COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS.

RECORDS

RECORDS 1960 No. 58

TESTS ON SOME INDUSTRIAL VIBRATIONS TO DETERMINE THE LIKELIHOOD OF THEIR CAUSING DAMAGE; MELBOURNE 1960

by

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ABSTRACT.

Measurements were made of a wide variety of industrially caused vibrations in the Melbourne area. The vibrations have been classified on the scale of Thoenen and Windes, according to the likelihood of their causing damage to buildings.

Blasting of rock during excavations is the vibration most likely to cause damage; next in importance is the movement of people inside buildings.

Traffic movements (including trams and trains) and machinery (except for pile-drivers) are not likely to cause damage beyond a radius of 20 or 30 ft.

INTRODUCTION.

The Bureau of Mineral Resources is often called upon to measure industrially caused vibrations, and to assess the likelihood of their causing, or having caused, damage to buildings. This report describes a survey undertaken between January and March 1960, of a wide variety of industrial vibrations in the Melbourne area. It was intended both to give general information on the subject, and to simplify the planning and conduct of future tests of individual cases.

2. METHODS.

Vibrations were recorded with a Sprengnether three-component Portable Blast and Vibration Seismograph; this instrument has been developed by the W.F. Sprengnether Instrument Company, as a complete tool for the recording of vibrations by blasting and industrial operations. Three mutually perpendicular components of the ground motion, as detected by the seismometer system, are recorded photographically on a single strip of photographic paper. Timing lines are placed across the record at 20-millisecond intervals. Sample records are shown on Plates 1, 2 and 3.

The ground displacement is magnified 100 times by means of a mechanical optical lever system. (i.e. a ground displacement of 0.01 in. causes the record to be displaced 1 in.)

In this report the amplitude and frequency of the ground motion are defined as follows:-

> The amplitude and frequency of the three components of the vibration are scaled from the seismogram. The amplitude of each component (half the distance from peak to trough) is measured at the same instant for each component. The frequency is defined as the predominant frequency in cycles per second, at the time an amplitude is measured.

If the ground motion is assumed to be simple harmonic motion (most industrial vibrations closely resemble simple harmonic motion) the acceleration of a component of the ground motion may be calculated from the equation

$$a = 4 \pi^2 f^2 A .$$

where a = acceleration in in/sec^2

f = frequency in c/s

A = amplitude of movement in in.

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

$$a_R = \sqrt{a_L^2 + a_V^2 + a_T^2}$$

The results of the vibration tests including details of the vibration sources, are shown on Tables 1, 2 and 3.

Thoenen and Windes (1942) made experiments to try to classify vibrations according to the damage caused to structures. They arrived at the conclusion that ground acceleration was the best index for classifying the vibrations. This does not necessarily mean that vibration is the cause of damage, but simply that the acceleration value is useful as a guide to determining the likelihood of damage.

An acceleration equal to gravity ($g \doteq 32.2$ ft/sec^2) is a practical index of damage. Thoenen and Windes, in tests carried to the damage point, found that damage occurred frequently when the acceleration nearly equalled, or exceeded 1g. They designated accelerations between 1g and 0.1g, by the word "caution", and lower values of acceleration by the word "safe". Table 5 is based on a Table produced by Thoenen and Windes; it shows amplitudes, frequencies, and accelerations for a large selection of vibrations.

Vibrations of very low amplitude (0.0001 in.) and short duration (high frequency) were found by Thoenen and Windes not to cause damage even when the accelerations were high.

3. RESULTS.

Tables 1, 2 and 3 show the results of the present tests. The highest recorded ground displacement was 0.021 in., and frequencies ranged from 2 c/s to 120 c/s.

Only in two of the tests did the ground acceleration enter the "danger" zone of Thoenen and Windes. These were -

(1) 5 ozs. of AN60 gelignite exploded 10 ft. from the recorder, and

(2) a 209-lb. man jumping to the floor from a height of 3 ft. 4 in.

This confirms the findings of Steffens (1952) who stated that local movements within a building (heavy men jumping, doors slamming etc.) almost always produce stronger vibrations than outside sources.

Ten of the tests showed accelerations in the "caution" zone. Of these, four were from blasting and three from pile drivers. Only one was from moving vehicles, in this case a seven-carriage train passing within 15 ft. of the seismograph.

In the tests on ordinary industrial machines (other than pile drivers) all but one of the measured accelerations were well within the "safe" zone. It must be accepted, therefore, that neither machinery nor moving vehicles are very likely to cause damage to structures.

4. ACKNOWLEDGEMENT.

The results shown in tests 1 to 4 of Table 3 are taken from a report by Polak (1959).

