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COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

RECORD No. 1967/4

LAKE BELLFIELD DAM SITE VIBRATION TESTS,

VICTORIA 1963 AND 1965

by

P.E. MANN

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ILLUSTRATIONS

1967/4

SUMMARY

Tests indicate that there is a correlation between the explosive charge and the resulting acceleration multiplied by distance to the power 1.5. By adopting a maximum permissible acceleration of 0.2 g, the relation between permissible explosion distance and explosive charge is derived. At distances of 300, 600, and 1000 feet the corresponding charges should be equal to or less than 50, 400, and 950 lbs.

1. INTRODUCTION

Vibration tests had been made in 1963 for the State Rivers and Water Supply Commission, Victoria (SRWSC), at the Lake Bellfield dam site to determine the maximum permissible explosive charge to be used to excavate a spillway without damaging the concrete lining of a diversion tunnel (Mann, 1964). However, excavation of the partly completed spillway revealed several major faults in the bedrock and the SRWSC considered it necessary to relocate and redesign the spillway. Also other circumstances have delayed lining the tunnel and constructing an outlet tower. Blasting in the new spillway closer than previously will increase the possibility of damage to the concrete works soon to be constructed.

The SRWSC requested the Bureau of Mineral Resources to make further tests to compare the effects of ripple firing with 17-millisecond detonating relays and 100-millisecond L-series short delay electric detonators for charges used to blast the rock. Vibration tests of two charges detonated on the 1st September 1965 were made by the author and C. Shade (an officer of the SRWSC). Subsequent tests in September, October, and November were made by C. Shade, and seismograms of all the tests were interpreted by the author.

2. METHOD AND EQUIPMENT

A Sprengnether portable Blast and Vibration Seismograph, serial No.1577 was used to record the vibrations produced by instantaneous and ripple-fired charges used to blast rock. Different types of blasts as used in the construction programme were recorded at different distances from the seismograph. For each test the siesmograph was mounted on a small concrete block poured on fresh bedrock, except at station 6 on the uncompleted earth and rock-fill retaining wall (hachured area in Plate 1). Test 31/65 (Plate 2) was made to gain some information about the vibrations at a private building produced by a weight of charge commonly used for blasting. It was possible to record the vibrations only at a station 1500 ft from the blast i.e. approximately one third of the distance between the blast and the building. Test 33/65 was made to measure the vibrations transmitted to the bedrock by a vibrating flat drum roller that was crushing filter-zone material about 15 ft from an outcrop.

Two Spregnether seismographs (serial Nos.1577 and 1863) were used during the 1963 tests. A brief description of the instruments and the technique for computing the results has been given by Mann (1964). It was assumed that the magnifications were respectively 100 and 160. However, a check calibration of the instruments showed that the magnification of instruments 1577 and 1863 is 50 and 100 respectively. The data given in Table 1 and formula 3 by Mann (1964) are incorrect. Useful results from the previous tests have been recomputed (Plate 2) and combined with the results obtained in 1965.

In some tests with 100-millisecond delays it is possible to distinguish on a seismogram waves produced by the detonation of individual charges in the firing sequence, e.g. Test 30/65. In this instance the amplitude and frequency of each vibration was treated as being equivalent to the vibration produced by the detonation of a single charge of the same weight; i.e. a delay of 100-milliseconds between charges allows the waves from a blast to decay to a negligible level before waves from the next blast arrive. However, a 100-millisecond delay is too small for this assumption to be strictly valid. The frequency and amplitude of the later waves are greater or less than these parameters for waves from the first blast.

It was attempted to establish a relation between the resultant acceleration r, the charge E, and the distance d of the type:

$$r = \frac{1}{d^m} f(E) \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

By using the data of Plate 2, a plot of E versus d was made, at the same time noting the values of r. It appeared that the values of r could be contoured. Then for constant values of E, log r was plotted against log d^m and the best fitting value for m in equation 1 was found to be 1.5. The next step was to make a statistical correlation between E and $rd^{1.5}$, or between log E and log $(rd^{1.5})$. Because a plot of E versus $rd^{1.5}$ shows a regular pattern, and also because of the easier computation, the statistical analysis was made on values of E and $rd^{1.5}$, and is given in the Appendix.

