DEPARTMENT OF NATIONAL RESOURCES

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

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KINGSWOOD AMMUNITION DEPOT VIBRATION TESTS, NSW, 1976

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SUMMARY

The Bureau of Mineral Resources, Geology & Geophysics has carried out a series of measurements to determine the level of ground vibrations caused by the detonation of various-sized explosive charges at the Kingswood Ammunition Depot, NSW. The survey was undertaken at the request of the Department of Defence, after people living near the demolition range had complained of excessive vibration and noise. In addition, three seismic refraction spreads were recorded to determine the nature of the subsurface.

All of the vibration levels recorded were below the Standards Association of Australia recommended level for safe blasting vibrations. It was predicted that the detonation of a larger explosive charge would also result in vibration levels below the recommended figure.

1. INTRODUCTION

At the request of the Department of Defence, the Bureau of Mineral Resources, Geology & Geophysics (BMR) measured ground vibrations resulting from the demolition of various-sized explosive charges at the Kingswood Ammunition Depot, NSW. The net explosive charge ranged from 0.5 kg (1 lb) to 227 kg (500 lb). Four charges of 0.5 kg were detonated on the surface of the ground, and other charges of different weight were detonated at a depth of 2.1 m (7 ft) or 3.7 m (12 ft) below the ground surface. Simultaneous measurements of the sound levels produced by these explosions were made by personnel from the National Acoustics Laboratories (NAL), Department of Health.

The vibrations were monitored at three sites (Fig. 1). Site 1 was at the northern boundary of the demolition range and consisted of two sensors at distances of 440 m (Site 1A) and 600 m (Site 1B) from the shot inside the demolition area. Site 2 was just outside the northwestern boundary and consisted of six geophones with 35 m spacing along a radial line, the nearest geophone being 840 m from the shot. Site 3 was at a private residence in Wentworth Road, 2.1 km north of the shot.

Two intersecting seismic refraction spreads were placed at the demolition site centre and one at recording site 1B at the northern boundary, to measure seismic velocities, thickness of the overburden, and depth to bedrock.

The recordings were carried out on 18, 19 and 20 August 1976 by a field party from the Engineering Geophysics Group, consisting of D.C. Ramsay, D.G. Bennett, and D.H. Francis.

2. GEOLOGY

The area of the Ammunition Depot is underlain by shale and sandstone of the Triassic Wianamatta Group (Sydney 1:250 000 Geological Series map). The demolition range is thought to be sited on Bringelly Shale, which normally has a highly weathered lateritic profile to about 9 m depth (C. Herbert, pers. comm.). Ashfield Shale, another member of the Wianamatta Group, occurs at a depth of about 30 m. Tertiary alluvium consisting of 6 m of clay on top of 6 m of gravel occurs farther north and east.

3. METHODS AND EQUIPMENT

Three sets of equipment were used to record the vibrations. A Sinco Vibration Monitor, Model S-3, was used at site 1. This instrument consists of two sensors each containing three mutually orthogonal velocity-sensitive geophones (oriented radial to the shot, transverse and vertical) and an oscillograph. One sensor was positioned at site 1A and the other at site 1B. The frequency response of the entire system is essentially uniform from 6 to 150 Hz.

At recording site 2, six three-component velocity sensitive geophones (types HS-J-LP3D and HS-1-LP3D) were placed 35 m apart in a straight line radial to the demolition site. The outputs were fed into a 24-channel SIE amplifier bank and recording oscillograph. By calibrating the gains of the amplifiers and measuring the outputs of the geophones over a range of frequencies, the particle velocities of the ground vibrations were calculated.

At recording site 3, a Sprengnether VS-1200 Engineering Seismograph was used. Although similar in principle to the Sinco Model S-3, it has only one three-component sensor, but the maximum gain attainable is greater. The frequency response is flat between 2 and 200 Hz. This instrument also incorporates a sound detector for measurement of the intensity of air blast. Air-blast measurements were taken so that they could be compared with the recordings of the more accurate and sensitive NAL instruments.