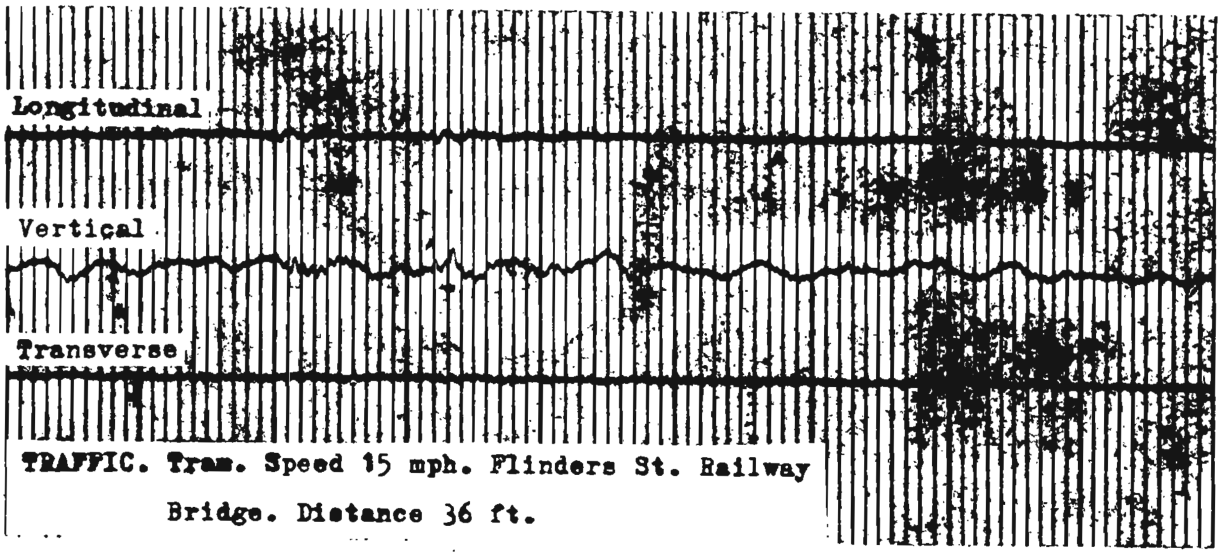
5. REFERENCES.

THOENEN, J.R. and WINDES, S.L., 1942 - Seismic effects of quarry blasting. *U.S. Bull. Bur. Min.* 442.

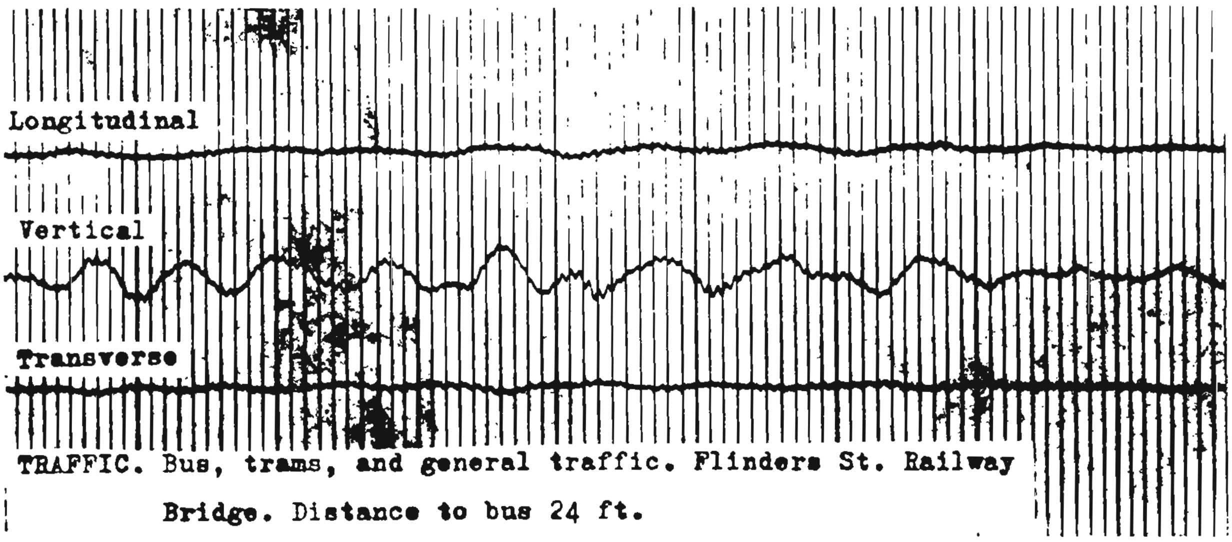
STEFFENS, R.J., 1952 - The Assessment of vibration intensity and its application to the study of building vibrations. *Nat. Build. Stud. Spec. Rep.* 19. H.M.S.O.

POLAK, E.J., 1959 - Vibration tests at Kirkstall-Repco Pty.Ltd., Clayton, Victoria. *Bur. Min. Resour. Aust. Records* 1959 No. 65.

