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DEPARTMENT OF MINES
SOUTH AUSTRALIA.

COMPLAINTS REGARDING QUARRYING - GREENHILL QUARRIES.

by MN/I 29/45

L.L. Mansfield, Inspector of Mines and Quarries.

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DEPARTMENT OF MINES
SOUTH AUSTRALIA.

MN/I 29/45

COMPLAINTS REGARDING BLASTING.

GREENHILL QUARRIES.

INTRODUCTION.

The extension of the suburban residential areas into the foothills has resulted in building operations in closer proximity to existing quarries. Subdivisions in the Burnside, Burnalta, and Greenhill areas have accelerated the erection of homes near Greenhill Quarries owned by J.H. Leverington. A further subdivision of land adjoining Leverington's property is anticipated to take place in the near future. This will mean a greater number of homes adjacent to the quarry.

As the owners move in they realise that a quarry is located behind the ridge and the sudden shock of explosions in the quarry is startling. Consequently when the foundations settle and cracks develop in the walls, and the timber shrinks, causing cracks to develop along the joints of fibrous plaster in wooden framed houses, the obvious thing is to blame the quarry blasting for the damage.

Complaints.

As more houses are built and occupied the greater the number of complaints that are received by the Inspection Branch alleging damage to the structures. This has culminated in the receipt of a petition from the "Quarry Protest Committee" reading as follows:-

"We, the undersigned residents of Burnside present this petition to our local member of Parliament, which we trust he will place before the proper authorities, in order to eliminate the following grievances due to the operation of the quarries in the vicinity of this residential area:-

1. Damage to houses due to blasting.
2. Dust and noise nuisance from quarries and quarry trucks.
3. Disfiguration to the historic 'Greenhill' by cutting an access road through the Government Reserve, removing trees to form same, closing the reserve road by a locked gate and placing a 'No Thoroughfare' notice on same.
4. Danger to the public using 'Greenhill Reserve' from blasting, due to the proximity of the new quarry face."

The Effects of an Explosion.

A small volume of explosive, usually nitro-glycerine based, or blasting powder is changed by detonation or ignition into a large volume of gas, usually instantaneous, but varying with the proportion of nitro-glycerine. Blasting powder is much slower. The energy or pressure of this volume of gas is dissipated by -

1. breaking rock.
2. rock vibration.
3. air blast and noise.

An efficiently planned hole, when fired, will give a maximum of broken ground and a minimum of vibration, noise and air blast. An unconfined charge of explosive as used in a "blister" or "sand blast" will cause noise out of all proportion to the same amount of explosive fired in a hole. "Blisters" or "sand blasts" are unconfined charges of explosives used to bring down dangerous ground that cannot be made safe by barring and too inaccessible to bore. Such charges should now be the exception rather than the rule since quarry faces now comply with the 65 foot height regulation. One particular quarry, which had high faces, and where such blasts were frequent, with consequent complaints, has not been the subject of a complaint since the height of faces was reduced about twelve months ago.

PREVIOUS INVESTIGATIONS.

Numerous complaints from suburban municipalities caused the Inspection Branch ro carry out investigations in 1954. These activities, fully covered in Mr. Armstrong's report in D.M. 701/47 MN/I/4 entitled "Blasting in Metropolitan Quarries", were concerned with Noise, Air Blast, and Ground Vibration, and the results of the investigation were briefly as follows:-

Noise.

A Sound Level Meter was used to measure noise from a number of explosive charges detonated in a quarry, and the results varied between -

1. 90 - 114 decibels from a ten pound blister to
2. 90 decibels from a 500-lb. charge in a hole
3. 70 decibels from a number of 40-oz. pops.

For comparative purposes a diesel truck going up Greenhill Road gave 88 decibels, and a light car in second gear, 76 decibels.

The tests showed that there was no real cause for complaint, and realizing that the plus 90 decibel noises would be practically eliminated with lower faces, no further work on this angle was justified. (The startle effect on residents will be discussed later).

Air Blast.

The Department of Mechanical Engineering, University of Adelaide, carried out tests with an Altec. M 11 capacity microphone and recorded with a Furzhill Oscilliscope and camera.

The results varied between

20 oz. blister at 200' giving .00025 blast pressure lb/sq.in.

15 lb. blister at 5,600' giving .000014 blast pressure lb/sq.in.

10 lb. blister at 3,300' Indistinguishable from effect of a light breeze.

In his report on the above, Mr. Armstrong states:-

"A 500-lb. bomb exploded in the open air produces a maximum positive pressure of 6 lb./sq. in. at 50 feet from the explosion, 2.3 lbs. at 100 feet, and .4 lbs. at 200 feet............ If a 500-lb. bomb in the open air would not damage a building at 200 feet, it is not to be expected that local blasting would cause damage by air blast in residential areas."

No further work on this angle was considered justified.

Ground Vibration.

