

17. Some observations on the vibration induced in piles and rock outcrop by blasting in water.

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A series of 75 test firings using more than 800 kg of surplus explosives were fired near the Powder Jetty approximately 2 km south of Howden, in North West Bay [EN244340]. This location was chosen for the experiments due to its close but rather isolated proximity to Hobart; the jetty apart from being a source of piles for testing simplified logistic problems; deep water (up to 25 m) was present close inshore and the nearby magazine expedited the storage and handling of explosives.

The objective of the monitored experimental firings of moderate weights of explosive was to, at least in part, provide further knowledge. A great deal of work has been undertaken on energy transfer-attenuation in land-solid situations and on blast-damage, and although a full evaluation of all geological factors is yet to be attained, usable rules of thumb now exist. A good summary of the criteria and present thinking in land situations is given by Tynan (1973). Although the criteria for damage to solids resulting from the use of explosives in water will be the same as for on land, no rules of thumb exist which allow for shot distance, depth or charge size in water. It was hoped that the test firings might establish limits on such relationships, or at least indicate the sizes and types of firings which are likely to cause damage to solids in water or adjacent to water.

EQUIPMENT

The equipment used for blast monitoring consisted of a 6 channel seismograph using Philips velocity sensitive vibration transducers, an amplifier interface with gain control and an ultra-violet oscillographic recorder with time base. The equipment could thus be used to provide up to two 3-component geophone sets. The entire system was calibrated to provide conversion charts for input peak particle velocity and width of recorder trace. Frequency was measurable directly from the record and the frequency response of the system was virtually 'flat' above 20 Hz, but markedly divergent below 10 Hz.

A Honda 1.5 kVA portable generator was used to power the installation and most shots were fired with a Beethoven exploder. A linear relationship between the recorder trace width and particle velocity was found to exist at any given frequency for each channel.

TEST SITES

Three sites were selected for the location of the mutually perpendicular geophone assemblies. Two were located on the jetty and the third in an outcrop near the jetty.

The position of the geophones on the jetty was dependent upon the location of the charge. When the charges were fired on a line perpendicular to the shore, the geophones were clamped to the third pile from the shoreline. When the charges were fired on a line parallel to the shore the geophones were clamped to the main pile in the 'T' of the jetty. In each case the positions were chosen such that the shot-pile and shot-rock distances were equal. The geophones were clamped to the piles at a point just above the extreme high water mark.

The rock site was initially prepared by drilling a shallow hole and the geophone assembly was wedged into it. This site was adjacent to the jetty end and was also just above high water mark.

Some topographic details of the area are also relevant. A broad shelf of rock up to 10 m in width lies parallel to the shore and is exposed at low water. The water deepens rapidly from this shelf and exceeds 10 m at the cross-arm of the jetty. The third pile of the jetty is just seaward of this shelf and thus rests on rock at shallow depth, whereas the innermost corner pile is in deep water. Further out to sea from the jetty there is another deep slope to the bed of the Bay at 22-25 m below sea level.

Triassic sandstone is the only rock present at the site and is medium-grained, slightly weathered with a variable bedding thickness. The unit is generally massive and contains a few major joints. Density is in the range 2400-2450 kg/m³ and the longitudinal seismic velocity is approximately 3000 m/s.

METHODS

Before the firing of any charges at a given position, an anchor-buoy system was established. At this stage knowledge of charge-geophone distance was not critical, but a distance was estimated and two anchors dropped. Each anchor rope was supported by a buoy and the two buoys were also roped together with a 12 m length rope. An additional buoy was attached to the centre point of the tie rope and this supported the shot wire and all charges. By using this system it was possible to maintain the position of the buoys and perform all actual firing clear of the anchor ropes. The charge was roped to the centre buoy by either a 6, 12 or 18 m length of rope, and in this manner the depth of firing was controlled. Having established the firing position, the shot wire was attached to the support buoy and the distance to the shore position was determined with an accuracy of $\pm 3\%$.

With the geophones clamped or grounded, the buoys and shot wire in position, charges were set and fired. Several charges were fired in a given position but at differing depths or with differing explosive types.

EXPLOSIVES

Four types of explosive were used for the tests.

