DEPARTMENT OF
MINERALS AND ENERGY

# BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Record 1973/118



## MOURA COAL MINE, BLASTING VIBRATION MEASUREMENTS, MOURA, QUEENSLAND, 1973

by

E.J. Polak and D. Ramsay

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## PLATES

## SUMMARY

Measurements of the vibration due to blasting of 100 tonnes of ammonium nitrate in an opencut coal mine at Moura, Queensland, were taken at a distance of 335 m from the shot. The purpose of the measurement was to determine the possible effect of the blast on buildings. It is unlikely that buildings could be damaged by present shooting practice, but risks could be further restricted by an increase of shot delay times.

# 1. INTRODUCTION

At the request of Thiess Peabody Mitsui Coal Pty Ltd of Brisbane, the Bureau of Mineral Resources, Geology & Geophysics, has made vibration measurements on the open-cut site near Moura, Queensland.

The management of the mine received complaints that a house located 3 km east of the workings was cracking as a result of vibration from the firing of large charges of explosives. The matter was then discussed with the officers of the Mines Department of Queensland and with Dr J.P. Webb, Director of the Seismological Unit of the Department of Geology and Mineralogy of the University of Queensland.

BMR officers measured the vibration from the blast on 22 June 1973 in the course of a geophysical survey in the area. The results of that test are the subject of this Record. As this is BMR's first record dealing with blasting vibrations in Queensland the basic considerations are discussed more fully than in a routine report. For this reason parts of an earlier BMR Record (Polak, 1970) are reproduced here as Chapters 4 and 5.

In the interpretation of data the following textbooks were used: Parkin & Humphreys, 1969; Richardson, 1957; Sharman, 1963; Cook, 1958; Stephens & Bate, 1966; Wood, 1964; Encyclopedia of Science and Technology; Langefors & Kihlstrom, 1967.

# 2. GEOLOGY

Plate 1 shows the locations of the shot and of the recorder. The 'A' coal seam is the uppermost in the productive section of the Upper Permian Baralaba Coal Measures. The shots and the recorder were located in the shales of the roof of the coal seam.

# 3. INSTRUMENT

The instrument used was a Sprengnether Portable Blast and Vibration Seismograph, Model VS.1200, which comprises a 3-component seismometer, recorder, and control unit.

The seismometer contains three suspended coil transducer units accurately aligned along orthogonal axes and housed in a cast aluminium box. The seismometers are velocity sensitive with an electrodynamic constant of 50V/metre/sec. All three have a natural period of 0.5 seconds.

In addition to velocity, acceleration or displacement can be selected by panel switch as the recording mode. This is achieved by the use of differentiating and integrating circuits prior to amplification. Operational amplifiers with switched feedback control are used to obtain stable calibrated gain. Output is to 200-Hz galvanometers and recording is on direct-write photographic paper.

## 4. BASIC CONSIDERATIONS

### Waves generated

When an explosive charge is detonated below the ground surface, pressure waves are generated. Two groups of waves will radiate from the explosion: body waves through the Earth, and sound waves through the air, the amplitude of each group being attenuated with distance from the blast.

### Body waves

Each explosion produces several types of body waves, of which the fastest and least attenuated is the longitudinal wave. This wave is recorded and indicated with a letter L in Plate 2. It carries a small amount of energy.

The second to arrive is the transverse wave (marked on plate with letter T). It carries more energy, but is attenuated at a greater rate than the longitudinal wave.

The third to arrive is the Rayleigh wave (marked R). It is the slowest wave, is of lower frequency and has a very high rate of attenuation.

The frequency characteristics of the recorded wave depend greatly on the nature of the rock and overburden at the recording site and will accordingly vary from site to site. The amplitude recorded and the duration of the disturbance also depend greatly on terrain conditions.

For equal explosive charges and distances from the shot, rock outcrops give vibrations of lower amplitudes, higher frequencies, and shorter duration than overburden. On outcrops, recorded frequencies typically range from 20 to 80 Hz, whilst on overburden 4 to 20 Hz is more typical.