Tests were made concurrently with a "falling pin" seismometer. This instrument consisted of a heavy base capable of being levelled horizontally, on which is a glass plate. Provision is made for a number of ½" diameter rods of varying lengths to be stood upright on the glass plate. The lengths of the rods or pins measured 6", 7", 8", 12" and 15" respectively. When standing on end the pins are each encircled by a hole of about 1½ inches diameter in a steel plate so that each pin could fall over independently without affecting its neighbours. This instrument is in reality a limit recorder of the intensity of seismic vibration initiated by a quarry blast. The longer the pin the less energy required to topple it. The length of the shortest pin that falls is noted and calculations can be made to ascertain the energy required to make each pin fall. In practice it has been accepted that if the shorter pins, up to 10 inches remain standing, then there is no possibility of structural damage to a building by a blast.

Tests were made with this instrument in 1954, no reaction of the pins being recorded in the following blasts selected as within a comparatively short distance:

400 lbs. explosives	250 feet distant.
625 lbs. explosives	350 feet distant.
800 lbs. explosives	400 feet distant.

However, on a test carried out at Rapid Bay, all pins fell when 1326 lbs. of explosives was detonated 100 feet distant from the seismometer.

At the end of 1955 a Cambridge Vibrograph was purchased to enable accurate records of the amplitude of ground waves to be obtained. This instrument produces on a celluloid film, lines that can be optically magnified to give accurate readings to .001 millimetres. A permanent photographic print can be obtained. The recording member is a stylus, two of which are supplied, and the one used has a magnification of 5 to 1 of the actual amplitude. The instrument has a mass mounted on a spring stirrup attached to the recording unit. To record horizontal movement, the instrument is set up to allow the mass freedom of movement in the direction from which the waves are expected. The film in contact with the stylus is fed by a clockwork mechanism, and a time recording stylus, indicating .1 second intervals and a signal stylus, both operated by a six volt battery. The speed of film can be varied from 3.5 mm per second to 19 mm per second. Slow speed is used to conserve film and to assure that the photographic record of the shock wave may be within the length of the postcard size print used. Film is supplied in ten foot lengths which, at the low speed, would last approximately 14½ minutes. It is thus necessary to have the co-operation of the quarry owner to record the effects of a blast, the procedure being, on advice from a quarry that firing is contemplated at about noon, to visit the quarry, ascertain the poundage of explosive, number of and depth of holes, the number of delays, synchronise watches and arrange for the electric firing to take place at, say, 12.04 p.m. The instrument is then set up, generally on the concrete verandah of a complainant's house, and the mechanism set in motion at 12.03½ p.m. On hearing the shot, the operator presses the signal button and a stylus records this signal on the film. The instrument is then allowed to run for a few seconds to clear the wave record from the stylus drums, then stopped and the section of film cut off. This section is then placed in the clips behind the lens in the case provided. The lens is then illuminated by the six volt battery, and an image is reflected on the ground glass screen, the film being moved backwards and forwards until the signal mark is noted; then the stylus line showing the vibration is sought, brought to a central location and a photographic print made. The print would show three stylus lines -

1. The time marking in tenths of seconds.
2. The signal line.
3. The vibration line.

The instrument is housed in this same case complete with batteries, which serve the dual purpose of actuating the timing and signal mechanism, and of illuminating the ground glass screen. The actual photographic print magnifies the vibration wave 50 times.

Permanent Records of Ground Vibration.

The purchase of the Cambridge vibrograph towards the end of 1955 has enabled the Mining Branch to accumulate a mass of data on this question. Complaints have been investigated, and no shock wave has been recorded that would cause damage to a building.

Comments.

The Mining Branch has maintained the opinion for some time that residents hear noise and imagine damage. The investigations have supported this viewpoint as the following cases show:-

(a) 650 lbs monograin exploded 1200 feet distant gave .0016 amplitude. The hard slamming of a door at the same set up produced an amplitude of .028.

(b) 300 lb. blasting powder exploded 1150 feet away produced .0006 amplitude. The resident lightly slamming a door gave an amplitude of .0006.

(e) A complainant residing half a mile from a country quarry kept a log of times and dates of "heavy blasts that shook his house". He had no record of a 1000 lb. shot, the greatest amount ever fired at one time in the quarry, and which gave an amplitude of .0005 at the residence next door to him, but had recorded two pops each containing 1½ oz. of gelignite fired within 200 feet of the quarrying company's office, to demolish a concrete wall.

HUMAN RESPONSE TO INDUSTRIAL BLASTING VIBRATIONS.

Overseas Investigations.

In a paper by Jules E. Jenkins under the above title, appearing in the May 1956 issue of Mining Engineering, this question is fully discussed and illustrated with graphs. After discussing the frequency of low amplitudes, he states: "If these curves are extended to the upper edge and beyond the limits of the graph, into the range of earthquake frequencies, amplitudes of the order of inches would be required to produce the same degree of human sensation experienced by amplitudes of less than One-thousandth of an inch in the blast frequency range. This offers some explanation of the claim frequently advanced that the results of some industrial blasts are worse than an earthquake.

One important phase of human reactions not covered by the investigations of Reiher and Meisher, has to do with what is called STARTLE REACTION. This reaction, induced by the ear, is known to bring about momentary increases in heart rate and respiration. The source need not be loud or intense, but only unexpected. It has been well established that these sudden disturbances exert profound influence on a person's decision that he detests a certain sound, and, incidentally, those responsible for making it.