The correlation coefficient was found to be 0.58, and the standard error in the correlation coefficient was 0.12. With 32 pairs of values for E and $rd^{1.5}$, and for a correlation coeffieient of 0.58, the probability that E and $rd^{1.5}$ are unrelated is less than 1 in 1000 (Young, 1962).

The two regression lines are :

$$E = 60.4 \frac{rd^{1.5}}{10^3} + 220 \pm 260 \text{ - - - - - - - - - - } (2)$$

and

$$\frac{rd^{1.5}}{10^3} = \frac{0.56}{100} E + 0.76 \pm 0.63 \text{ - - - - - - - - - } (3)$$

in which the terms after $\pm$ indicate the standard error, E is the charge in lbs, d the distance in feet, and r the acceleration in terms of g.

Equation 3 is preferred to equation 2 because it is desired to estimate the permissible explosion distance d in terms of explosive charge E for an adopted acceleration r.

Figure 1 shows a plot of equations 3 and 2 for r = 0.2g, and a graph giving the limits according Edwards and Northwood (1960).

It is believed that permissible charges according to equation (3) for r = 0.1g (boundary safe/caution zone) are too small (Thoenen and Windes, 1942), i.e. estimates are too conservative. Hence, the value r = 0.2g was adopted. The resulting estimates for permissible charges then agree closely with the curve given by Edwards and Northwood (1960) as shown in Figure 1.

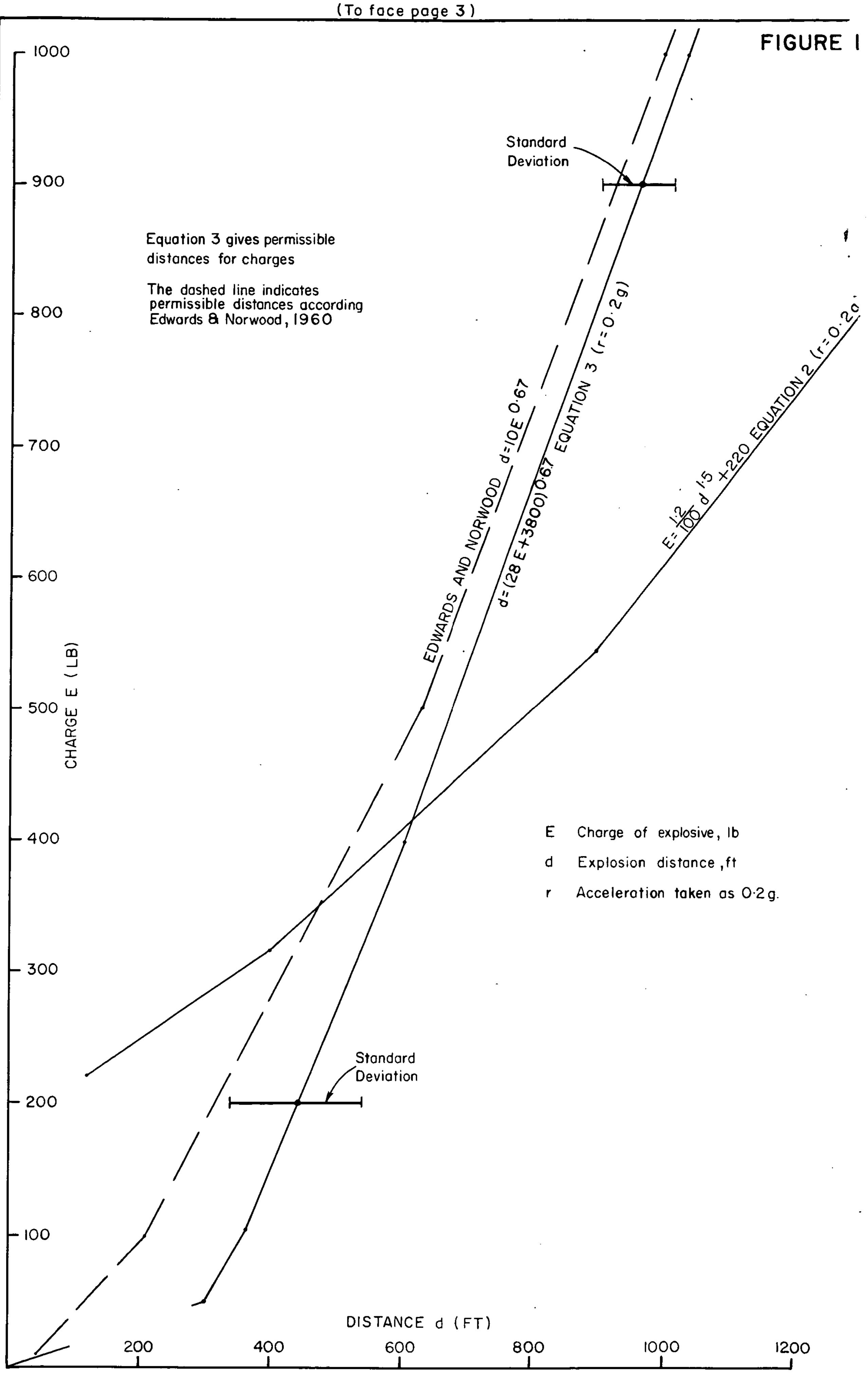
The tests shown on Plate 2 show features specially worth mentioning :