Seismonex. A proprietary canister explosive made in Germany. At the time of use it had deteriorated to some extent and was extremely variable in output. Shots 42 and 47 represent examples of this explosive in good condition. Each canister contained 15.1 kg.

Sismogel. Made in Portugal and fired in 28.5 kg case lots. It was found to be more consistent than the *Seismonex*, but more difficult to handle and prepare for firing.

P.E.T.N. Used in the form of Size 8 electric detonators or *Cordtex*. Variable weights were fired for experimental purposes.

Plastergel. Fired for comparison purposes as 22.7 kg boxes.

The use of *Seismonex* as the basic explosive was rather unfortunate due to its variability and consequently less than definitive results were produced. The other explosives were fired for comparative purposes and were found to be potentially more destructive.

RESULTS

With the exception of 21 single detonator test firings for attenuation

determinations, the details of all major firings are given in Table 1. Where the records have been complex and more than one type of arrival is indicated, a breakdown has been made of the frequency - amplitude measurements. In general, primary high frequency arrivals rarely exceed 100 ms duration while low frequency surface waves may persist for 500-600 ms and may show reflection.

The results when seen in the tabulated and somewhat cryptic form of Table 1, are probably less satisfactory than desired. The variability of the explosive energy of the control explosive is the principal reason for this, although the number of shots fired is a contributing factor.

However, some qualitative observations may be made directly.

- (1) *Plastergel* and *P.E.T.N.* explosives are far more damaging and energy than *Sismogel* and *Seismonex* respectively.
- (2) *Rock arrivals.*
 - (a) Primary arrivals exhibit frequencies in excess of 80 Hz and surface arrivals are generally of the order of 30-35 Hz. Only vertical arrivals exhibit the higher frequency character.
 - (b) In nearly all cases the vertical velocity component significantly exceeds the horizontal components and often dominates the resultant motion, although only for a very short duration. The vertical component of surface waves has been generally minor where recorded.
 - (c) The resultant motion, calculated at peak values, is usually dependent on vertical motions. For this reason two calculations are given for many of the firings. There is, as indicated in (b), a short duration impulsive motion and a longer term periodic motion. The resultant of the latter is approximately one half the former and is controlled by horizontal components.

In summary; there is a sharp vertical movement followed by a more subdued but regular horizontal 'rocking' movement.

- (3) *Pier arrivals.*
 - (a) All primary arrivals have a high frequency component, generally in excess of 60-80 Hz. Surface arrivals normally induce 25-35 Hz motions, although frequencies as low as 12-18 Hz were recorded.
 - (b) Components recorded on piles are exaggerated by factors of 3 to 10.
 - (c) The high frequency introduction to horizontal component wave trains suggests that the water-rock interface or rock path to rock station severely attenuates these parts of the motion. The water-pile system is most sensitive to all motions.
 - (d) The vertical component is more significant than in the rock case and the duration of high frequency high velocity motions is far longer. The calculated resultant is a better measure of the motion than in the rock case where dispersion, attenuation and filtering are more evident.
 - (e) No consistent relationship between depth of water and resulting effect has been observed. Since very few shots were shallower than 6 m, it may be assumed that the explosive was adequately and equivalently confined.