Not only is the ear involved. Skin areas, muscles, tendons, joints and internal organs are excited as well. The individual or collective effects on these parts of the body frequently cause people to conclude that the earth or building supporting them is shaking violently, when, as a matter of fact, they are actually being moved through microscopic dimensions.

It must be remembered that the average person can feel vibrations that are ONE HUNDREDTH to ONE THOUSANDTH parts of the magnitude necessary to damage structures. Until these facts are firmly implanted in the public mind, those whose business requires them to discharge blasts will undoubtedly be confronted from time to time, with claims for structural damage, which are in fact based on misconceptions arising from human reactions.

Mr. Jenkins also refers to the extensive research carried out by the U.S. Bureau of Mines, "Seismic Effects of Quarry Blasting", and states that further research has confirmed the conclusions drawn by the Bureau of Mines. Mr. Armstrong, in his paper, also states that the results of the tests with the 'Falling Pin' seismometer "were in accordance with results overseas, indicating the unlikelihood of damage to buildings from normal quarry blasting here in Adelaide."

The evidence accumulated since the acquisition of the Cambridge Vibrograph further confirms the findings of the U.S. Bureau of Mines.

The Mining Branch was not aware of the research that had been carried out on "Human Response", and the magnification of vibration by people complaining was considered to be pure exaggeration. Tests were continued in an endeavour to show complainants that the slamming of a door would produce more amplitude than normal blasting in a quarry.

Vibrograph Tests at Greenhill Quarries.

Date	Location of Vibrograph	Poundage of Explosive	Distance Away.	Result.	
14.12.55	344, Greenhill Rd.	300	1600'	.0006	Safe
14.12.55	344, Greenhill Rd.	Slamming door	12'	.0006	
15. 3.56	Wiener Lot 5, Burnalta	70 lbs.	1100'	No recording	
26. 3.56	Quarry Compressor House	75 lbs.	950'	.0025	Safe
27. 3.56	Quarry Compressor House	200 lbs. elec. Delay	600'	(No recording (but complaint (received.	
5. 4.56	Quarry Compressor House	750 lbs	600'	.0005	Safe
6. 4.56	Quarry Comp. House	400 lbs. elec, Delay	500'	.0008	Safe
11. 4.56	Quarry Comp. House	230lbs. elec. delay	450'	.0005	
11. 4.56	Quarry Comp. House	150lbs.elec.delay	450'	No recording	
17. 4.56	Further work on plus 65 foot face prohibited.				
20. 6.56	344, Greenhill Rd.	200lbs.elec. delay	1800'	No recording	
29. 6.56	344, Greenhill Rd.	100lbs.elec. delay	1800'	No recording.	
3. 7.56	344, Greenhill rd.	60lbs.elec. delay	1800'	No recording.	
17. 8.56	Parbury, 23,Queen's Avenue.	125lbs.elec. delay	1200'	.0006	Safe
30. 8.56	Wiener, Lot 5, Burnalta,	150lbs., MG., elec. delay	650'	.0004	Safe
4. 9.56	Wiener, Lot 5, Burnalta	215lbs. gel., elec. delay	1400'	.0016	Safe
6. 9.56	292, Greenhill Rd.	550lbs. BP., elec. delay.	3300' (approx)	No recording.	

A complaint was received on 13.12.55 that two windows had been cracked by firing at the quarries that day. A vibrograph test carried out on 14.12.55 gave a safe amplitude of .0006. On being asked to slam the front door the complainant explained that the glass had been blown out by high winds on the night of 12.12.55. An inner door was lightly slammed, giving an amplitude of .0006.

In the United Kingdom a maximum of .008 inches displacement is considered safe. In the vicinity of "irreplaceable monuments" the maximum is .003 inches. Both these figures allow for a fair margin of safety. The amount of amplitude is dependent on the poundage of explosive and the distance away from the instrument.

Attitude of Quarry Owner and Sequence of Events.

When the 65 foot face regulation came into force, Leverington sought an extension of time to enable him to convert his faces. Actually his problem was the most difficult of all the metropolitan operators, and he was given the longest period, 21 months to March 1956, to comply, but did least of all the operators to convert his face.

Early in March, because of continuing complaints of excessive blasting, Leverington was instructed to notify the Mining Section two hours before any hole was fired; all holes of which notice had been given were monitored with little or no vibration until 3rd. July, 1956, when the instruction was modified to apply to

1. Any firing of 200 lbs. of explosive.
2. All holes on the shale face (closest to Wieners).

On the 17th. April, further work was prohibited on his faces of plus 65 feet, and he ~~applied~~ appealed to the Hon. the Premier. This appeal not being upheld, he approached the Mining Section for technical and moral assistance to gain access to his new faces which he established in a couple of weeks. Representations were made by the Mining Section to the Tourist Bureau in support of Leverington's application for use of the track through the Greenhill Reserve, until such time as the Burnside Corporation formed and bituminised the direct road.

After a few days' work on the new low shale faces, Leverington stated that the shale was unsuitable for the Cement Company, and an officer of the Department accompanied a Cement Company official to the old Northfield quarry, which was re-opened.