1) Tests 1/63, 3/63, 4/63, and 7/63 at distances of 335 to 450 ft, with charges between 10 and 447 lb, give accelerations of 0.15g to 0.19g.

2) Generally, tests for distances less than 300 ft show abnormally high scatter for the acceleration. It is considered that more reliable data are obtained from tests with a shot-distance greater than 300ft.

(To face page 3)

FIGURE 1



RELATIONS BETWEEN E AND ($rd^{1.5}$) FOR r=0.2g

3. CONCLUSIONS

An empirical relation between charg E, resultant acceleration r, and distance d in the form

$$rd^{1.5} = 5.6E + 760$$

derived from the data can be used to determine the permissible distance for blasting if an acceptable ground acceleration is known. A ground acceleration of 0.2g or less is considered to be safe. The following table shows the suggested permissible charges for charges without delay times. If delay blasting is applied the same table can be used but delay times should be 100 milliseconds or greater.

Distance (ft)	Permissible explosive charge (lb)
300	50
400	150
600	400
800	670
1000	950
1200	1200

The relation is not considered reliable for distances of less than 300 ft, when the permissible charge can only be estimated from experience. The chance that the variables are unrelated is less than 1 in 1000, and their correlation coefficient is 0.6.

4. REFERENCES

EDWARDS, A.T. and NORTHWOOD, T.D.	1960	Experimental studies of the effects of blasting on structures. The Engineer 210, 538 - 546.
MANN, P.E.	1964	Lake Bellfield dam site vibration tests, near Halls Gap, Victoria 1963. Bur. Min.Resour.Aust.Rec. 1964/71.
THOENEN, J.R. and WINDES, S.L.	1942	Seismic effects of quarry blasting. Bull.U.S.Bur. Min. 442.
YOUNG, H.D.	1962	STATISTICAL TREATMENT OF EXPERIMENTAL DATA. New York, McGraw Hill Book Comp. Inc.