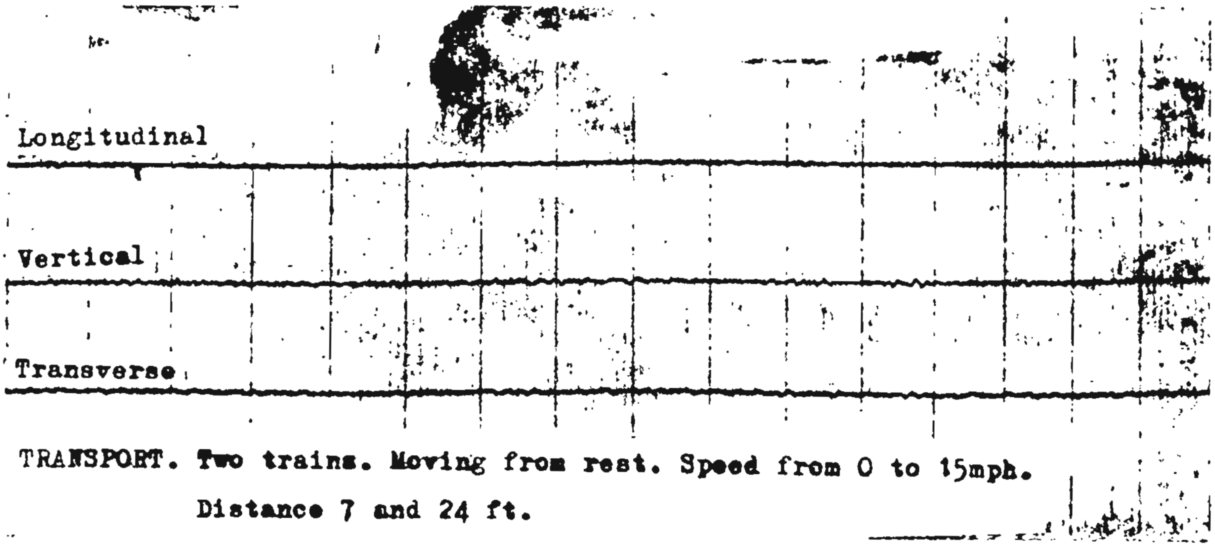
SAMPLE RECORDS PLATE 1



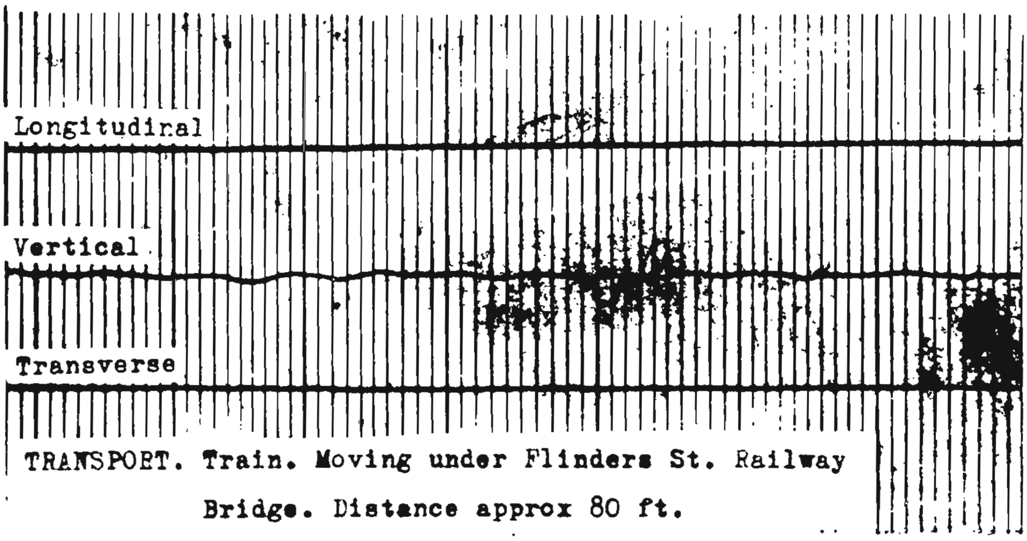
TRAFFIC. Tram. Speed 15 mph. Flinders St. Railway Bridge. Distance 36 ft.



TRAFFIC. Bus, trams, and general traffic. Flinders St. Railway Bridge. Distance to bus 24 ft.



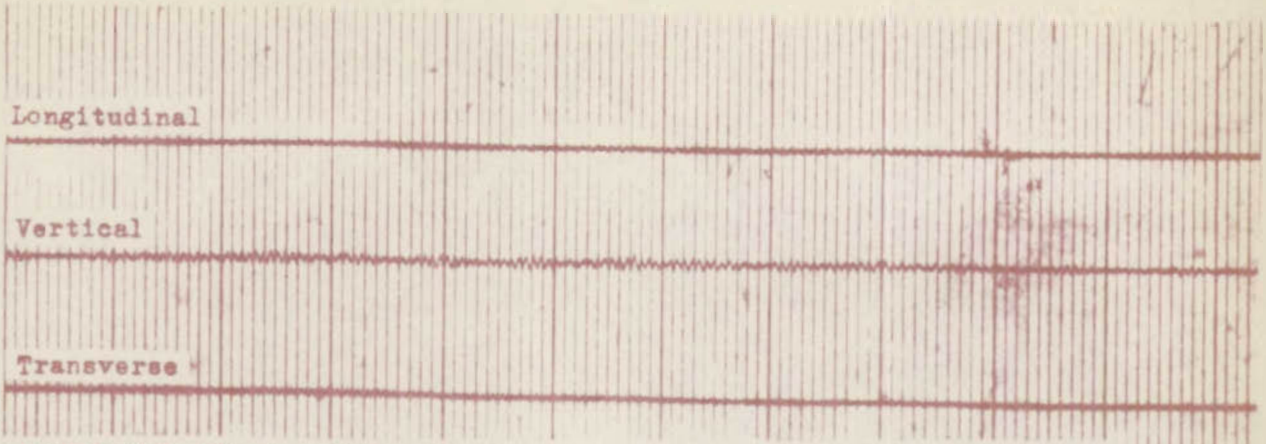
TRANSPORT. Two trains. Moving from rest. Speed from 0 to 15mph. Distance 7 and 24 ft.