No further notification of the firing of holes was received from Leverington, and officers investigating the claims of the petitioners, were surprised to find that the shale was again being quarried. Asked why no notification of firing on the shale faces had been given, Leverington's reply was to the effect that the instructions had been misunderstood, and in any case firing had been done at week-ends when Departmental officers were off duty. There is little doubt that Leverington deliberately confined his firing to week-ends, to avoid notifications to the Mining Branch, even though he knew that the results of the vibrograph tests showed his blasting to be within safe limits. He resents having to comply with the Regulations and instructions, and has no consideration for the feelings, fears, or comfort of the neighbouring residents. There have been suspicions that unnecessary "blistering" has occurred in this quarry; the Inspectors are loth to restrict him in this as any restrictions could lead to unsafe working in his quarry, for which he would endeavour to blame the inspectors.

COMPLAINTS OF PETITIONERS.

Tabulation.

A tabulation of the opinions of the petitioners interviewed is appended hereto; also a report by Mr. Boyes of the Architect-in-Chief's Department, of his inspections of the houses.

General Analysis.

Signatories to the petition totalled forty-seven (47) from 30 occupied homes, two houses in the course of erection, and the owner of a vacant block.

One petitioner had no complaints and requested his name be removed from the list - his home was not inspected.

One woman had no complaints and resented her husband signing the petition.

The residents of 22 homes were interviewed, and eight homes visited twice, information from the neighbours being to the effect that most of the occupants were only home at week-ends. It would thus appear that by firing at week-ends Leverington had caused at least eight people to sign the petition.

The 30 homes visited represent 34 per cent of the homes within an equal radius of the furthest signatory from the quarry.

Most of the residents interviewed believed that the loud blasts caused vibration and damage to their homes. Only one person was aware that vibration from a large amount of explosive in a deep hole, that made little noise, was the one that could do damage to structures.

Conflicting opinions regarding dust, noise, and vibration were given by neighbours. One person signed the petition because of the belief that "Wiener had been handed a raw deal by the Tourist Bureau", and there/were several people who objected to the locked gate on the reserve.

A fair proportion signed because the quarries were "spoiling the hills"; three confused Stonyfell with Greenhill; but the majority objected to the roadwork in the Greenhill Reserve itself.

Damage.

Mr. A.J. Boyes, Structural Engineer from the Architect-in-Chief's Department accompanied the investigators, and his report is appended hereto. No damage in the homes visited could be attributed to blasting at Greenhill Quarries. This report confirms the opinion of the Mining Branch, and the findings of the U.S. Bureau of Mines.

Dust.

Eight people complain of dust from trucks and blasting, two complain of dust from blasting only; one woman said that occasional dust, probably once in three months. Contradictions were again encountered, one woman complaining of dust from blasting and trucks; two neighbours, however, had no complaints about dust. One person complained about the dust he saw rising from Stonyfell (about 4000 feet away), which he confused with Greenhill.

On the various occasions I have taken vibrograph tests, I have never seen dust produced by firing descend on the residential area. Such dust rapidly subsides, but it could be possible, with a strong wind, for such dust to be blown into the area occupied by homes. There would probably be more dust produced by ordinary traffic.

Noise.

Of those interviewed, ten complained of noise, particularly at week-ends. One woman stated her children were terrified of the blasting. One woman complained of the noise of Leverington's trucks roaring up the new road empty. The general opinion was that Leverington took advantage of the absence of Departmental officers at the week-end to fire shots that would record on the instruments if fired during the week. I do not consider that a legal "nuisance" has been established.

Danger from Blasting.

Two people stated that, with their children, they had used Greenhill Reserve for picnics at week-ends, but feared they might be struck by flying stones. They could not say that stones had ever landed near them. A Regulation under the Mines and Works Inspection Act, 1920-1955 reads "When blasting is being done, no blast shall be fired, until all avenues of approach within danger have been properly guarded by men stationed at suitable positions."

On 27.10.54, at the Norwood Police Court, Leverington was convicted on two charges of failure to comply with the above regulation, and fined a total of £10, plus £4-7-0 costs, on a complaint made by Inspector Mansfield. It is unlikely that Leverington will again offend, but if he confined his blasting to the normal working week, there would be much less chance of people being present in the Reserve.

Defacement of Greenhill Reserve.

As the Mines Department has no control over this contentious matter, no questions were asked the residents on the subject. Probably half those interviewed raised the question of the defacement of the hills generally, and particularly the road through the Greenhill Reserve. Actually a track did exist, and Leverington widened it and placed a certain amount of metal on it to form a road. The fresh red earth is noticeable from most of the residences whereas the track could not be seen. Grass will soon cover the displaced soil on the sides of the road, and there will again be no evidence of a road. Three people confused Stonyfell with Greenhill. The locking of the gate and the erection of a "No Thoroughfare" sign is no concern of the Mines Department.

SUMMARY AND CONCLUSIONS.

1. Signatories to the petition are from 30 houses, representing 34 per cent of the homes in the area,

2. No damage is attributable to blasting in the quarry.

3. There is no legal nuisance regarding dust.

4. There is no legal nuisance as far as noise is concerned.

5. Employees of Greenhill quarries have been observed guarding the approaches to the quarry prior to firing.

6. The alleged defacement of the reserve is no concern of the Mining and Inspection Branch.

7. Leverington, to avoid the monitoring of his firing, has done this at week-ends, leaving himself open to allegations that excessive charges are fired in the absence of Departmental officers.