APPENDIX

STATISTICAL ANALYSIS OF RESULTS

The 32 results used in the statistical analysis are listed on the opposite page.
For convenience the following substitutions are made:

$$x = \frac{rd^{1.5}}{10^3} \qquad \text{and} \qquad y = E$$

The average values of x and y are $X_o = 3.35$ and $Y_o = 423$

$$\Delta x = x - X_o \qquad \Delta y = y - Y_o$$

$$\Sigma(\Delta x)^2 = 313 \qquad \Sigma(\Delta y)^2 = 3,403,515$$

Standard deviation $Sx = \left(\frac{\Sigma(\Delta x)^2}{n}\right)^{\frac{1}{2}} = 3.13$; $Sy = \left(\frac{\Sigma(\Delta y)^2}{n}\right)^{\frac{1}{2}} = 326$

$$\Sigma(\Delta x\, \Delta y) = 18,506$$

The correlation coefficient $C = \frac{\Sigma\, \Delta x\, \Delta y}{n\ Sx\ Sy} = 0.58$

The standard error in C is $M_c = \frac{1 - C^2}{\sqrt{n}} = 0.12$

The two regression lines are therefore:

$$y - Y_o = C\,\frac{Sy}{Sx}\,(x - X_o)$$

and

$$x - X_o = C\,\frac{Sx}{Sy}\,(y - Y_o)$$

which become

$$E = 0.06rd^{1.5} + 220 \pm 260$$

and

$$rd^{1.5} = 5.6E + 760 \pm 630$$

When r = 0.2, the equations become

$$E = \frac{1.2}{100}\,d^{1.5} + 220 \quad \text{-------- (2)}$$

and

$$d = (28E + 3800)^{0.67} \quad \text{-------- (3)}$$

Equation 3 is used to compute the permissible charges.

Test No. and year	d(ft)	r(g)	x: $\frac{rd^{1.5}}{10^3}$	y: E(lb)	ΔY	ΔX
1/63	335	0.15	0.92	10	-413	-243
3/63	345	0.18	1.13	40	-383	-222
4/63	430	0.18	1.58	100	-323	-177
7/63	450	0.19	1.81	447	+ 24	-154
7/63	610	0.09	1.36	Same	+ 24	-199
8/63	420	0.25	2.15	444	+ 21	-120
8/63	650	0.13	2.16	Same	+ 21	-119
9/63	715	0.20	3.84	500±	+ 77	+ 49
1/65	207	0.62	1.82	27	-396	-153
3/65	460	0.05	0.49	48	-375	-286
4/65	500	0.44	4.95	800±	+377	+160
5/65	95	0.72	0.69	16	-407	-266
6/65	250	0.40	1.55	470±	+ 47	-180
7/65	410	0.09	0.75	45	-378	-260
8/65	810	0.47	1.08	940±	+517	-227
13/65	600	0.08	1.19	150	-273	-216
14/65	665	0.22	3.77	730±	+307	+ 22
17/65	395	>0.78	>6.12	175?	-248	+277
18/65	315	0.66	3.66	660±	+237	+ 31
19/65	435	1.3	11.77	870±	+447	+842
20/65	360	0.11	7.45	84	-339	+410
21/65	340	0.47	2.93	170±	-253	- 42
23/65	335	1.6	9.85	940±	+517	+650
24/65	675	0.38	6.67	760±	+337	+332
25/65	290	0.42	2.07	665±	+242	-128
26/65	230	0.54	1.90	835±	+412	-145
27/65	560	0.14	1.85	270	-153	-150
28/65	780	0.09	1.97	650	+227	-138
29/65	330	0.66	3.99	180±	-243	+ 64
30/65	275	0.30	1.37	300±	-123	-208
31/65	1590	0.2	12.70	1120±	+697	+935
32/65	215	0.5	1.58	205±	-218	-177


PLATE 1
E106800
N106000
E106800
N104600
N106000
E106200
N104600
E106200
9°15'
T.N.
M.N.
Centre line of original spillway
1020
1000
980
960
940
920
900
880
860
840
820
800
TOWER
Earth and rockfill retaining wall
LOCALITY MAP
142°30'
142°40'
142°50'
143°00'
37°00'
37°10'
37°20'
Lake Lonsdale Res.
BRIDGE INN
STAWELL
HALLS GAP
SURVEY AREA
POMONAL
GREAT WESTERN
ARMSTRONG
ARARAT
MOYSTON
Fyans Lake Res.
Inlet Channel
Outlet Channel
Pipe Line
MILES
VICTORIA
Melbourne
BALLARAT
REFERENCE TO AUSTRALIA
1:250,000 STANDARD
MAP SERIES
(BASED ON SRWSC PLAN 8281 AB)
LEGEND
Shot location 1963
Shot location 1965
Sprengnether seismograph No.1577 1963
Sprengnether seismograph No.1577 1965
Sprengnether seismograph No.1863 1963
Rock-face cutting
LAKE BELLFIELD DAM SITE
VIBRATION TEST
LOCALITY MAP
FEET
(Contour Interval 20 ft)
TO ACCOMPANY RECORD No. 1967/4
Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics
J54/B5-5