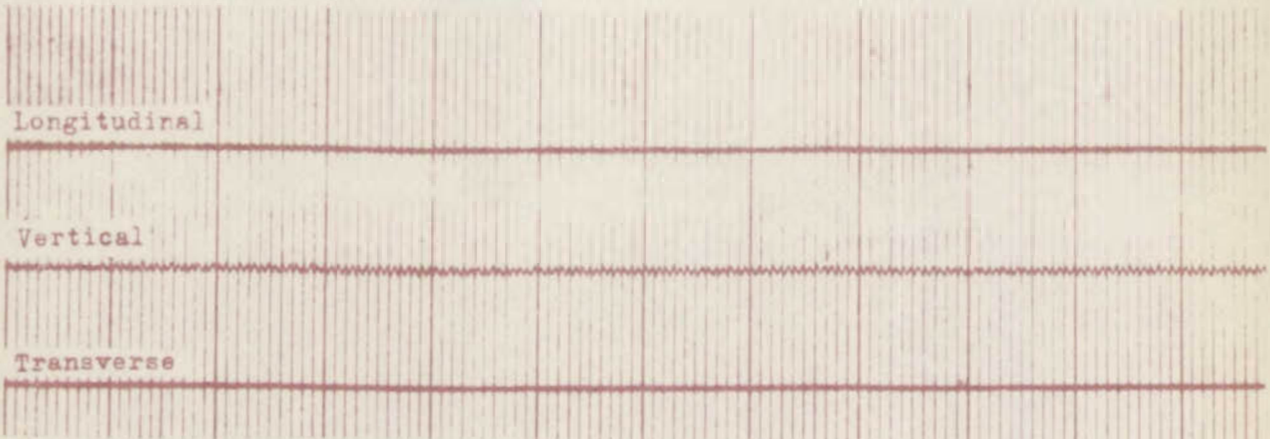
TRANSPORT. Train. Moving under Flinders St. Railway Bridge. Distance approx 80 ft.

SAMPLE RECORDS

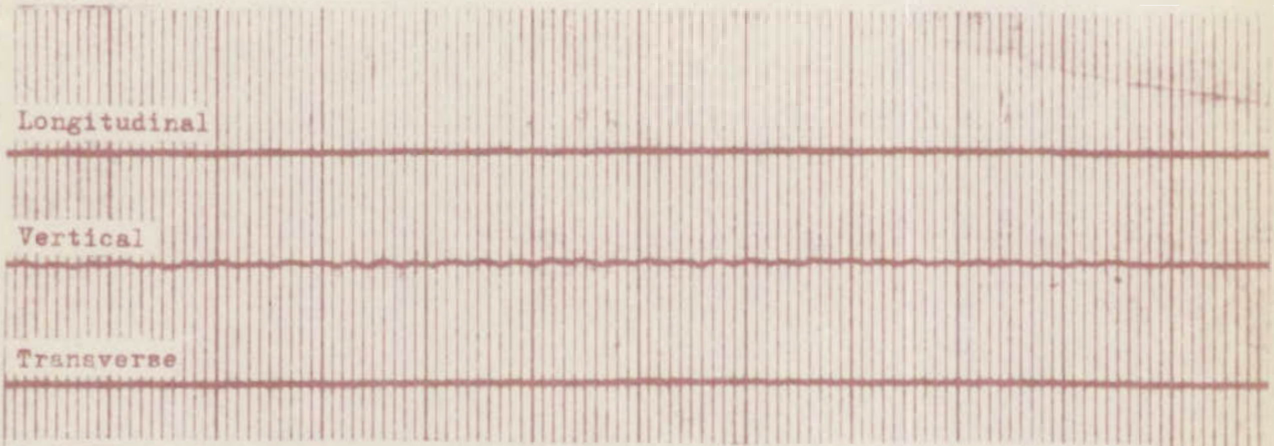
PLATE 2



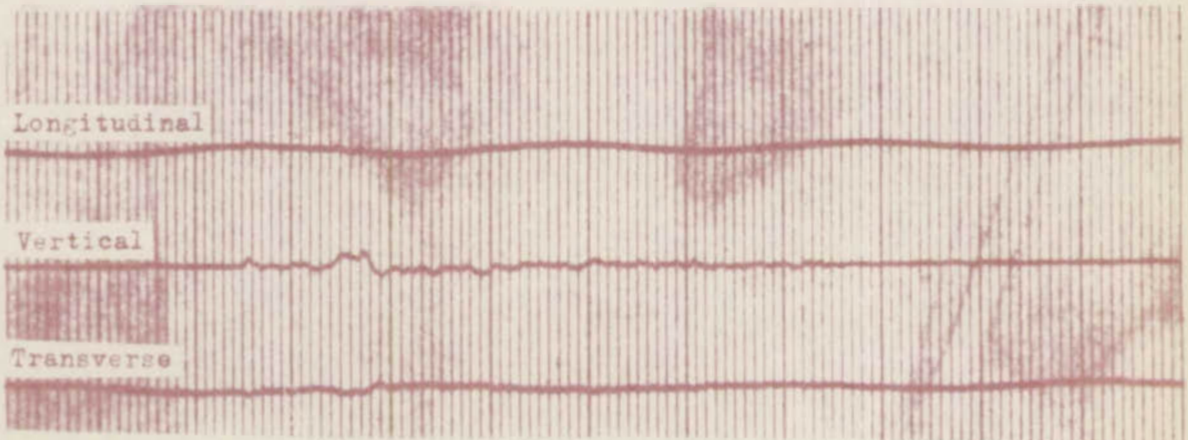
MACHINERY. Winch and frankipile. 15 hp motor and 15cwt pile dropped approximately 6 ft. Distance 3 and 15 ft respectively.



MACHINERY. Winch. 15 hp motor.
Distance 3 ft.