8. It is more than likely that Leverington, with a complete disregard to the feelings of his neighbours, has used "blisters" at week-ends.

9. People can feel vibrations that are one-thousandth part of the magnitude necessary to cause damage.

10. Monitoring of blast vibrations will be continued in an endeavour to educate the residents of the above fact.

OFFICERS CONDUCTING THE INVESTIGATIONS.

The following officers have been concerned in the investigation of the complaints and the monitoring of blasting with the vibrograph:

Mr. A.J. Boyes,	Structural Engineer, Architect-in-Chief's Department.
Mr. B. Sowry,	Mining Engineer, Department of Mines.
Mr. R.A. Love,	Assistant Battery Manager, Dept. of Mines.
Mr. A. Wilson,	Biophysicist, Department of Mines.

10.9.56

Cransfield

INSPECTOR OF MINES & QUARRIES.

TABULATION OF COMPLAINTS.

Reference Number	Well Built	Poor Construction	Damage Claimed	No Damage Claimed	Noise	No Noise	Week-end Noise	Dust from Blasting	No Dust from Blasting	Dust from Trucks	No Dust from Trucks	Occasional Dust	Greenhill Reserve	Danger from Blasting
1	X													
2		X	X				X			X		(occasional dust)		
3	X		X											
4		X	X						X			X		
5	X			X		X			X					
6		X	X											
7	X		X		X		X	X		X				
8		X	X			X			X					
9	X													
10		X	X											
11	X			X						X				
12	X			X				X					X	
13	X			X	X		X	X		X			X	X
14	X			X		X				(dust bad with East wind)				
15		?		X	X		X					(sudden noise)		
16	X			X		X			X		X			
17	X		X			X			X		X			
18	X													
19	X													
20		?	X		X		X		X		X		X	
21		?	?		X		X	X		X			X	
22	X		?			X			X		X		X (confused with Stonyfell)	
23	X			X		X		X					X	
24		X	X		X		X	X		X		(noise sudden)		
25		X												
26	X				X		X	(occasional loud blast)					X	
27	X			X	X		X		X		X			
28	X													
29	X			X	X		X		X		X		X	X
30	X			X		X			X		X			

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The Principal Architect.

Re Inspection of residences Burnside.

In company with Messrs. L.L. Mansfield and B. Sowry of the Department of Mines, I inspected all the residences on the attached list, the individual reports being contained on three other sheets.

In no case did I find that the observed or reported damage was anything but what could be normally expected in domestic buildings in that or any other area, and in fact some of the minor cracking was considerably less than what takes place in areas much further away from the quarries.

As a general rule, the amount of cracking varied inversely with the standard of workmanship and the suitability of the materials used.

Also it will be observed that there were several cases where no complaints of damage have been made even though neighbouring residences were supposed to have suffered.

AJB:AP
4.9.56

(Sgd.) A.J. Boyes.

SENIOR STRUCTURAL ENGINEER.

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STRUCTURAL REPORT ON RESIDENCES.

Numbers in brackets refer to name and address of owner as per separate sheet and the order in which they were inspected.

(1) Well built brick, approx. 10 years old. No apparent external damage. Not possible to see interior as owner never home on week days.

(2) Brick, cement rendered, 12 years old approx., natural external settlement and shrinkage cracks in masonry, cracks in ceiling at cornice due to normal movement and shrinkage. Construction not suitable for the plastic soil of the site.

(3) Timber frame and weatherboards, approx. 2 years old, no apparent damage externally. Not possible to see inside as owner never home week days.

(4) Badly built, at least 45 years old, severe settlement cracks particularly along western verandah piers. Front door frame out of square through settlement and cracks along inside cornice and at front door.

Front wall is 9" brick with no apparent headers and further cracking can be expected.

(5) Very old, at least 70 years, stone but well built on plastic soil plateau almost at edge of creek. Previously bolted up many years ago.

One medium crack in internal wall due to settlement, but is not serious. Recent brick additions 3 years ago show no sign of cracking.

(6) Previously inspected with Mr. R. Armstrong about 2½ years ago, and report rendered at that time.

(7) Timber frame and weatherboards, with 4½" brick infilling between timber posts. About 3½ years old, well built on plastic site, random rubble retaining wall shows earth pressure cracks.

Interior walls and ceilings are flush jointed fibrous plaster sheets on timber framing and no cover or cornice moulds. In places these have opened at the horizontal and vertical joints due to natural movement of the timber.

(8) Timber frame and fibrolite outside, Inside as for (7) but poor quality, 6 - 8 years. Brick walls outside below ground floor roughly built and showing considerable movement, settlement, and cracking but no complaint made about this latter. Chimney has commenced to lean outward and some interior brick piers are out of plumb. Interior cracking as for (7) but worse, probably owing to poorer timber and construction.

(9) Well built brick, not yet completed. No damage externally excepting slight settlement crack where later added garage is not toothed into wall of main building.

(10) Timber frame and fibrolite, of poor construction and about 20 years old. On plastic soil with steep slope. Masonry walls below ground floor and front porch show considerable movement and cracking due to settlement.

COPY

SIGNATORIES TO PETITION.

