50	.192		.294
	5	60	.156		.239
4 ■	1	20	12.85	.95670	12.29
	2	30	6.077		5.81
	3	40	.836		.800
	4	50	.620		.593
	5	60	.200		.191
5 ◇	1	20	22.64	.58801	13.313
	2	30	5.10		2.999
	3	40	1.29		.759
	4	50	.828		.487
	5	60	.418		.246
6 ◆	1	20	131.00	.28552	37.40
	2	30	15.50		4.425
	3	40	2.203		.629
	4	50	2.452		.700
	5	60	.722		.206

In spite of this rather discouraging result, one may attempt to establish the ground shock factors by introduction of the "shot factors" β_j as shown in [3] and then determine these by means of the method of the least squares. The result is shown in Table XI where the data from Event 7 have been disregarded entirely. The result ought to be such that the data $(d_i, \beta_j A_i)$, when exhibited in an attenuation diagram, would gather around a straight line with the slope λ . In the present case the calculation is based on the data from the pickups 3, 4 and 5 only, and the result is shown in Fig. 14. The slope λ of the straight line and the mean deviation m of the points from this line will be

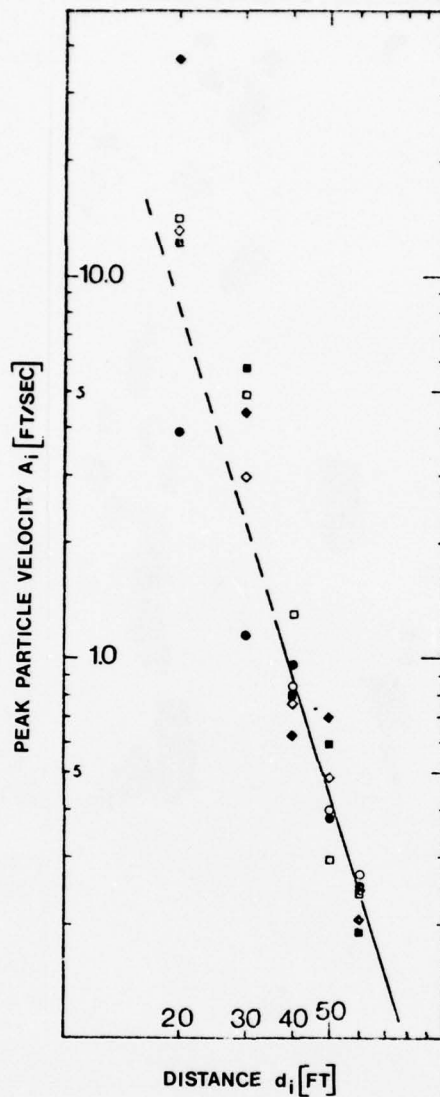


Fig.14 . Corrected data βA_i plotted as function of the distance d_i . The straight line represents the attenuation curve for particle velocity.

$$\lambda = -3.21792, \quad m = \pm 27.0\% \quad (8.3)$$

It should be noted that the scatter indicated by m only reflects the deviation of the data from the pickups 3, 4 and 5. Fig.14 reveals a much greater scatter as far as the data from pickups no. 1 and 2 are concerned.

Event	j	i	A_i [ft/sec]	B_i [ft/sec]	β_j	$\beta_j B_i$ [ft/sec]	d_i [ft]
1 ○		3	.463	.500	1.68912	.845	40
		4	.219	.248		.419	50
		5	.147	.125		.211	60
2 ●		1	1.767	1.600			20
		2	.514	*			30
		3	.432	.800			40
		4	.170	.233			50
		5	.112	-			60
3 □		1	9.32	-	1.45665	-	20
		2	3.184	-		-	30
		3	.844	.851		1.24	40
		4	.192	.200		.291	50
		5	.156	.142		.207	60
4 ■		1	12.85	-	.82302		20
		2	6.077	-			30
		3	.836	.867		.714	40
		4	.620	.729		.600	50
		5	.200	.212		.174	60
5 ◇		1	22.64	26.25	.49382	12.96	20
		2	5.10	5.94		2.93	30
		3	1.294	1.399		.691	40
		4	.828	.866		.428	50
		5	.418	.512		.253	60
6 ◆		1	131.00	134.36			20
		2	15.50	-			30
		3	2.203	*			40
		4	2.452	*			50
		5	.722	.721			60
7 △ ▲		1	(116.75)	-			20
		2	63.05	69.80			30
		3	(24.04)	*			40
		4	(10.00)	*			50
		5	1.863	1.83			60
		6	31.78	-			20
		7	4.726	4.31			36
		8	3.688	*			48
		9	2.955	*			65
		10	1.411	*			85
		11	.891	*			100