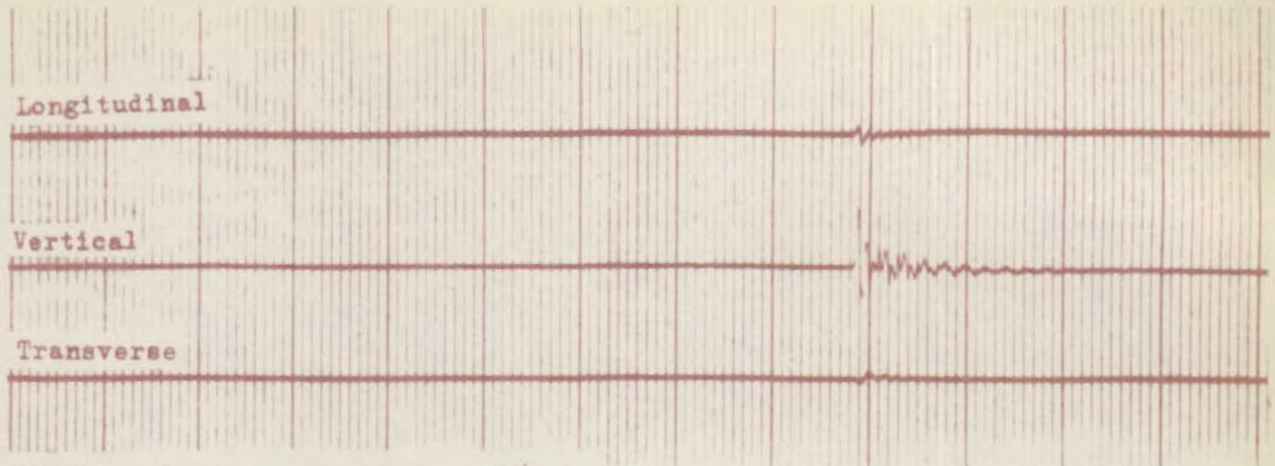
MACHINERY. Two 75 lb hammer drills and large compressor. 6th floor of building. Distance 13 and 20 ft respectively.



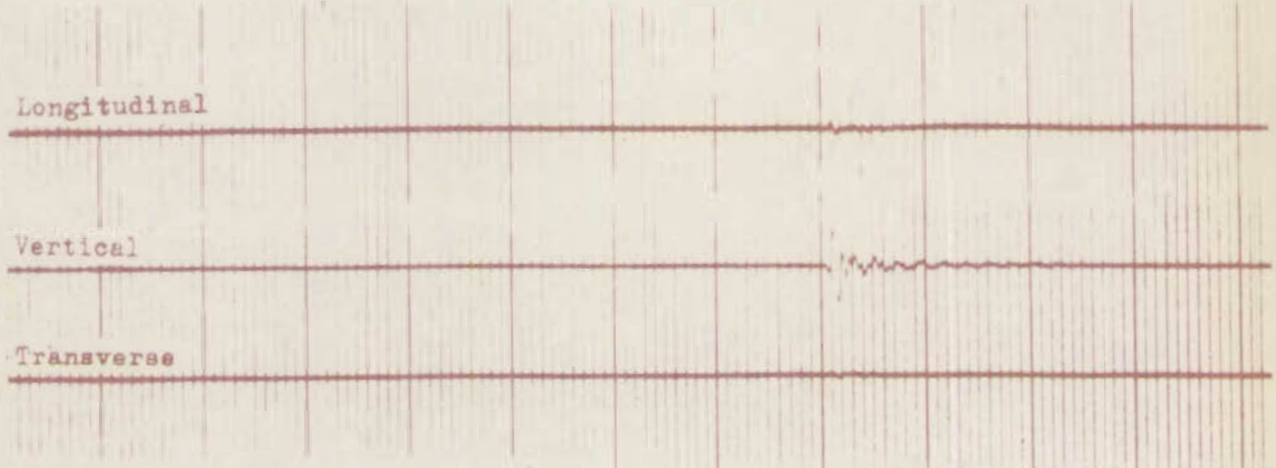
MACHINERY. Front end loader dropping 400 lb of bricks from a height of 2 ft. Distance 3 ft.

SAMPLE RECORDS

PLATE 3

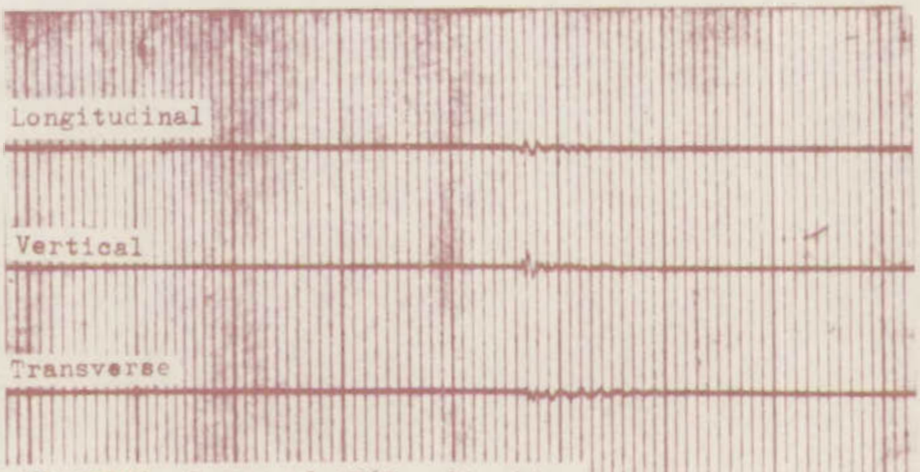


IMPULSE. 209 lb man jumping 3-1/3 ft onto floor. Distance 5½ ft.