(1)	A.R. Mazzarol	Old Greenhill Road.
(2)	Henry	314 Greenhill Road.
(3)	W. Place	312 Greenhill Road.
(4)	G. Rosenbauer	369 Greenhill Road.
(5)	D.V. Stephens	375 Greenhill Road.
(6)	R. Beard	322 Greenhill Road.
(7)	N. Wright	326 Greenhill Road.
(8)	A.R. Morgan	336 Greenhill Road.
(9)	Pike	340 Greenhill Road.
(10)	C. Barnes	344 Greenhill Road.
(11)	R.A. Agars	25 Queen's Avenue, Burnside.
(12)	R. Parbury	23 Queen's Avenue, Burnside.
(13)	Burgess	19 Queen's Avenue, Burnside.
(14)	J.G. Sprod	Queen's Avenue, Burnside.
(15)	Dyson	1 Wyatt Road.
(16)	J. Turich	290 Greenhill Road.
(17)	G. Norton	292 Greenhill Road.
(18)	W.J. Warne	Lot 6, Greenhill Road.
(19)	Wiener	Lot 5, Burnalta.
(20)	D.W. Milich	30 Queen's Avenue, Burnside.
(21)	L.E. Retalic	24 King's Avenue.
(22)	R.R. Schahinger	22 King's Avenue.
(23)	Boundy	Windsor Avenue.
(24)	Ewart	21 Sitters Drive.
(25)	K. Patfull	17 Sitters Drive.
(26)	J.S. Millen	20 King's Avenue.
(27)	J.E. Glass	34 Queen's Avenue, Burnside.
(28)	E.C. Hall	Windsor Avenue.
(29)	Potter	Windsor Avenue.
(30)	G.R. Shedley	12 Royal Avenue.

(11) Timber frame and weatherboard, not yet completed. No complaints about damage. In view of (7) and (8), the owner has taken precaution of using V-jointed caneite in lieu of fibrous plaster.

Cement brick spandril wall to steps on Eastern wall has cracked due to mortar too rich in cement.

(12) Timber frame and weatherboards almost new. No structural complaints.

(13) As for (12) but about 3 years old. No structural complaints. Interior walls as for (7) but cracks worse if anything, although no complaints as being due to blasting, these appeared about 12 months ago.

(14) Two storey well built brick, about 3 years old, on piers and beams. Two small cracks in ground floor interior walls which owner admits may be due to differential settlement. From his description of these piers it would appear that the footing slabs are deficient in area.

(15) Very old building and cracking from settlement, considerable distance from the quarry. No structural complaints.

(16) Brick War Service Home, 7 years old. Normal shrinkage cracks in fibrous plaster ceiling. One sheet in Kitchen ceiling shows the normal radial cracks that appear when plasterers mis-handle same when fixing or when electricians put their feet on same after it is fixed.

(17) Well built brick, State Bank House, 29 years old. Slight to severe cracks in internal walls due to settlement on very plastic yellow clay. Verandah piers and floor slab leaning out considerably through earth movement.

Several large cracks that appeared during earthquake, and since repaired, have not opened appreciably. Owner admits that some movement to be expected, especially as in bad earthquake region.

(18) Being built of cement bricks, concrete and old tram rails, No damage.

(19) As for (18)

(20) Mount Gambier stone blocks 7 years old. Several Joint cracks in front wall due to earthquake have been patched and not re-opened. Some slight cracks in inner and Eastern walls along the joints, most probably due to settlement as top soil vey plastic in this region.

(21) Mount Gambier stoneblocks, 5 years old, One external crack to settlement at North East corner, characteristic internal cracks at junction of walls due to butting of blocks. Owner admits that some could be due to earthquake cracks that have re-opened.

(22) Mount Gambier stone blocks, 5 years old, slight cracks inside due to natural movement and shrinkage, owner admits that these may be due to the earthquake and may not in any case be due to blasting

(23) Timber frame and weatherboards, 2 years old, no structural complaints.

(24) Concrete blocks and cement bricks rendered, 8 years old, shrinkage settlement and earthquake cracks, inside and outside. Most of the earthquake cracks have been filled up and some have re-opened. House is situated on a plastic slope and small retaining walls etc. outside show considerable settlement.

(25) Concrete blocks cement rendered, 8 years old, settlement, shrinkage cracks, vertical crack opening up at rear walls where newer structure has been butted against the original wall without toothing in. Condition of interior unknown. Soil conditions as for (24).

(26) Mount Gambier stone blocks, well built on pier and beams 5 years old. No external damage. Slight cracks in ceilings where flush jointed, a slight earthquake crack in interior wall.

(27) Very well built brick house, 3 years old. No apparent external damage, no structural complaints, no earthquake damage.

(28) Well built Basket Range stone house, about 3 years old, no apparent external nor internal damage.

(29) Timber frame, T&G. V.J. lining boards. 5 years old. No structural complaints.

(30) Mixed construction of two separate buildings. No structural complaints.

AJB:AP
22.8.56

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SENIOR STRUCTURAL ENGINEER.

HUMAN RESPONSE TO INDUSTRIAL BLASTING VIBRATIONS,

by

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(From Mining Engineering, May, 1956.)