RESULTS OF VIBRATION TESTS AT [illegible] DAM SITE, VICTORIA 1963 AND 1965

Test Number and Year	Total charge (lb)	Charge W and delay (lb)	(msec)	Inclined distance d (ft) 1577	1863	Maximum displacement (in) 1577	1863	Resultant amplitude (in) 1577	1863	Frequency (c/s) 1577	1863	Acceleration (in/sec^2) 1577	1863	Resultant acceleration (in/sec^2) 1577	1863	Resultant acceleration (g) 1577	1863
1/63	10	10	0	335		L0.0003				40		19.0					
						V0.0003		0.00047		66		51.8		58.6		0.15	
						T0.0002				50		19.8					
3/63	40	40	0	345		L0.0006				40		38.0		67.7		0.18	
						V0.0004		0.0008		50		39.6					
						T0.0004				50		39.6					
4/63	100	100	0	430		L0.0022				20		34.8					
						V0.0014		0.0027		30		49.8		69.9		0.18	
						T0.0008				33		34.5					
7/63	1338	447	0	450	610	L0.0030	0.0014			20	25	47.5	34.6				
		447	98			V0.0016 0.0002	0.0010 0.0001	0.0056	0.0017	22 60	8 50	3.1 28.5 } 20.7	2.5 9.9 } 10.2	75.0	36.4	0.19	0.09
		444	185			T0.0044	0.00003 0.00005			17	10 50	50.4	.01 5.0 } 5.0				
8/63	444	444	0	420	650	L0.0036	0.0010			25	25	89.0	24.8				
						V0.0010	0.0003 0.0003	0.0039	0.0012	25	14 60	24.8	2.3 42.7 } 42.8	94.3	51.0	0.25	0.13
						T0.0012	0.0005			20	25	19.0	12.4				
9/63	3664	32	0	715	715	L0.0002 0.0006	0.00008 0.0008			50 6	66 6	19.8 0.9 } 19.8	13.8 1.1 } 13.8				
		32	10			V0.0004 0.0012	0.0003 0.0008	0.0017	0.0012	66 4	77 4	68.8 0.8 } 68.8	70.4 0.5 } 70.4	72.0	83.5	0.19	0.22
		88	20			T0.0002 0.0010	0.0003 0.0003			30 8	60 8	7.1 2.5 } 7.5	42.7 0.8 } 42.7				
		137	30														
		183	40														
		273	50														
		380	60														
		394	70														
		503	80														
		485	90														
		396	100														
		317	110														
		243	120														
		155	130														
		46	140														
1/65	27	27	0	207		L0.0009				40		57.0					
						V0.0005		0.0011		100		200		240		0.62	
						T0.0003				100		120					
2/65	2282	326	0	178													
		326	17														
		326	34														
		326	51			Motion too fast to record satisfactorily											
		326	68														
		326	85														
		326	102														
3/65	48	48	0	460		L0.0003				25		7.4					
						V0.0003		0.00047		40		19.0		21.0		0.05	
						T0.0002				25		4.9					
4/65	3129	166	0	502		L0.0008				50		79.2					
		354	17			V0.0008		0.0017		50		79.2		170		0.44	
		624	34			T0.0013				50		128.6					
		798	51														
		705	68														
		482	85														
5/65	16	16	0	96		L0.0025				30		89.2					
						V0.0025		0.0037		50		248		278		0.72	
						T0.0009				50		890					
6/65	2286	235	0	247		L0.0033				25		81.6					
		444	015			V0.0037		0.0062		25		91.5		154		0.40	
		468	204			T0.0038				25		94.0					
		450	310														
		438	400														
		251	495														
7/65	45	45	0	410		L0.0002				50		19.8					
						V0.0003		0.0004		45		24.0		36.9		0.09	
						T0.0002				50		19.8					
8/65	3786	264	0	807		L0.0017				50		168.5					
		392	17			V0.0007		0.0019		50		69.3		182.7		0.47	
		741	34			T0.0004				30		14.2					