On the refraction spreads (Dobrin, 1952) near the demolition site and at site 1B, depths to refracting surfaces were calculated from intercept times and a modification of the reciprocal method (Hawkins, 1961). Each spread consisted of 24 geophones arranged in a straight line with a spacing of 4 m. Five shots per spread were fired: one in the centre, one at 2 m beyond either end, and one at 60 m beyond either end. BMR truck-mounted 24-channel SIE RA-49R amplifier bank, SIE VRO-6D recording oscillograph, and 14-Hz Geospace HS-J geophones were used.

4. VIBRATION RESULTS

The records indicate that three groups of vibrations arrive at a site as a result of the detonation of an explosive charge. The first to arrive is the longitudinal wave ('Long.' in Table 1), which is generally of high frequency and shows a low attenuation rate with distance. At two recording sites its apparent propagation velocity was measured as 4300 m/s with a frequency between 60 and 70 Hz. The longitudinal wave is followed by a complex mixture of low-frequency wave types, which usually carries the highest proportion of energy (designated 'G. Motion'). This composite wave contains the transverse, Rayleigh, and Love waves with frequencies ranging between 9 and 22 Hz. The last to arrive is the ground vibration induced by the air blast as it passes over the recording site ('Air Blast Ind.'). This produces firstly a high-frequency (about 125 Hz) shock wave, followed by a wave with a lower frequency (about 20 to 35 Hz, which may be a harmonic of the ground-roll frequency; Cook, 1958).

Table 1 lists the peak particle velocities for the longitudinal, ground motion, and air-blast induced vibrations recorded at the three sites from the detonation of different explosive charges during the two days of tests. All the figures quoted in Table 1 are the resultants of three mutually orthogonal components of ground vibration (oriented radial to the shot, transverse and vertical) expressed in terms of peak particle velocity in cm/s. The maximum value of each component, independent of time, was measured, as this gives the largest possible resultant. These figures may be compared with the Standards Association of Australia (1967) Explosives Code, which recommends that 1.9 cm/s be the maximum allowable resultant of the three components of ground motion for blasting in built-up areas.

The values of ground vibration recorded by the six geophones at site 2 varied, and so the average was taken to represent the site. Further, as can be seen from Table 1, these average values are disproportionately low, considering the distance of the site from the shot location. This could be due to insufficient coupling between the geophones and the ground. A possible explanation is that the three-component geophones have densities of about 2.1 and 3.0 g/cm^3, which is considerably more dense than the soil in which they were buried (about 1.6 g/cm^3). This would cause some degree of mismatch, resulting in the geophones recording a lesser amplitude than actual. At this stage it is not possible to estimate the degree of mismatch, but it is intended to carry out tests to determine this. These results are therefore considered to be questionable and will not be discussed further.

For sites 1A, 1B and 3, the amount of energy transmitted through the ground (i.e., Longitudinal and Ground Motion in Table 1) increased as the weight of explosive detonated at a given depth increased. At site 1A the maximum vibration recorded was 0.41 cm/s, and at site 1B, 0.30 cm/s; both of these were due to the explosion of a 227 kg charge at a depth of 3.7 m. The approximate amplitude of vibration can be predicted from the empirical formula (SAA, 1967):