In the past quarter century the seismograph has played an increasingly important role in evaluating vibratory effects transmitted to adjacent communities by industrial blasting operations. In this period research has advanced through two major phases - from falling pin seismometers to three-component recording seismographs. The initial phase of this research is now regarded as the era of recording, during which the seismograph merely recorded occasional events. It has emerged from this stage into the era of control and analysis and in this later period has been recognised as a full-fledged industrial tool.

Although the falling pin machines of earlier years indicated probable amplitudes of industrial blasting vibrations, they gave no reliable measure of such displacements, nor did they provide essential information concerning direction or frequency of motion.

The first contribution of the three-component recording seismograph was the weight-for-distance formula developed by the U.S. Bureau of Mines. This empirical formula enabled users of commercial explosives to determine beforehand the probable vibratory effects of a blast when the weight of the explosives charge and the distance from the shot point were known. This formula has withstood the test of time and is still applicable for blasts detonated by instantaneous methods.

The second major contribution of the three-component recording seismograph followed the introduction in 1945 of short period or millisecond delay detonation. This might be described as a two-stage contribution, the first of which revealed a 50 pct reduction in the vibration magnitude when millisecond delay detonation was used rather than instantaneous discharge. The second part of this double contribution led to the discovery of the vibration dip phenomena.

In Fig. 1 the horizontal coordinates indicate the displacements amplitude in inches, and the vertical coordinates, the explosives weight in pounds. The top curve is that of the U.S. Bureau of Mines for instantaneous detonation. Its curvature conforms to the two-thirds power of the explosive weight as provided in the weight-for-distance formula; hence the vibratory effects increas proportion in proportion to an increase in the explosive charge. If the other curves shown below are temporarily disregarded, it may be considered that the entire area below this top curve represents both useful and waste energy.

As mentioned previously, when millisecond delay detonation was first investigated it was found that in general the U.S. Bureau of Mines curve could be decreased by about 50 pct. or to the position of the middle curve. At the outset it was assumed that this curve would likewise increase in some proportion to the explosive charge, as did the top curve, that is, the curve would indicate a continuous upswing. As seismographic data accumulated this assumption was found to be erroneous in part. It was discovered that for the smaller explosive loadings, vibrational effects conformed to expectancy only up to a point. In Fig. 1 this point is indicated at 1250 lb. Thereafter the vibrational effects assumed a downward trend that continued to the bottom of the dip, which is shown at 2500 lb. After reaching this low point, the curve rose again until it leveled somewhere near expectancy for the higher loadings. There is good reason to believe that this curve continues to the right and beyond the limits of the graph in a series of smaller dips. As of now loadings are up to 70,000 lb, but blasts of this size are few and far between. Consequently data is scant for loadings of over 25,000 lb.

For the purpose of illustration, the dip is shown in Fig. 1 as extending over a 100 pct increase in the explosive loadings. In actual practice, the increase in the explosives loading varies from 20 to 80 pct, depending on individual blasting procedures and local terrain conditions.

When explanation is sought for this dip phenomena, the laws governing distribution of energy seem to apply best. Blasting vibrations transmitting beyond the shot point are classified as residual energy, which consists of two parts, irreducable minimum and waste. If the low point of the displacement dip is accepted as the point below which it is not possible to reduce, and if a final curve is drawn through this low point to the family of curves, the values falling on this curve represent the irreducable minimum - in other words, the amount of energy that must be driven into the earth to effect a new line of cleavage. It is with this waste energy that human response to industrial blasting vibrations begin.

In the course of these seismographic studies, investigators have been constantly alert to the wide discrepancies between reported vibration intensities based on human evaluations and and actual intensity as determined by instrumental measurement. Although it was early recognised that these human factors extended into the fields of physiology and physchology, investigators refrained from straying into these fields, believing them outside their professional scope. Nevertheless, the point has been reached where someone must lead the way.

Investigations of human reaction to vibration are largely confined to steady state motion, for example, the riding qualities of vehicles and vibrations in ship structures and aircraft. At first reading, published reports are confusing and contradictory. But on further study each report is found to have merit within the limits investigated.

Unfortunately, aside from the fact that they provide valuable knowledge concerning human reaction to constant agitation, these reports say nothing of the transient or impact forces that occur as the result of an embedded dynamite blast. However, they do disclose interesting trends, which undoubtedly will be defined further in impact investigations.

The work of Reiher and Meister at the Institute of Technology in Stuttgart, Germany, in 1931 and 1935 provides important clues in this direction. These researchers subjected a group of 15 persons 25 to 40 years old, of various occupations, to the continuous oscillations of a vibrating platform, through amplitudes from four ten-thousandths of an inch to 4 in., at frequencies from 1 to 70 per sec. They exposed each subject to various vibrational modes for 8-min. intervals during which the subject stood or reclined. When the subject reclined, motion was applied both parallel and transverse to the axis of the body. After each test the sensations experienced by the subject were rated as 1) not noticeable, 2) barely noticeable, 3) well noticeable, 4) strongly noticeable, 5) objectionable, and 6) uncomfortable. Thus between categories 1 and 3 the threshold of irritation was established, and between categories 4 and 6 the threshold of discomfort.