Amplitude variations may be as much as 30 to 1 between extremes of abnormally responsive overburden and hard rock outcrops, for recordings at equal distances from the same blast.

The rate of attenuation of waves with distance from the blast is complex and also depends on terrain conditions. However, these conditions remain more or less constant in any one locality, and in practice several empirical formulae can be used to compute expected vibrations at a given distance. One of these is discussed in chapter 6 of this Record.

### Air waves

The detonation of an explosive charge in the ground produces appreciable air waves only if the ground is broken and debris is thrown out. The uplift of the ground produces a low-frequency air wave, which is only recognizable at a short distance.

## 5. DAMAGE DUE TO VIBRATION

The history of criteria applied to determine the likelihood of damage to buildings from ground vibration shows that (1) particle displacement, (2) particle displacement and frequency, (3) particle acceleration, and (4) particle velocity have all been used by different investigators and authorities. Perhaps the first comprehensive report and accepted reference for many years was by Thoenen & Windes (1942), who concluded that acceleration was the most useful parameter. However, a more recent study by Duvall & Fogelson (1962), who applied modern statistical methods to the data obtained by previous investigators including Thoenen & Windes, has shown that velocity is the most generally useful parameter. Their findings are now most widely accepted and are probably the best available guide today.

Generally the vibration occurs at one dominant frequency, and by assuming that the motion is sinusoidal, values of displacement, velocity, and acceleration can be calculated no matter which is recorded. Values of these parameters accepted as criteria are discussed below.

Amplitude criteria. Some examples of authors and authorities who have considered the magnitude of particle movement as a criterion to damage resulting from blasting are quoted below.

(1) State of Pennsylvania, U.S.A. (1947) which states, 'in no case shall the ground displacement be in excess of 0.03 inches (0.76 mm) at any dwelling house, etc.'

(2) Morris (1950) states, 'the limiting amplitude of 0.0082 inches gives a conservative estimate of the limiting amplitude for conventional structures'.

(3) Teichman & Westwater (1955) state, 'The caution limit for property, houses, etc. closely congested is 0.008 inches (0.18 mm)'.

Acceleration criteria. Thoenen & Windes (1942) arrived at the conclusion that ground acceleration is the best index. They did not claim that acceleration is the cause of damage, but simply that the acceleration value is a useful guide in determining the likelihood of damage. In tests carried to the damage point, they found that damage occurred frequently when the acceleration nearly equalled or exceeded 1g ($g = 32.2$ ft/sec$^2$ = acceleration due to gravity). They classified acceleration between 1g and 0.1g by the word 'caution' and lower values by the word 'safe'.

If the ground motion is assumed to be a simple harmonic motion the acceleration of one wave component of the ground motion may be calculated from the equation

$$a = 4\pi^2 f^2 A \qquad \text{(Formula 1)}$$

where $a$ = acceleration in in/sec$^2$

$f$ = frequency in Hz

$A$ = amplitude of movement in inches.

From the three components of the acceleration the resultant acceleration is calculated from the equation.

$$a = (a_V^{\,2} + a_L^{\,2} + a_T^{\,2})^{1/2} \qquad \text{(Formula 2)}$$

Velocity criteria. Duvall & Fogelson (1962) found that the peak ground velocity is the most significant parameter and concluded that peak velocities in excess of 2 inches per second (5.1 cm/sec) may cause damage.

Several other authorities have used a factor of frequency multiplied by amplitude (a factor which is proportional to velocity) as a criterion of damage. Crandell (1949) suggests $fA = 0.745$ as the damaging level and $fA = 0.527$ as the safe level.

The State of New Jersey (1954) in USA allows a maximum vibration amplitude of 0.0305 inches (0.77 mm) for 10 Hz and amplitude of 0.0153 inches (0.39 mm) for 20 Hz, both of which correspond to a velocity of approximately 2 inches per second.