Table 1. Ground vibrations recorded for various charge sizes

Charges buried 3.7 m (18/8/76)					Charges buried 2.1 m (19/8/76)				
Charge Size kg	(lbs)	Long. (resultant in cm/s)	G. Motion (resultant in cm/s)	Air Blast Ind. (resultant in cm/s)	Charge Size kg	(lbs)	Long. (resultant in cm/s)	G. Motion (resultant in cm/s)	Air Blast Ind. (resultant in cm/s)
Site 1A									
4.5	(10)	0.005	0.03	0.005	4.5	(10)	0.005	0.02	0
23	(50)	0.05	0.09	0.005	23	(50)	0.03	0.06	0.01
91	(200)	0.10	0.19	0.01	91	(200)	0.05	0.11	0.10
136	(300)	0.17	0.30	0.01	136	(300)	0.06	0.13	0.01
227	(500)	0.30	0.41	0.03	182	(400)	0.07	0.16	0.23
0.5 (on surface)	(1)	0	0	0.04, 0.05	0.5 (on surface)	(1)	0	0	0.02, 0.02
Site 1B									
4.5	(10)	0.005	0.02	0.005	4.5	(10)	0.003	0.01	0
23	(50)	0.03	0.04	0.005	23	(50)	0.01	0.03	0.005
91	(200)	0.05	0.11	0.005	91	(200)	0.02	0.06	0.10
136	(300)	0.08	0.17	0.005	136	(300)	0.03	0.07	0.005
227	(500)	0.12	0.30	0.03	182	(400)	0.05	0.08	0.17
0.5 (on surface)	(1)	0	0	0.03, 0.04	0.5 (on surface)	(1)	0	0	0.01, 0.01
Site 2									
4.5	(10)	*	*	0.003(?)	4.5	(10)	0	0.003	0
23	(50)	*	0.008	0.003(?)	23	(50)	0.003	0.005	0.003
91	(200)	0.008	0.02	0.005	91	(200)	0.005	0.01	0.04
136	(300)	0.01	0.02	0.008	136	(300)	0.008	0.02	0.01
227	(500)	0.02	0.04	0.008	182	(400)	0.01	0.02	0.07
0.5 (on surface)	(1)	0	0	0.008, 0.02	0.5 (on surface)	(1)	0	0	0.01, 0.005
Site 3									
4.5	(10)	*	*	*	4.5	(10)	0.001	0.001	0
23	(50)	0.005	0.005	*	23	(50)	0.004	0.004	0.002
91	(200)	0.01	0.01	0.01	91	(200)	0.01	0.01	0.02
136	(300)	0.01	0.02	0.01	136	(300)	0.01	0.01	0.04
227	(500)	0.03	0.03	0.01	182	(400)	0.01	0.02	0.06
0.5 (on surface)	(1)	0	0	0.01	0.5 (on surface)	(1)	0	0	0.01

* Not recorded.

$$A = KE^{\frac{1}{2}}d^{-1}$$

where A is the amplitude of ground displacement in cm

E is the weight of the explosive charge in kg

d is the distance from the explosion in m

and K is a constant determined on the site.

In addition, assuming sinusoidal motion, the vibrational velocity of ground particles may be calculated from the formula:

$$V = 2\pi f A$$

where V is the velocity in cm/s

f is the frequency in Hz

and A is the amplitude of ground displacement in cm.

Thus, combining the two formulae, V is proportional to $E^{\frac{1}{2}}$ for a given d. Accordingly, in Figure 2, maximum particle velocity in the ground motion component recorded at sites 1A and 1B has been plotted against the square-root of charge size detonated at 3.7 or 2.1 m depth. This formula assumes that the explosive charge is always of the same chemical composition, but it was not. Nevertheless, approximate relations are shown by the lines, which have been extrapolated to a charge size of 455 kg, the proposed upper limit of charge to be detonated at this location: the maximum ground motion vibration due to a 455 kg charge at 3.7 m depth would be at site 1A and is expected to be about 0.6 cm/s, still safely within the SAA recommended limit; although the relation for site 1B is less well defined, the vibration level due to the same charge will be less than that at site 1A.

When an explosive charge is detonated below the surface, energy is transferred through the air as well as through the ground. The energy distribution between the two media depends mainly on the depth of burial: appreciable air waves are produced only when the ground surface is broken and debris is thrown out. As the air wave passes over the ground, coupling between the air and ground induces a vibration in the ground. The attenuation of the air blast with distance is influenced by atmospheric conditions such as wind speed and direction, wind velocity gradient, and temperature gradient with height.