As was expected, the degree of sensation varied widely between subjects. Furthermore, the same sensation was not always experienced by the same subject reacting to the same vibrations. Even so, the test results were carefully plotted and a wealth of valuable data obtained. These data are condensed in Figs. 1 through 6, which reproduce only three of the six curves by Reiher and Meister, namely, the second, fourth, and sixth, indicated as perceptible, objectionable, and uncomfortable. Horizontal lines in Fig, 2 and in the illustrations to follow indicate vibration amplitude in mils, or thousandths of an inch, and vertical lines the frequency in cycles per sec. The bottom curve represents perceptible, the middle curve objectionable, the top curve uncomfortable. The arrows on the right indicate three vibrational characteristics. The top arrow indicates the rate of change of acceleration, sometimes referred to as jerk, the middle arrow indicates acceleration, and the bottom arrow, velocity. When the slope of the curve corresponds to the direction of one of these arrows, it indicates that the human sensations within this segment of the curve are stimulated and reacting to the vibration characteristic shown by the arrow. This reveals that in the lower frequencies, below 5 cycles, the reaction tends to conform to the rate of change in acceleration; in the middle frequencies, 5 to 10 cycles, the acceleration; and in the higher frequencies, above 10 cycles, to velocity.

In this case, at 10 cycles (bottom-center reading up) the effect of vertical movement applied to a person standing must be increased nine time over perceptible before becoming objectionable, and 32 times before becoming uncomfortable. The difference between objectionable and uncomfortable represents an increase of three and a half times.

When the person remains standing while being subjected to horizontal movement, Fig. 3, the motion must be increase 13 times over perceptible to become objectionable, and 39 times before becoming uncomfortable. The difference between the objectionable - uncomfortable limits is three times, or approximately the same differential as that for vertical movement. In general, when someone is standing, twice as much horizontal as vertical movement is required to invade objectionable - uncomfortable limits.

When the subject reclines and is moved in the vertical direction, Fig. 4, and increase of 13 times over perceptible is required to become objectionable, and an increase of 51 times to become uncomfortable. When this reclining position is compared with the standing position, it is found that three times as much vertical movement is required to invade the objectionable-uncomfortable limits. In other words, the body is more sensitive to vertical vibrations when in an upright position. When the subject is still reclining and being moved horizontally, parallel to the axis of the body, Fig. 5, the reaction is similar to that for horizontal-standing.

When the subject reclines and motion is applied transverse to the axis of the body, human reaction is more pronounced than for any of the various combinations with the exception of vertical-standing.

In summary, the human body under steady state agitation is most sensitive to vertical motion when the person is standing and least sensitive when he is reclining, as shown in the left diagram of Fig.7. When the movement is confined to the horizontal, the reclining person is most sensitive to motion applied transverse to the body axis, as shown in the lower diagram. Sensations of this kind are experienced in sleeping cars of trains.

Finally, although this discussion is confined to amplitudes having a frequency of ten cycles per sec., the importance of frequency on these human reactions must not be overlooked. For example, in Fig. 6, if the frequency were increased six times to 60 cycles, the objectionable sensations would be experienced at 0.19 mils, or about two ten-thousandths of an inch. This motion is but one-sixth of that considered objectionable at 10 cycles. Furthermore, objectionable motion at 60 cycles would not be perceptible at 10 cycles

Now, if frequency is decreased to 5 cycles, the objectionable sensation would not be experienced until an amplitude of 5 mils was reached, or four times the movement considered objectionable at 10 cycles.

If these curves are extended to the upper edge and beyond the limits of the graph, into the range of earthquake frequencies, amplitudes of the order of inches would be required to produce the same degree of human sensation experienced by amplitudes of less than one thousandth of an inch in the blast frequency range. This offers some explanation of the claim frequently advanced that the results of some industrial blasts are worse than an earthquake.

One important phase of human reactions, not covered by the investigations of Reiher and Meister, has to do with what is called startle reaction. This reaction, induced by the ear, is known to bring about momentary increases in heart rate and respiration. The source need not be loud or intense, but only unexpected. It has been well established that these sudden disturbances exert profound influence on a person's decision that he detests a certain sound, and incidentally, those responsible for making it.

Not only is the ear involved. Skin areas, muscles, tendons, joints, and internal organs are excited as well. The individual or collective effects on these parts of the body frequently cause people to conclude that the earth or building supporting them is shaking violently, when, as a matter of fact, they are actually being moved through microscopic dimensions.

It must be remembered that the average person can feel vibrations that are one hundredth to one thousandth parts of the magnitude necessary to damage structures. Until these facts are firmly implanted in the public mind, those whose business requires them to discharge blasts will undoubtedly be confronted, from time to time, with claims for structural damage, which are in fact based on misconceptions arising from human reactions.

Although these facts point to the road ahead, they do not in themselves hold any immediate application to industrial blasting procedures. They do, however, clearly disclose the urgent need for further investigations into the complexities of human response to impact. There is every reason to believe that the body can withstand a far greater degree of shock under impact than it can under prolonged agitation.

The Vibration Measurement Engineers organization has made an exhaustive review of its files and endeavoured to correlate some of the measured seismographic data with statements made by people the company regards as chronic complainers. On the basis of this approach, there is reason to believe that industrial blasting vibrations might be increased as much as five to ten times that of steady state motion before the objectionable - uncomfortable zones are invaded.