		938	51														
		929	68														
		522	85														
9/65	2187	326	0	164		L											
		326	80			V		Motion too fast to record satisfactorily									
		326	155			T											
		327	250														
		335	340														
		314	430														
		233	495														
10/65	459	175	0	197		L											
		192	10			V		Motion too fast to record satisfactorily									
		92	20			T											
11/65	3079	293	0	295		L											
		597	17			V		Photographic paper did not run freely during test.									
		1077	34			T											
		714	51														
		398	68														
12/65	1499	183	0	235		L											
		398	17			V		Motion too fast to record satisfactorily									
		416	34			T											
		404	51														
		99	68														
13/65	152	152		603		L0.0003				40		19.0					
						V0.0004		0.0006		30		14.3		30.4		0.08	
						T0.0003				40		19.0					
14/65	2699	365	0	664		L0.0005				50		49.5					
		497	10			V0.0010		0.0012		40		63.3		85.4		0.22	
		626	20			T0.0003				50		28.7					
		731	30														
		314	40														
		166	50														
15/65	2674	95	0	374		L											
		301	10			V		Motion too fast to record satisfactorily									
		494	20			T											
		782	30														
		1002	40														
16/65	1767	292	0	153		L											
		273	80			V		Motion too fast to record satisfactorily									
		303	155			T											
		295	250														
		302	340														
		150	430														
		152	495														
17/65	175	175	0	395		L0.0037				25		91.5					
						V0.0032? >0.0028		0.0053?		50		316? >277		336? >300		0.87? >0.78	
						T0.0020				30		71.3					
18/65	2227	231	0	314		L0.0075				10		29.7					
		440	17			V0.0040		0.0103		40		254		257		0.66	
		662	34			T0.0058				10		23.0					
		553	51														
		232	68														
		109	85														
19/65	4532	248	0	435		L0.0037				20		58.5					
		867	17			V0.0050		0.0091		50		495		502		1.3	
		797	34			T0.0067				15		59.7					
		721	51														
		541	68														
		395	85														
		488	102														
		308	119														
		167	136														
20/65	84	84	0	358		L0.0003				50		29.7					
						V0.0003		0.0004		50		29.7		43.2		0.11	
						T0.0001				50		9.9					
21/65	1206	168	0	339		L0.0050				25		124					
		168	10			V0.0036		0.0068		25		89.0		182		0.47	
		168	20			T0.0028				30		100					
		168	30														
		168	40														
		152	50														
		168	60														
		46	70														
22/65	1727	298	0	141													
		298	17			L											
		298	34			V											
		298	51					Light source failed during test									
		244	61			T											
		253	68														
		38	71														
23/65	1985	509	0	336		L0.0073				25		180					
		226	17			V0.0063		0.0119		40		399		623		1.6	
		937	34			T0.0070				40		443					
		345	51														
		356	68														
		112	85														
24/65	2603	276	0	675		L0.0017				30		60.6					
		603	17			V0.0010		0.0024		50		99.0		146		0.38	
		758	34			T0.0014				40		88.7					