The ratio of the amplitude of the ground motion to air-blast induced wave for shots buried at 3.7 m and 2.1 m clearly shows that more energy is transmitted through the ground from the deeper shot. Unlike the longitudinal and ground motion vibrations, the magnitude of the air-blast induced wave does not necessarily show an increase with increasing charge size. The largest air-blast induced ground vibration - 0.23 cm/s at site 1A - was produced by a 182 kg charge detonated at 2.1 m, and was well below the SAA Limit. it is interesting to note that the air-blast induced ground vibration from a 0.5 kg surface charge is of the same order of magnitude as that produced by the larger shots at 3.7 m depth.

The type of explosive device appears to play an important role in determining the size of the air wave. In holes 2.1 m deep the Mk 82 bomb used for the 91 kg shot produced substantially larger air waves than the naval depth charge used for the 136 kg shot. Differences in type of explosive, casing, and physical size (which would alter the effective depth of burial) may be contributing factors.

5. SEISMIC REFRACTION RESULTS

The interpreted seismic refraction recordings are presented as cross-sections in Figure 3.

At the demolition site centre the subsurface forms a basically three-layer structure. Dry or partly wet clay with a seismic velocity of 600 to 700 m/s forms the surface layer, ranging in thickness from 2 to 4 m; this is the material in which the explosive charges are placed. The second layer, with a measured seismic velocity of 1700 to 1800 m/s, is probably saturated clay grading to highly weathered rock with depth. This sequence of gradually decreasing weathering with depth is not very amenable to seismic interpretation; however, this layer is thought to extend to about 10 m. Underlying this is slightly weathered to fresh shale with seismic velocity ranging from a lower limit of 2500 m/s to 3100 m/s, which may increase further with depth. With this type of weathering it is difficult to predict how deep holes to hold explosive charges might be augered into the second layer.

At vibration recording site 1B the subsurface appears to be generally similar to the demolition site. The surface layer of clay is 3.5 to 5 m thick, and overlies material less weathered than at the demolition site, having a seismic velocity of 2500 m/s. This second layer again extends to about 10 m depth, under which is fresher rock with a measured velocity of 3500 m/s.

6. CONCLUSIONS AND RECOMMENDATIONS

Based on the recordings taken during the two days of tests, the following conclusions and recommendations are presented.

1. The energy transferred into the ground increases with the size of the explosive charge and with the depth of burial. The maximum ground vibration amplitudes monitored at the recording sites for explosive charge sizes ranging from 0.5 to 227 kg detonated at the surface or 2.1 m or 3.7 m below the surface were below the SAA limit, and would not cause damage to buildings in fair condition. It is predicted that the ground vibration amplitude (with the possible exception of the air-blast induced component) produced by the explosion of 455 kg charge at a depth of 3.7 m would also be below the SAA limit at the same recording sites.

2. For a particular charge size, the air-blast induced ground vibration level decreases as the depth of burial increases and could also be expected to be influenced by meteorological conditions. It is therefore recommended that explosive charges be buried to at least 3.7 m. All of the air-blast induced ground vibration levels recorded were below the SAA limit,

but it is not possible to predict how these levels would change under different meteorological conditions.

3. With limited knowledge of the subsurface geology at and around the demolition range it is not possible to predict accurately ground vibration levels at points other than those measured. However, it appears unlikely that there would be large deviations from those recorded at the test sites.