IMPULSE. 209 lb man jumping 3-1/3 ft onto floor. Distance 15 ft.

BLASTING. 5 ozs of AN60 gelignite. Chewton. Distance 40 ft.



BLASTING. 5 ozs of AN60 gelignite. Chewton. Distance 75 ft.

RESULTS: TABLE 1

SOURCE OF VIBRATION	DETAILS OF VIBRATION SOURCE	LOCATION OF RECORDER	DIST OF RECORDER FROM SOURCE (ft)	LONGITUDINAL COMPONENT			VERTICAL COMPONENT			TRANSVERSE COMPONENT			RESULTANT ACCEL'N. ratio of 'g'	RESULTANT DISP'T. (ins)	DAMAGE EFFECT
				Amplitude (ins)	Frequency (cps)	Acceleration ratio of 'g'	Amplitude (ins)	Frequency (cps)	Acceleration ratio of 'g'	Amplitude (ins)	Frequency (cps)	Acceleration ratio of 'g'			
TRAFFIC	Tram. Speed approximately 20 m.p.h.	Bitumen footpath. Gordon St Footscray.	35	–	–	–	0·0002	29	0·017	0·0001	29	0·009	0·013	0·0002	[illegible]
TRAFFIC	Tram. Speed approximately 20 m.p.h.	Bitumen footpath. Gordon St. Footscray.	23	–	–	–	0·0001	27	0·008	–	–	–	0·008	0·0001	S
TRAFFIC	Tram. Speed approximately 15 m.p.h.	Bitumen footpath. Gordon St Footscray	35	–	–	–	0·0002	37	0·028	–	–	–	0·028	0·0002	S
TRAFFIC	Trams. Speed approximately 15 m.p.h.	Bitumen road. Flinders St railway bridge.	36	–	–	–	0·0007	10	0·007	–	–	–	0·007	0·0007	S
TRAFFIC	Tram, bus and general traffic. Speed 15 m.p.h.	Bitumen road. Flinders St railway bridge.	24	0·0003	5	0·001	0·0011	7	0·005	0·0002	7	0·001	0·005	0·0012	S
TRAFFIC	3½ ton truck. Not loaded. Speed 10 mph.	Bitumen footpath. Gordon St. Footscray.	20	–	–	–	0·0001	29	0·009	–	–	–	0·009	0·0001	S
TRAFFIC	Council truck. Speed 35 m.p.h.	Bitumen footpath. Gordon St. Footscray.	33	–	–	–	0·0001	30	0·009	–	–	–	0·009	0·0001	S
TRAFFIC	Car. Light utility. Speed 10 m.p.h.	Bitumen footpath. Gordon St. Footscray.	20	–	–	–	–	–	–	–	–	–	–	–	S
TRANSPORT	Two trains. Moving from rest. Speed 15 mph.	Concrete platform. Flinders St. Station.	7 24	0·00005	36	0·007	0·0002	37	0·028	0·0001	26	0·007	0·030	0·0002	S
TRANSPORT	Train beneath bridge. Traffic on bridge.	Bitumen road. Flinders St. railway bridge.	80	0·0002	8	0·001	–	–	–	–	–	–	0·001	0·0002	[illegible]
TRANSPORT	Train. Six carriage passenger.	Bitumen garden path. King St. Glen Iris.	50	0·0003	20	0·012	<0·0001	20	0·004	0·0003	20	0·012	0·017	0·0004	[illegible]
TRANSPORT	Train. Four carriage passenger.	Bitumen footpath. King St. Glen Iris.	40	0·0002	50	0·051	0·0002	50	0·051	0·0002	50	0·051	0·088	0·0003	[illegible]

Abbreviations: D-Damage C-Caution [illegible]