The velocity of the ground particles for a sinusoidal motion may be calculated from the formula:

$$V = 2\pi fA \text{ in/sec} \qquad \text{(Formula 3)}$$

where V = velocity in in/sec

f = frequency in Hz

A = amplitude in inches

The Standards Association of Australia (1967) states (page 57) 'When blasting in built-up areas, the resulant of the three components of the ground vibration caused by blasting measured at the site where vibration effects are of concern, shall not exceed 0.008 inches in amplitude provided that the frequency of the shock wave as recorded by the amplitude type measuring instrument does not exceed 15 cycles per second........The maximum allowable resultant of the three components of ground vibration shall not exceed 0.75 in/sec if a particle velocity type measuring instrument is used.....The above recommended limits are a compromise between safety and comfort, but are heavily biased towards comfort. The above recommendation gives a factor of safety for light damage of about 6 when considering a building in good condition.'

## 6. RESULTS

Plate 2 shows the actual field record at Moura. The instrument was set up to record a particle velocity of 1 in/sec with a trace amplitude of one inch from its centre position. The seismometer was directed towards the blast.

On the three traces, the particle velocities of the longitudinal wave (L) and the transverse wave (T) are much lower than that of the Rayleigh wave (R), therefore only the Rayleigh will be considered in this record.

Amplitudes of the particle velocities resulting from the arrival of Rayleigh wave were:

| | | |
|---|---|---|
| Component: | left and right | 0.40 in/sec |
| | up and down | 0.44 in/sec |
| | to and from | 1.05 in/sec |
| | vector sum | 1.20 in/sec |

An appreciable left and right component appears on the record since the area is not seismically homogeneous. The frequency spectrum is quite complicated, with a lower frequency of approximately 7 Hz on which is superimposed a higher frequency of about 15 Hz. Using formula No. 3 (section 5) and the lower frequency of 7 Hz we may compute the amplitude of the particle displacement. The lower frequency is used, to obtain the highest value of displacement for safety reasons.

Amplitudes of the particle displacement are:

| | |
|---|---|
| left and right | 0.002 in |
| up and down | 0.007 in |
| to and from | 0.018 in |
| vector sum | 0.019 in |

In quarry blasting practice the approximate amplitude of vibration due to blasting is calculated from an empirical formula.

$$A = kE^{1/2}/d \qquad \text{(Formula 4)}$$

where A = amplitude of ground vibration in inches

E = weight of explosives in pounds

d = distance in feet

k = site constant

The site constant k is normally determined on the site of actual blasting. The value for k is given by Morris & Westwater (1953) as between 0.04 and 0.4 and by Fish (1951) between 0.05 and 0.2; here the first value is for a normal ground, and the second value 0.2 is for sand and clay fully saturated with water.

Applying formula 4 to the conditions of the Moura test where

A = 0.019

E = 50 tons

d = 1100 ft,

The value of $k = 0.08$ is found. Although the value was obtained in one test only, it can be used for approximate computation of the expected vibrations at any distance from a shot of any size.

The peak particle velocity of the ground vibration is related to the weight of explosives and the distance by (Nicholls, Johnson, Duvall, 1971).

$$V = H\,(d/E^{1/2})^{b}$$

where v = particle velocity in in/sec (Formula 5)

d = distance from shot in feet

E = weight of explosives in lbs.

H and b are constants which vary according to the conditions of the site. The average value for b measured by Nicholls et al. (1971) varied from -1.083 to -2.346. Larger particle velocities will result from smaller b; therefore for safety reasons the value of $b = -1$ is generally accepted. H is normally determined from a shot on the site.

Plate 3 gives a plot of formula 5 for the conditions met with at Moura and also shows the observed velocity. Two cases are considered: 50 tons and 100 tons of explosives, fired in one charge to indicate the vibrational effects of a blasting delay malfunction in which case two 50 ton loads of explosives would be detonated together. It can be seen that at a distance of 2000 ft the particle velocity is not likely to exceed the safe level set by the Standards Association of Australia.

The double frequency shown on the Moura record is the result of delay blasting. The waves from the first explosions are followed after a 25-millisecond interval by the waves of the delayed explosions. At the sections of the maximum amplitude the particles are still on one side of the zero line, when the delayed blast movement pushes them farther away, increasing the amplitude of vibrations.