7. REFERENCES

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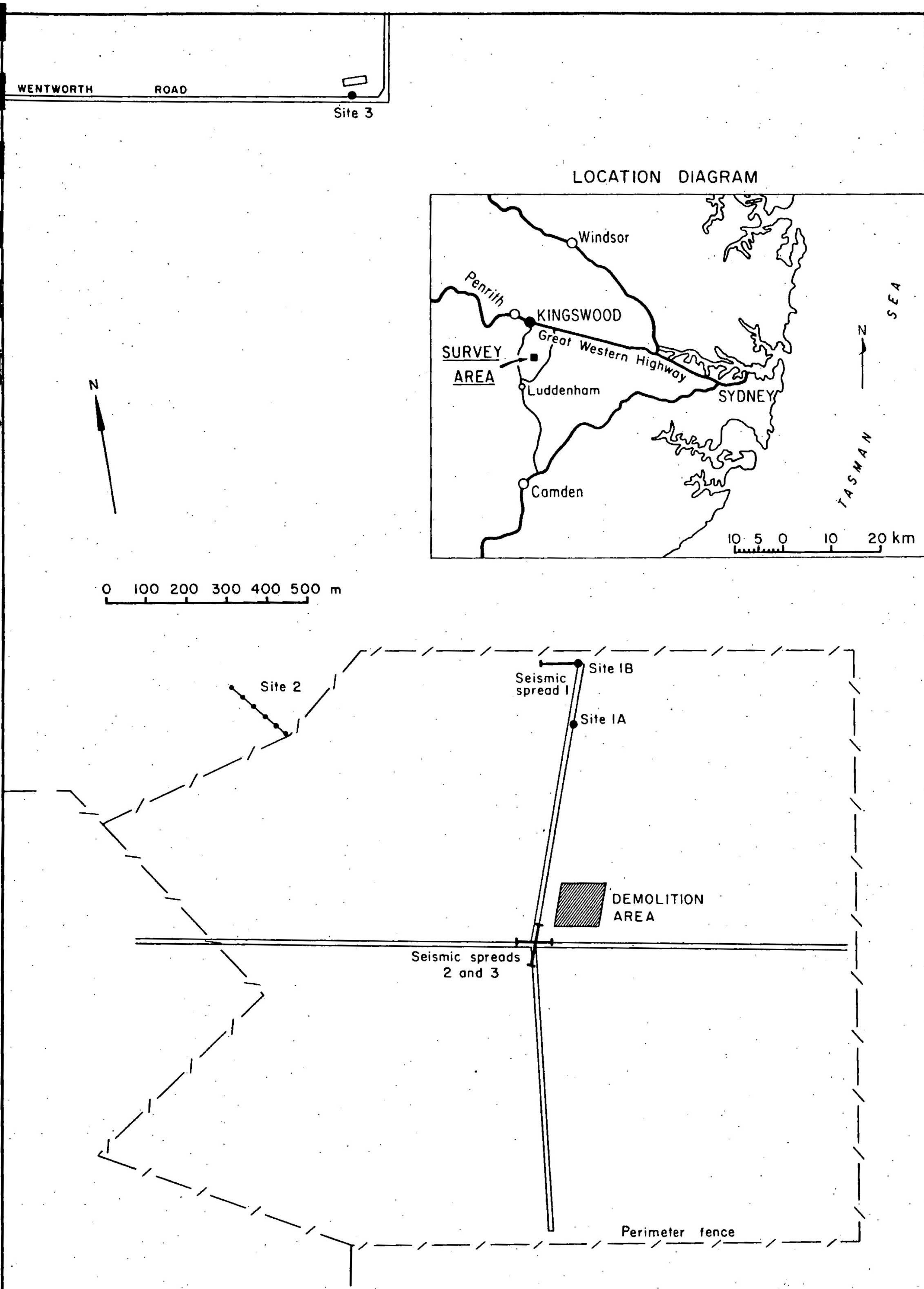