RESULTS TABLE 2

SOURCE OF VIBRATION	DETAILS OF VIBRATION SOURCE	LOCATION OF RECORDER	DIST OF RECORDER FROM SOURCE (ft)	LONGITUDINAL COMPONENT			VERTICAL COMPONENT			TRANSVERSE COMPONENT			RESULT-ANT ACCEL'N ratio of 'g'	RESULT-ANT DISP'T (ins)	DAMAGE EFFECT
				Amplitude (ins)	Frequency (cps)	Acceleration ratio of 'g'	Amplitude (ins)	Frequency (cps)	Acceleration ratio of 'g'	Amplitude (ins)	Frequency (cps)	Acceleration ratio of 'g'			
TRANSPORT	Train. Seven carriage passenger.	Pedestrian subway. York Rd. Glen Iris.	< 15	0·0005	50	0·128	0·0003	25	0·019	0·0004	6	0·202	0·129	0·0006	C
MACHINERY	Metal Shear. 2HP motor.	Concrete floor. BMR workshop, Footscray.	6 16 24	–	–	–	–	–	–	–	–	–	–	–	S
MACHINERY	Pile driver 15cwt, dropped 6ft. 15HP winch.	Concrete foundation. Cnr Swanston + Lt. Bourke.	7 5	–	–	–	0·0002	85	0·147	0·0001	90	0·083	0·170	0·0002	C
MACHINERY	Pile driver, 15cwt, fall 6ft. 15 HP winch.	Concrete floor corner Swanston + Lt Bourke St.	7 5	–	–	–	0·0002	72	0·011	0·00015	120	0·221	0·221	0·0003	C
MACHINERY	Winch 15HP. Pile driver 15cwt, fall 6ft.	Concrete floor. Corner Swanston + Lt. Bourke St.	3 15	0·0001	72	0·053	0·00035	77	0·212	0·0001	111	0·126	0·250	0·0004	C
MACHINERY	Winch 15HP motor.	Concrete floor. Corner Swanston + Lt. Bourke St.	3	≃0·0001	77	0·030	0·0002	77	0·121	0·00015	111	0·185	0·223	0·0003	C
MACHINERY	Compressor (≃700lb), 2, 75lb hammer drills.	Sixth floor. Colonial Mutual Building.	11 40	0·00015	2	–	0·0002	17	0·006	0·0003	~2	–	0·006	0·0004	S
MACHINERY	2 Hammer drills, 75lb Compressor (≃700lb)	Sixth floor. Colonial Mutual Building.	13 20	–	–	–	0·00015	17	0·004	–	–	–	0·004	0·0002	S
MACHINERY	Hammer drills and Compressor on 6th floor.	Concrete floor Colonial Mutual Bdg. 4th floor.	120	0·0002	2	–	–	–	–	0·00015	~3	–	0·000	0·0003	S
MACHINERY	Front end Loader. 400lb of bricks falling ~2ft.	Sixth floor. Colonial Mutual Building.	3	0·0003	~2	0·000	0·0006	22	0·030	0·00025	20	0·010	0·032	0·0007	S
MACHINERY	20 ton crane. Lifting empty box.	Concrete floor. Colonial Mutual Bdg. 4th floor.	19	0·0002	~3	0·000	0·0001	77	0·061	0·0001	~3	0·000	0·061	0·0002	S
MACHINERY	20 ton crane. Lifting approx 800lb of bricks.	Concrete floor Colonial Mutual Bdg. 4th floor.	30	0·0004	~3	0·000	–	–	–	0·00025	~3	0·000	0·000	0·0005	S

Abbreviations: D = Damage C = Caution S = Safe

RESULTS: TABLE 3

SOURCE OF VIBRATION	DETAILS OF VIBRATION SOURCE	LOCATION OF RECORDER	DIST OF RECORDER FROM SOURCE (ft)	LONGITUDINAL COMPONENT			VERTICAL COMPONENT			TRANSVERSE COMPONENT			RESULT-ANT ACCEL'N ratio of 'g'	RESULT-ANT DISP'T (ins)	DAM-AGE EFFECT
				Amplitude (ins)	Frequency (cps)	Acceleration ratio of 'g'	Amplitude (ins)	Frequency (cps)	Acceleration ratio of 'g'	Amplitude (ins)	Frequency (cps)	Acceleration ratio of 'g'			
MACHINERY	2½ ton forging hammer.	Overburden outside factory in Clayton.	80	0·0006	14	0·012	0·0005	14	0·010	0·0005	14	0·010	0·019	0·0009	S
MACHINERY	2½ ton forging hammer.	Overburden outside factory in Clayton.	110	0·0004	14	0·008	0·0003	14	0·006	0·0002	14	0·004	0·011	0·0005	S
MACHINERY	4 ton forging hammer.	Overburden outside factory in Clayton.	45	0·0008	17	0·024	0·0016	17	0·047	0·0011	17	0·032	0·062	0·0021	S
MACHINERY	4 ton forging hammer.	Overburden outside factory in Clayton.	62	0·0006	16	0·016	0·0008	16	0·021	0·0004	16	0·010	0·028	0·0011	S
IMPULSE	209 lb man jumping 3½ ft onto floor.	Concrete floor. 3rd floor. Wentworth House	5½	0·0004	43	0·076	0·0029	60	1·067	0·0002	43	0·038	1·070	0·0029	D
IMPULSE	209 lb man jumping 3½ ft onto floor.	Concrete floor 3rd floor Wentworth House	15	0·0003	60	0·110	0·0018	57	0·597	–	–	–	0·607	0·0018	C
BLASTING	5 ozs AN60 gelignite	Overburden – clay surface. Chewton.	10	0·0202	14	0·407	0·0047	59	1·670	0·0034	18	0·112	1·720	0·0210	D
BLASTING	5 ozs AN60 gelignite	Overburden – clay surface. Chewton.	40	0·0004	77	0·243	0·0006	77	0·364	0·0005	100	0·512	0·670	0·0009	C
BLASTING	5 ozs AN60 gelignite	Overburden – clay surface. Chewton.	75	0·0003	50	0·077	0·0007	77	0·425	0·0003	100	0·306	0·520	0·0008	C
BLASTING	1 lb of explosive, AN60 gelignite + monobel.	Concrete pavement [illegible] above tunnel. Spotswood	~100	0·0004	43	0·076	0·0003	43	0·057	0·0004	39	0·062	0·113	0·0006	C
BLASTING	2 lbs of explosive. AN60 gelignite + monobel.	Concrete pavement [illegible] above tunnel. Spotswood	~100	0·0003	50	0·077	0·0003	33	0·038	0·0005	50	0·128	0·154	0·0007	[illegible]
BLASTING	2½ lbs of explosive. AN60 gelignite + monobel.	As above. (NB. All spot- [illegible] — (time delays))	~100	0·0002	50	0·031	0·0002	38	0·030	0·0003	40	0·049	0·077	0·0004	S