The period is approximately 150 ms and ideally a single delay of 75 ms should be used to produce the second blast in antiphase. Delays of 50 or 100 ms would produce some cancellation and would be expected to reduce blast amplitude by about 25%. Delays longer than 100 ms should be used with care. e.g. a delay of 150 ms should be avoided as it would produce phase addition with the first blast and thus increase the amplitude.

## 7. CONCLUSIONS

Using the present procedure of blasting at Moura the ground vibrations at a distance of more than 2000 feet (600 m) from the shot will be unlikely to cause damage to a structure according to the Standards Association of Australia recommendation. Increase of the delay to 50 milliseconds should decrease the amplitude of vibration by about 25 percent.

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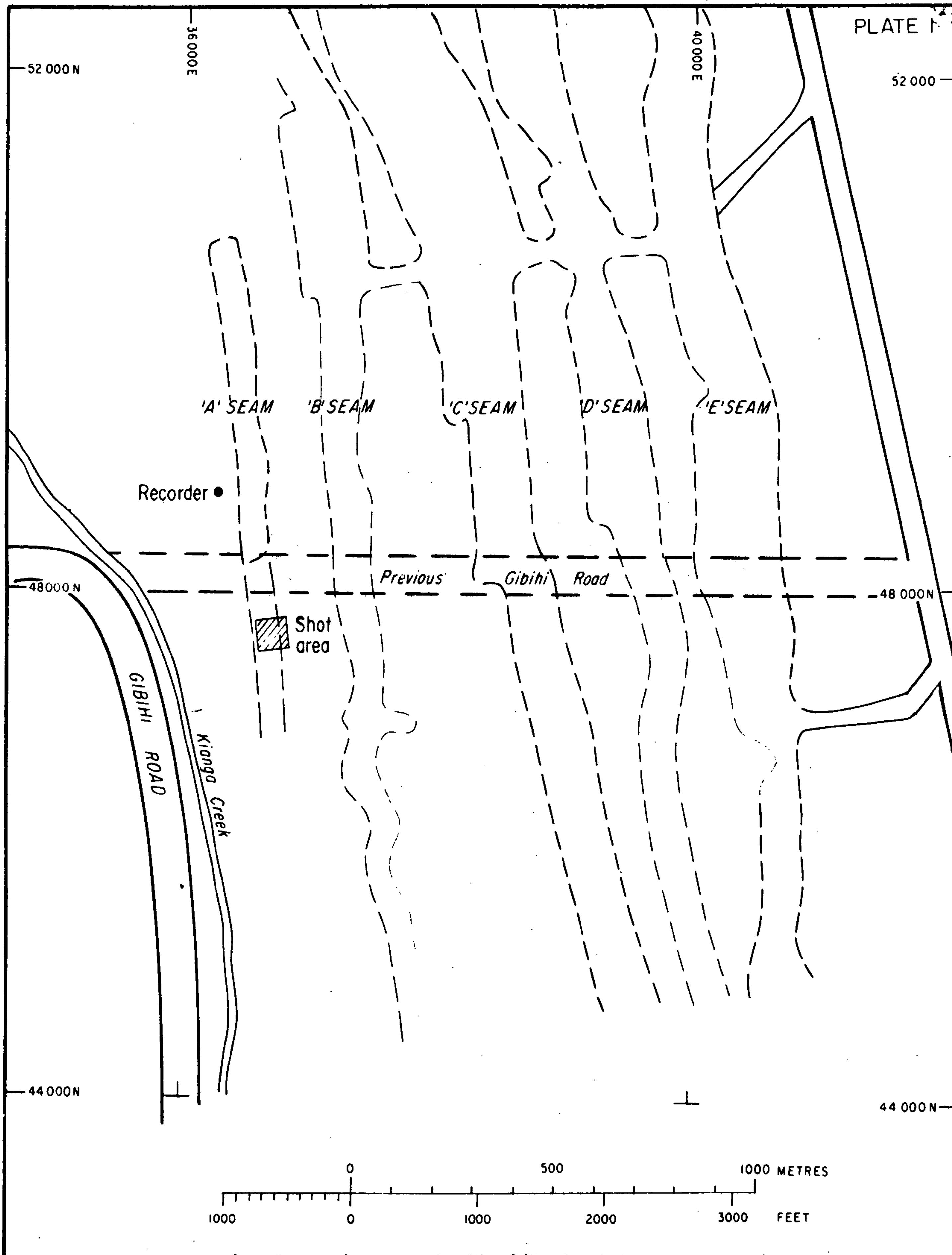
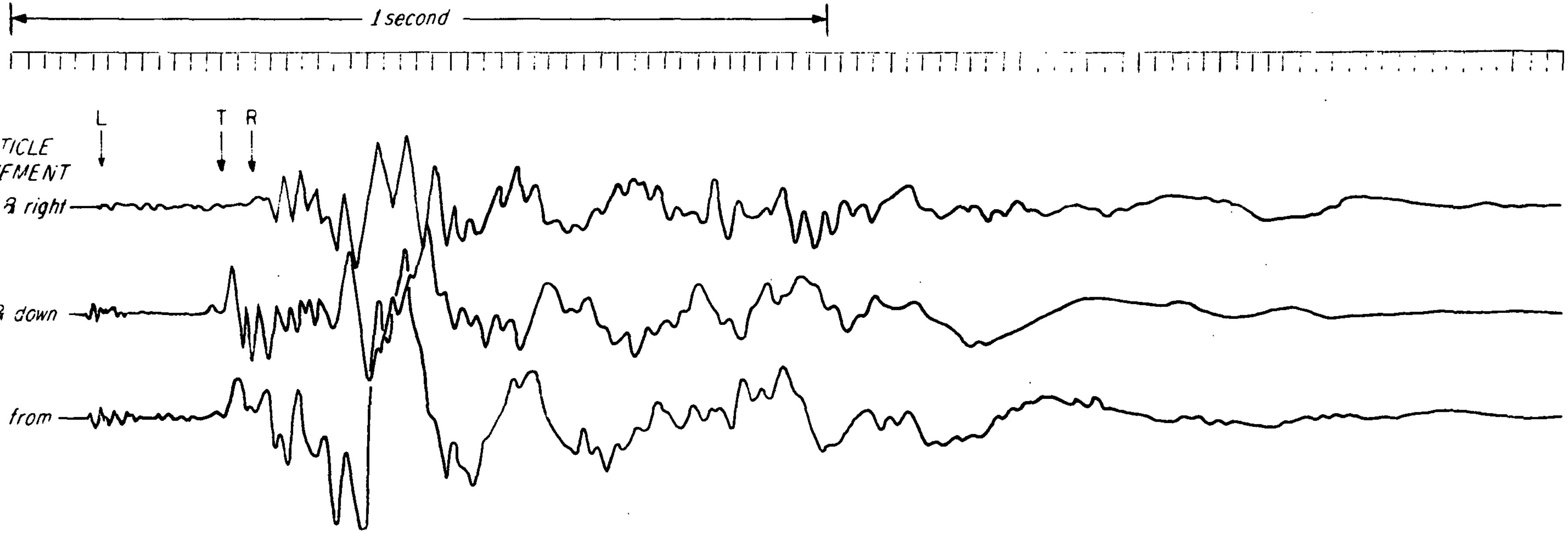