Fig. 1 LOCALITY MAP – KINGSWOOD DEMOLITION RANGE

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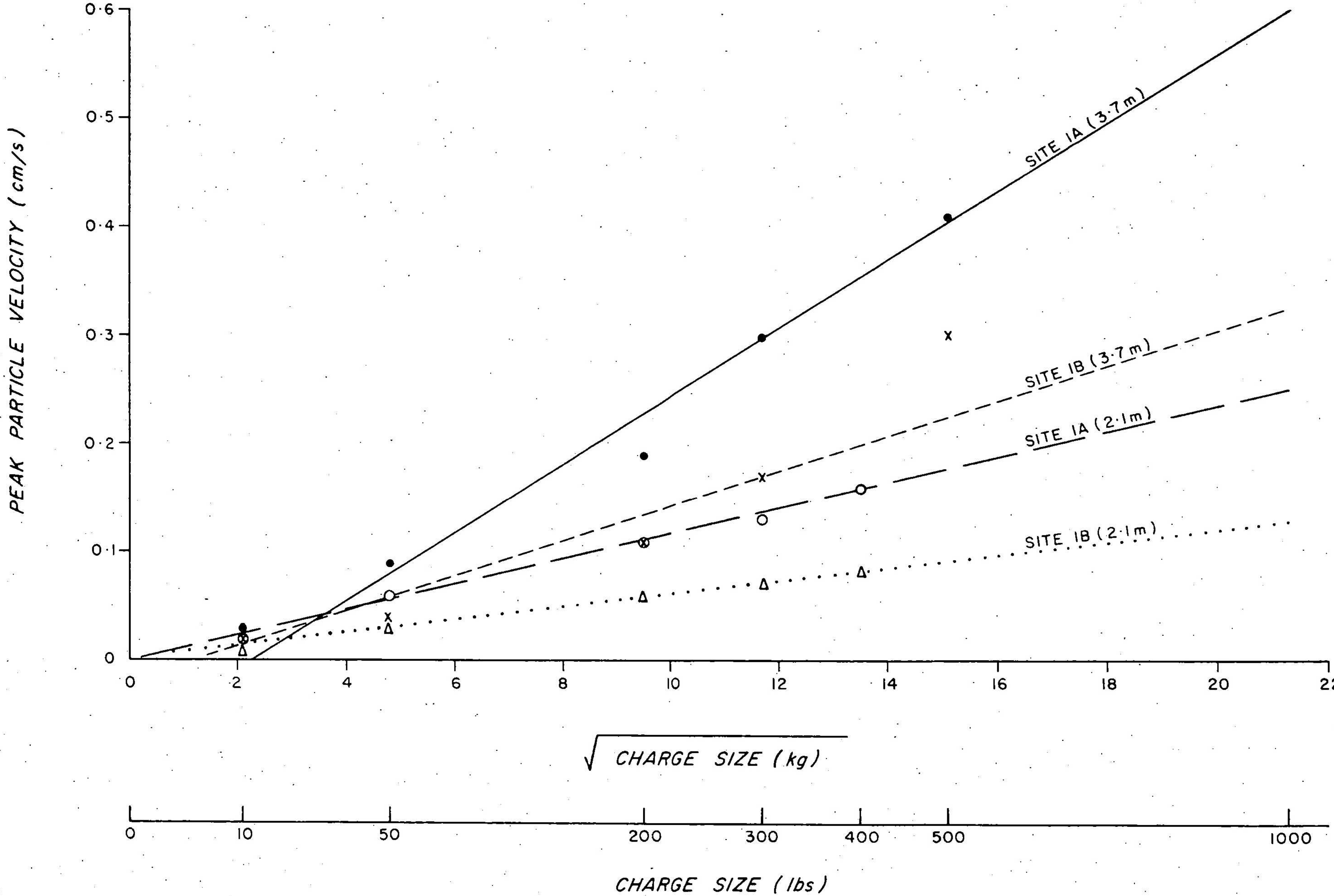