SUMMARY OF RESULTS - continued

SHOT NO.	DEPTH (m)	CHARGE Type	SHOTLINE DISTANCE (m) and DIRECTION		ROCK SITE DISPLACEMENT, FREQUENCY (Hz)			ROCK SITE VELOCITY (mm/s)				PIER SITE DISPLACEMENT, FREQUENCY (Hz)			PIER SITE VELOCITY (mm/s)				CHARGE WEIGHT (kg)
			Rock	Pier	V	H _{NS}	H _{EW}	V	H _{NS}	H _{EW}	R	V	H _{NS}	H _{EW}	V	H _{NS}	H _{EW}	R	
10	12	a	120EW	nd	1.1	1.4	0.6	3.7	1.2	0.5	3.9	nd	nd	nd	nd	nd	nd	nd	15.1
					>100	-	33												
11	12	a	120EW	nd	1.5	1.75	0.75	2.6	1.5	0.7	3.1	nd	nd	nd	nd	nd	nd	nd	15.1
					>60	33	33												
12	12	a/b	120EW	nd	11.5	10.8	10.5	33.0	9.7	9.2	35.6	nd	nd	nd	nd	nd	nd	nd	28.5
					100	33	33												15.1
					2.5			2.4											
					33														
13	12	b	120EW	nd	10.0	9.0	7.0	9.6	8.1	6.2	14.0	nd	nd	nd	nd	nd	nd	nd	28.5
					33	33	33												
14	12	b	120EW	nd	10.0	9.5	6.75	9.6	8.6	6.0	14.2	nd	nd	nd	nd	nd	nd	nd	28.5
					30	33	33												
15	12	b	230EW	230EW	4.25	11.25	7.0	6.6	12.0	6.2	15.0	20.5	nd	nd	59.4	nd	nd	>59.4	28.5
					>50	33	33					~100							
16	12	a	230EW	230EW	1.75	0.6	0.4	2.4	0.5	0.3	2.5	3.75	nd	nd	11.9	nd	nd	>11.9	15.1
					>50	33	33					~100							
17	12	a	230EW	230EW	-	0.6	0.5	-	0.5	0.4	nc	3.25	nd	nd	>10.3	nd	nd	nc	15.1
						33	33					>80							
18	12	a	230EW	230EW	0.6	1.0	0.75	0.5	0.8	0.7	1.2	6.5	nd	nd	>21.0	nd	nd	nc	30.2
						33	33					>100							
19	6	a	230EW	230EW	-	0.4	0.4	-	0.3	0.3	nc	4.2	nd	nd	>13.3	nd	nd	nc	15.1
						30						>100							
20	6	a	230EW	230EW	0.2	0.4	0.4	0.2	0.3	0.3	0.5	4.5	nd	nd	>14.6	nd	nd	nc	15.1
						33	33					>100							
21	18	a	230EW	230EW	-	0.75	0.4	-	0.7	0.3	nc	4.2	nd	nd	13.3	nd	nd	nc	15.1
						30						>100							
22	12	a	80EW	80EW	2.5	1.0	1.0	7.3	0.8	0.8	7.4	8.0	nd	nd	>12.5	nd	nd	nc	15.1
					>100	30	30					>50							
					1.5			0.7											
					16														
23	6	a	80EW	80EW	2.5	0.5	0.5	8.8	0.4	0.4	8.8	8.0	nd	nd	>17.7	nd	nd	nc	15.1
					~100	30						>80							
24	6	c	50EW	50EW	11.0	9.0	>10.0	>11.0	8.1	>10.0	>16.9	45.0	nd	nd	>87.2	nd	nd	nc	3.0
					>30	30	30					>60							
25	6	a	80EW	80EW	3.5	1.0	1.0	>10.0	0.8	0.8	10.0	21.5	nd	nd	>69.3	nd	nd	nc	15.1
					>100	30						>100							
26	12	a	80EW	80EW	1.5	0.5	0.5	>4.2	0.4	0.4	>4.2	8.0	nd	nd	7.7	nd	nd	nc	15.1
					>100	30													