# MOURA OPEN CUT VIBRATION TEST
## LOCALITY MAP

*To accompany Record No 1973/118*

G56/B5-90A



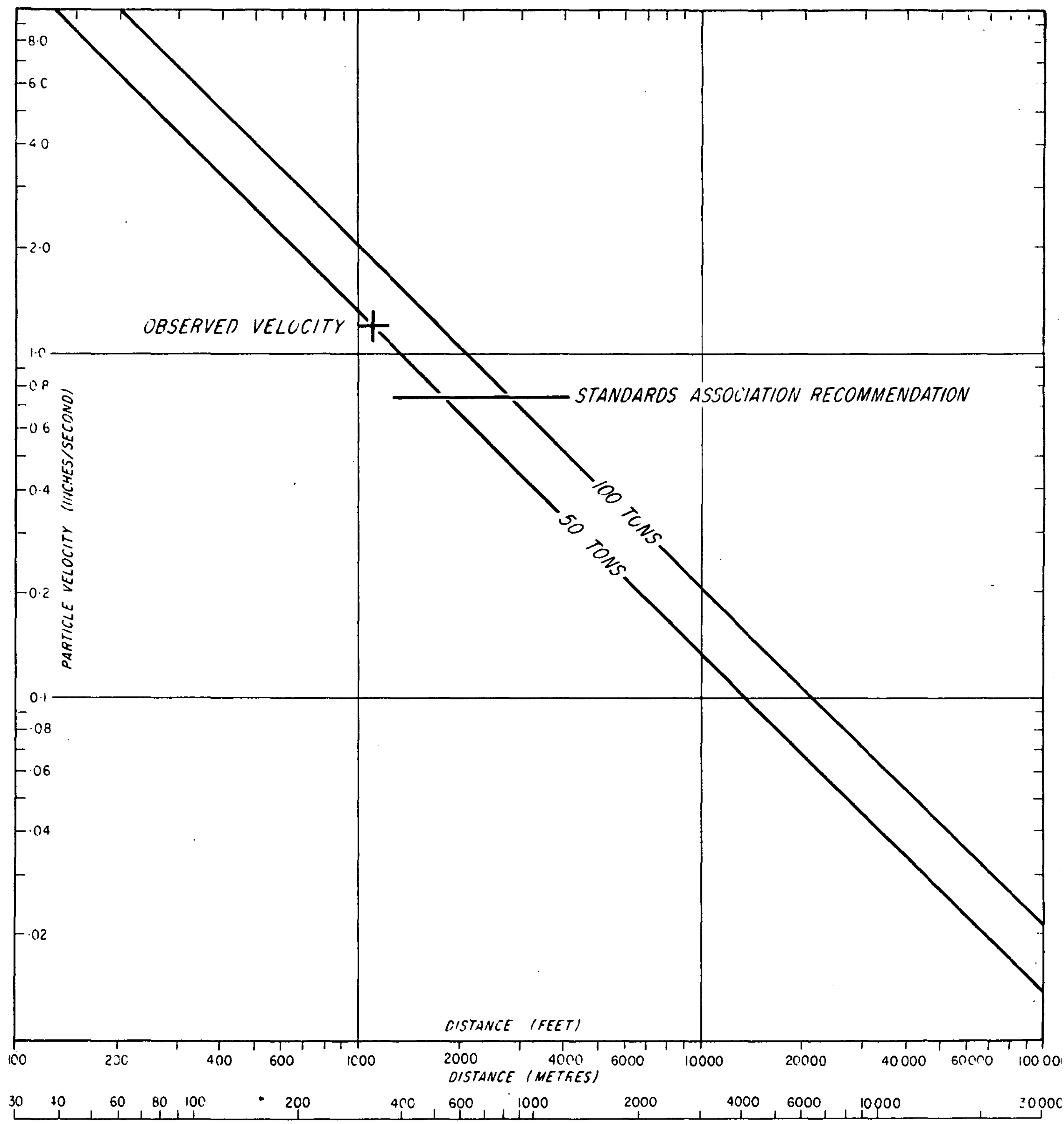

| | |
|---|---|
| *Date:* | *22/6/73* |
| *No. of shotholes:* | *112* |
| *Total charge:* | *100 tons (approx) ammonium nitrate* |
| *Depth of shotholes:* | *25 to 65 feet* |
| *Distance from shot:* | *1100 feet* |
| *Delay blasting:* | *25 milliseconds* |

VIBRATION TEST

PLATE 2

*To accompany Record No 1973/118*

G56/B5-91A




DISTANCE Vs PARTICLE VELOCITY
(Computed for Moura site)

*To accompany Record No 1973/118*

G56/B5-9