Fig. 2 GROUND MOTION MEASUREMENTS

I56/B5-35A

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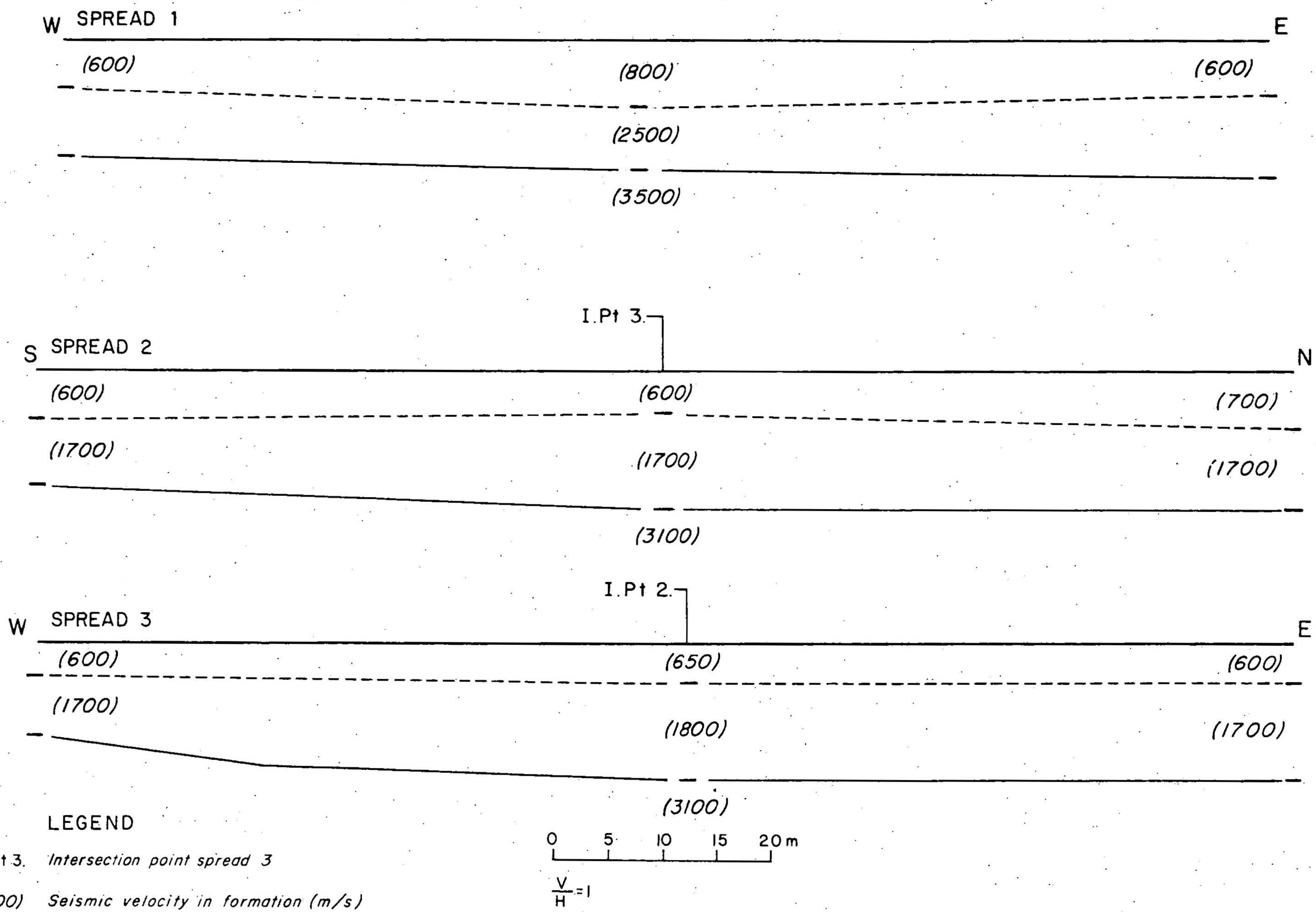

LEGEND

I.Pt 3. *Intersection point spread 3*

(2500) *Seismic velocity in formation (m/s)*

------ *Interpolated formation boundary*

—— *Bedrock boundary*

Fig. 3 SEISMIC CROSS-SECTIONS OF SPREADS 1, 2 and 3

156/B5-36A