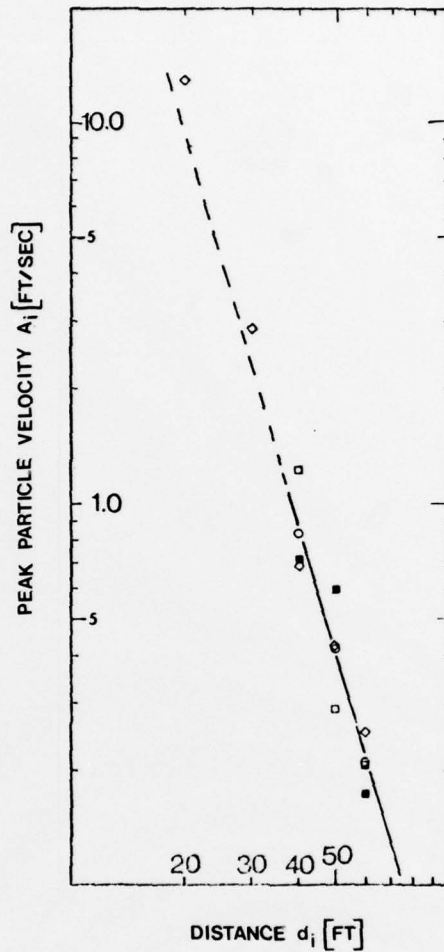


Fig.15 . Corrected data $\beta_j B_i$ plotted as function of the distance d_i . The straight line represents the attenuation curve for particle velocity.

It must be mentioned that the data can be obtained from a second set of curves, which is given with the first one. This set is not as complete as the first one, the peak particle velocities obtained from it are denoted by B_i , and they are given in Table XII, where for comparison the data A_i are repeated. Missing information is denoted by a star (*) in the table, and illegible signals with a bar (-).

The same procedure as before leads to the "shot factors" β_j in Table XII and the attenuation curve is shown in Fig.15.

The slope λ of the straight line and the mean deviation m of the data points from this line are

$$\lambda = -3.43792, \quad m = 26.7\% \quad (8.4)$$

The scatter is about the same as in the case of the first data, the slope λ is also about the same, but in both cases are the values (8.3) and (8.4) much greater than what was obtained in (8.2) and (8.1). All cases give greater values for λ than what is exhibited in Fig.13.

TABLE XIII

Event	The ground shock factor F_u					
	From [2]	From XI	From [2]	From XII	From [2]	From XI
1	.100	.156	.127	.292	.142	.322
2	.247	.128	.315		.351	.264
3	.398	.186	.507	.339	.566	.384
4	.566	.298	.722	.600	.805	.615
5	.703	.486	.896	1.000	1.000	1.000
6	.785	1.000	1.000			
7	1.000					

Finally the ground shock factor F_u is found from Fig.13 and given in Table XIII with Event 7 as basis. If Event 6 is used as basis, the factors will change as shown and compared with the factors which can be computed from the β_j -values of Table XI. With Event 5 as basis, it is possible to compare the factors from [2] with those computed from the β_j -values of both Table XI and XII. Even though the latter two agree reasonably well, it must be concluded that the data upon which the present investigation is based do not give results which conform with those reported earlier [2] from the same experiment.

9. Final remarks

The CENSE experiment distinguishes itself from the

VIKERSUND experiment in the basic philosophy upon which it is planned. The CENSE experiment considers cases where the detonating charge may be placed at all possible levels above as well as below the ground surface. It is assumed that the shock waves created in these cases can be related to each other and/or to the fully contained case by a ground shock factor.

The VIKERSUND experiment is based on the philosophy that a physically important difference exists between cases in which the shock wave is created in connection with a crater formation and cases where this is not the case. The VIKERSUND experiment thus concentrates entirely on cases where the charge is detonated above the surface or in contact with it. The case of the so-called half-buried charge is considered separately in [3], and in spite of the inadequate experimental support, it is believed that a way is suggested whereby the properties of the rock both as a wave-transmitting medium and its ability to withstand cratering is taken into account.

Because of this situation, the two experiments considered in this report do not cover the same physical situations. It could beforehand be expected, that they might in some way complement each other, but the discrepancies discovered prevent that.

The final result as far as the VIKERSUND experiment is concerned is thus contained in the two statements (1) and (2), equations (6.1) and (6.3). It should be emphasized, that further experimentation seems necessary to furnish an adequate experimental support for these results.

10. Acknowledgements.

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