SUMMARY OF RESULTS - continued

SHOT NO.	DEPTH (m)	CHARGE Type	SHOTLINE DISTANCE (m) and DIRECTION		ROCK SITE DISPLACEMENT, FREQUENCY (Hz)			ROCK SITE VELOCITY (mm/s)				PIER SITE DISPLACEMENT, FREQUENCY (Hz)			PIER SITE VELOCITY (mm/s)				CHARGE WEIGHT (kg)
			Rock	Pier	V	H _{NS}	H _{EW}	V	H _{NS}	H _{EW}	R	V	H _{NS}	H _{EW}	V	H _{NS}	H _{EW}	R	
27	6	c	80EW	80EW	8.0 100 1.0 14	2.25 30	1.75 30	25.6 0.5	1.8	1.5	25.7	36.0 >100	nd	nd	114.5	nd	nd	nc	3.0
28	12	c	80EW	80EW	12.0 ~100 2.0 14	6.0 30	5.0 30	29.8 1.0	5.4	4.4	30.6	38.0 ~100	nd	nd	121.2	nd	nd	nc	3.0
29	4	a	27EW	27NS	14.0 >100	6.0 33	6.0 30	43.0	5.4	5.2	43.6	30.5 >100	nd	nd	98.6	nd	nd	nc	15.1
30	6	a	30EW	30NS	3.5 >100 1.0 12	1.0	1.0	>11.3 0.4	0.8	0.8	11.4	11.5 >60	nd	nd	>22.0	nd	nd	nc	15.1
31	4	a	32EW	32NS	5.5 >100	4.0 33	4.5 33	>18.0	3.6	3.9	>18.8	6.5	nd	nd	6.2	nd	nd	nc	15.1
32	1	a	20EW	25NS	2.5 >50	3.0 33	1.5 33	>4.0	2.7	1.2	>5.0	15.0 ~20	nd	nd	9.8	nd	nd	nc	15.1
33	22	b	140EW	120EW	2.0 33	1.5	1.0	2.0	1.3	0.9	2.5	28.0 ~100	9.0 >50	4.5	87.9	>10.1	4.2	>88.6	28.5
34	22	b	140EW	120EW	12.0 >50	10.0 30	9.0 30	19.2	9.0	7.8	>22.5	100.0 ~100	41.0 40	20.0 >40	322.1	53.3	>25.8	327.5	28.5
35	12	b	140EW	120EW	18.0 ~50 2.0 10	20.0 30	>10.0 30	30.0 0.6	18.0	8.8	36.1	112.0 >100	44.0 >40	22.0 >40	>346.0	>48.0	>28.6	>350.5	28.5
36	22	a	140EW	120EW	1.0 30	1.5 30	-	1.0	1.3	-	nc	12.0 >50	4.0 50	2.0 50	>19.4	5.3	3.4	20.4	15.1
37	12	a	140EW	120EW	-	-	-	-	-	-	-	3.5	2.5	1.0	3.4	2.4	0.8	4.2	15.1
38	12	a	140EW	120EW	-	-	-	-	-	-	-	2.5	2.5	1.0	2.4	2.4	0.8	3.5	15.1
39	6	a	140EW	120EW	6.0 >60	2.0 33	-	>11.6	1.9	-	nc	39.0 >60	25.0 60	10.0 60	>76.0	40.8	19.2	>88.4	15.1
															4.8				

SUMMARY OF RESULTS - continued

SHOT NO.	DEPTH (m)	CHARGE Type	SHOTLINE DISTANCE (m) and DIRECTION		ROCK SITE DISPLACEMENT, FREQUENCY (Hz)			ROCK SITE VELOCITY (mm/s)				PIER SITE DISPLACEMENT, FREQUENCY (Hz)			PIER SITE VELOCITY (mm/s)				CHARGE WEIGHT (kg)	
			Rock	Pier	V	H _{NS}	H _{EW}	V	H _{NS}	H _{EW}	R	V	H _{NS}	H _{EW}	V	H _{NS}	H _{EW}	R		
40	6	a	140EW	120EW	-	-	-	-	-	-	-	5.0	3.0	2.0	>15.0	>9.0	6.0	>18.5	15.1	
41	6	a	140EW	120EW	2.0	1.0	-	>3.8	0.8	-	nc	~100	~100	~100	>32.8	15.2	6.6	>36.7	15.1	
42	6	a	25NS	25NS	>60	33	14.0	>19.0	64.6	25.6	18.4	71.9	76.0	>36.0	>55.0	>245.0	116.0	>176.5	>323.5	15.1
43	6	a	40NS	40NS	100	~60	30	-	-	-	-	>100	>100	>100	>45.3	>18.9	>19.3	>52.7	15.1	
44	6	a	40NS	40NS	-	3.0	-	-	2.4	-	nc	14.0	7.0	6.0	>142.4	>48.9	>41.9	>156.2	15.1	
45	6	a	70NS	70NS	-	6.0	6.0	-	5.3	5.2	nc	>100	>100	>100	>142.3	>51.0	>60.9	163.0	15.1	
46	6	a	50NS	50NS	-	4.0	4.0	-	3.7	3.7	nc	7.0	12.0	20.0	6.2	10.2	19.4	22.7	15.1	
47	6	a	70NS	70NS	2.5	10.5	8.0	2.3	9.4	7.0	11.9	36.5	18.0	6.0	169.0	49.3	>11.6	>176.4	15.1	
48	6	a	70NS	70NS	-	-	(1.5)	-	-	-	-	140	~100	>60	10.9	14.3	34.8	39.2	15.1	
49	6	a	100NS	100NS	-	-	-	-	-	-	-	20	40	30	1.2	3.2	4.4	5.6	15.1	
50	6	a	100NS	100NS	-	-	2.5	-	-	2.2	nc	8.5	4.0	1.5	25.5	10.6	4.0	27.9	15.1	
51	6	a	100NS	100NS	-	-	-	-	-	-	-	>100	100	100	1.0	1.6	1.5	2.5	15.1	
52	12	d	220EW	200EW	8.0	3.0	4.0	25.8	2.5	3.4	26.1	1.5	4.0	4.5	1.0	1.6	1.5	2.5	15.1	
					>100	33	33	80	>60	>60	>60	3.0	2.5	2.0	>5.6	>4.0	>3.8	>7.9	15.1	
												2.0	2.5	2.0	1.9	2.0	1.9	3.3	15.1	
												1.5	1.5	1.5	1.5	1.4	1.5	2.5	15.1	
												33	33	33					15.1	
												35.0	8.0	8.0	90.6	>12.8	>15.2	>92.7	22.7	
												24.0	7.0	7.0		12.0	2.4		22.7	
												18	12	12					22.7	