		588	51														
		317	68														
		61	85														
25/65	2613	666	0	290		L0.0062				15		55.0					
		257	17			V0.0055		0.0117		25		136		164		0.42	
		245	34			T0.0083				15		74.0					
		245	51														
		231	68														
		276	85														
		279	102														
		319	119														
		95	136														
26/65	2250	236	0	231		L0.0078				10		30.9					
		472	17			V0.0082		0.0143		25		203		208		0.54	
		834	34			T0.0088				10		34.8					
		472	51														
		236	68														
27/65	268	268	0	558		L0.0020				25		49.5					
						V0.0017		0.0028		10		6.7		52.9		0.14	
						T0.0011				20		17.4					
28/65	653	653	0	780		L0.0010				30		35.6					
						V0.0017		0.0022		10		6.7		36.4		0.09	
						T0.0010				10		4.0					
29/65	1073	168	0	332		L0.0025				30		89.0					
		168	10			V0.0025		0.0046		50		248		255		0.66	
		168	20			T0.0030				25		74.2					
		168	30														
		168	40														
		50	50														
		183	60														
30/65	904	(i) 304 (ii) 300 (iii) 300	0 105 204	275		L0.0030 (i) 0.0025 (ii) 0.0025 (iii)		0.0043 (i) 0.0036 (ii) 0.0043 (iii)		25 (i) 30 (ii) 30 (iii)		74.3 (i) 89.0 (ii) 89.0 (iii)		106 (i) 129 (ii) 125 (iii)		0.27 (i) 0.33 (ii) 0.32 (iii)	
						V0.0025 (i) 0.0025 (ii) 0.0025 (iii)				25 (i) 30 (ii) 25 (iii)		61.8 (i) 89.0 (ii) 61.8 (iii)					
						T0.0018 (i) 0.0012 (ii) 0.0025 (iii)				25 (i) 25 (ii) 25 (iii)		44.5 (i) 29.9 (ii) 61.8 (iii)					
31/65	4640	480 800	0 17	1590		L0.0003 (i) 0.0011 (ii)		0.0008 (i)		50 (i) 5 (ii)		29.8 (i) 1.1 (ii)		76.9 (i) 3.0 (ii)		0.20 (i) 0.008 (ii)	
		1120 1120	34 51			V0.0003 (i) 0.0008 (ii)		0.0024 (ii)		50 (i) 8 (ii)		29.8 (i) 2.0 (ii)					
		960 160	68 85			T0.0007 (i) 0.0020 (ii)				50 (i) 5 (ii)		64.3 (i) 2.0 (ii)					
32/65	1224	204 204 204	- 0 - 105 - 204	215		L0.0023 (i) 0.0013 (ii) 0.0010 (iii) 0.0013 (iv) 0.0011 (v) 0.0010 (vi)		0.0064 (i) 0.0042 (ii) 0.0025 (iii) 0.0040 (iv) 0.0028 (v) 0.0024 (vi)		25 (i) 25 (ii) 25 (iii) 25 (iv) 25 (v) 25 (vi)		57.0 (i) 32.2 (ii) 24.8 (iii) 32.2 (iv) 27.2 (v) 24.8 (vi)		194 (i) 105 (ii) 180 (iii) 107 (iv) 68.6 (v) 59.6 (vi)		0.50 (i) 0.27 (ii) 0.47 (iii) 0.28 (iv) 0.18 (v) 0.15 (vi)	
		204 204 204	- 310 - 400 - 495			V0.0043 (i) 0.0022 (ii) 0.0018 (iii) 0.0028 (iv) 0.0018 (v) 0.0015 (vi)				30 (i) 25 (ii) 50 (iii) 30 (iv) 25 (v) 25 (vi)		153 (i) 54.5 (ii) 178 (iii) 100 (iv) 44.5 (v) 37.0 (vi)					
						T0.0042 (i) 0.0034 (ii) 0.0015 (iii) 0.0025 (iv) 0.0018 (v) 0.0016 (vi)				25 (i) 25 (ii) 25 (iii) 15 (iv) 25 (v) 25 (vi)		104 (i) 84.0 (ii) 37.0 (iii) 22.2 (iv) 44.5 (v) 39.6 (vi)					
33/65				15		L0.0002				50							
						V0.0002		0.0003		50							
						T0.0002				50							

NOTE - In the column "Maximum displacement" L, V, and T refer to the displacement components in longitudinal, vertical and transverse directions in relation to the radius vector from instrument to shot-point.

To accompany Record No. 1967/4

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