Abbreviations: D: Damage, C: Caution, S: Safe

TABLE 4
SUMMARY OF VIBRATION SOURCES AND EFFECTS

DETAILS OF VIBRATION SOURCE	DISTANCE OF SOURCE TO RECORDER (ft)	Acceleration As a Fraction of Gravity 'g'		
		D	C	S
		1.000	0.500 0.100	0.050 0.010 0.005 0.001
BLASTING: 5oz of AN60 gelignite.	10	│		
IMPULSE: 209 lb man jumping 3½ ft onto floor.	5½	│		
BLASTING: 5oz of AN60 gelignite.	40		│	
IMPULSE: 209 lb man jumping 3½ ft onto floor.	15		│	
BLASTING: 5oz of AN60 gelignite.	75		│	
MACHINERY: Winch + 15cwt pile driver, together.	3+15		│	
MACHINERY: Winch 15HP.	3		│	
MACHINERY: 15cwt pile driver + winch together.	7+5		│	
MACHINERY: 15cwt pile driver + winch together.	7·5		│	
BLASTING: 2lb of charge – Monobel + AN60 gelignite.	100		│	
TRANSPORT: 7 carriage passenger train.	≈15		│	
BLASTING: 1lb of charge – Monobel + AN60 gelignite.	100		│	
TRANSPORT: 4 carriage passenger train.	40			│
BLASTING: 2½lb of charge – Monobel + AN60 gelignite.	100			│
MACHINERY: 4 ton forging hammer.	45			│
MACHINERY: 20 ton crane lifting empty box.	13			│
MACHINERY: Front end loader. 800lb of bricks falling 2ft.	3			│
TRANSPORT: 2 trains together. Speed 15mph.	7+24			│
TRAFFIC: Tram. Speed approximately 15mph.	35			│
MACHINERY: 4 ton forging hammer.	62			│
TRAFFIC: Tram. Speed approximately 20mph.	35			│
MACHINERY: 2½ ton forging hammer.	80			│
TRANSPORT: 6 carriage passenger train.	50			│
MACHINERY: 2½ ton forging hammer.	110			│
TRAFFIC: 3½ ton truck. Unloaded. Speed 10mph.	20			│
TRAFFIC: Council truck. Speed 35mph.	33			│
TRAFFIC: Tram. Speed 20mph.	25			│
TRAFFIC: Trams. Speed 15mph. Railway bridge.	36			│
MACHINERY: 700lb compressor, 2, 75lb hammer drills.	11+40			│
TRAFFIC: General traffic. Railway bridge.	24			│
MACHINERY: 2, 75lb hammer drills + compressor together.	13+20			│
TRANSPORT: Train below bridge. Traffic on bridge.	80			│
TRAFFIC: Light utility car. Speed 10mph.	20			→
MACHINERY: Metal shear. 2HP motor.	6			→
MACHINERY: Hammer drills + compressor together.	120			→
MACHINERY: 20 ton crane. Lift approx. 500lb.	30			→

Abbreviations: D = Damage C = Caution S = Safe → [illegible]

TABLE ACCELERATION IN TERMS OF GRAVITY 'g'

(Based on Table 7. Thoenan and Windes, Bull. U.S. Bur. Min. 442)

DISPLACEMENT (INS)	FREQUENCY C.P.S.										
	2	4	6	8	10	15	20	40	60	80	100
0·24	0·10	0·38	0·86	1·50	2·40	5·40					
·22	0·09	·35	·79	1·40	2·20	5·00	8·80				
·20	·08	·32	·72	1·30	2·00	4·50	8·00				
·18	·072	·29	·65	1·20	1·80	4·10	7·20				
·16	·064	·26	·58	1·00	1·60	3·60	6·40				
·14	·056	·22	·50	0·90	1·40	3·20	5·60				
·12	·048	·19	·43	·77	1·20	2·70	4·80				
·10	·040	·16	·36	·64	1·00	2·20	4·00				
·08	·032	·13	·29	·51	0·80	1·80	3·20				
·06	·024	·10	·22	·38	·60	1·30	2·40				
·04	·016	0·06	·14	·26	·40	0·90	1·60	6·40			
·02	·008	·03	0·07	·13	·20	·40	0·80	3·20	7·20		
·01	·004	·016	·036	0·064	·10	·20	·40	1·60	3·60	6·40	
·008	·0032	·013	·029	·051	0·08	·20	·30	1·30	2·90	5·10	8·00
·006	·0024	·010	·022	·038	·06	·10	·20	0·96	2·20	3·80	6·00
·004	·0016	·006	·014	·026	·04	0·09	·20	·64	1·40	2·60	4·00
·002	·0008	·003	·007	·013	·02	·04	0·08	·32	0·72	1·30	2·00
·001	·0004	·0016	·0036	·006	·01	·02	·04	·16	·36	0·64	1·00
·0008	·0003	·0013	·0029	·005	·008	·02	·03	·13	·29	·51	0·80
·0006	·0002	·0010	·0022	·004	·006	·01	·02	0·096	·22	·38	·60
·0004	·0002	·0006	·0014	·0026	·004	·01	·016	·064	·14	·26	·40
·0002	·0001	·0003	·0007	·0013	·002	·004	·008	·032	0·072	·13	·20
·0001	·0000	·0002	·0004	·0006	·001	·002	·004	·016	·036	0·064	·10

DAMAGE

CAUTION

SAFE