SUMMARY OF RESULTS - continued

SHOT NO.	DEPTH (m)	CHARGE Type	SHOTLINE DISTANCE (m) and DIRECTION		ROCK SITE DISPLACEMENT, FREQUENCY (Hz)			ROCK SITE VELOCITY (mm/s)				PIER SITE DISPLACEMENT, FREQUENCY (Hz)			PIER SITE VELOCITY (mm/s)				CHARGE WEIGHT (kg)		
			Rock	Pier	V	H _{NS}	H _{EW}	V	H _{NS}	H _{EW}	R	V	H _{NS}	H _{EW}	V	H _{NS}	H _{EW}	R			
53	15	d	220EW	200EW	10.0	3.0	5.0	25.6	2.2	4.2	26.0	36.0	11.0	8.0	68.4	18.0	15.2	72.3	22.7		
					80	25	33					>60	>60	>60						8.0	2.1
54	12	e	220EW	200EW	4.0	-	2.0	>3.8	-	1.6	nc	11.0	6.0	3.0	35.2	16.0	9.3	3.98	1.6		
					>33		33					~100	~100	~100						5.4	1.6
												10.0	4.0	20						12	

(4) All arrivals.

- (a) There is no direct relationship between the horizontal component and shot line direction implying homogeneity of both water and rock paths.
- (b) No evidence of anisotropy is indicated.

DEDUCTIONS

Quantitative deductions are difficult due to the charge variability. However, the series of detonator shots confirmed that an inverse square law operates in the relationship between distance and particle velocity (at constant frequency). Further, if the values of the peak resultant particle velocity are plotted against distance, it is possible to deduce an envelope line which encloses all results. This is necessary due to the result variability. Figure 43 presents the form of the envelope line when plotted logarithmically. Also shown on Figure 43 is the rule of thumb Duvall and Devine (1968) equation:

$$v = H \left(\frac{d}{w^{1/2}} \right)^{-\beta}$$

where v = particle velocity
 d = distance
 w = charge weight
 H, β = constants.

Duvall and Devine claim $H = 85, \beta = -1.7$ for in/s, feet, lb respectively
or $H = 550, \beta = -1.7$ for mm/s, m, kg respectively

However, the equation deduced from the North West Bay results requires H to equal 185 or 1100 (imperial or metric units respectively) for Seismonex and in excess of 850 or 5500 for the other explosives. Thus it appears that the discrepancy between the Duvall and Devine equation and the present work is a function of the type of explosives used, rather than weight or water transmission although this may well be a contributing factor.

All the above figures apply to rock motions and pier motions are considerably more violent. As mentioned above, a multiplicand of 3 is conservative and 5 to 8 is average.

The comparative efficiency of water transmission versus rock transmission can only be suspected from the results presently available. A comparison of north-south and east-west firings suggests that the transmission is more efficient in water by a factor of approximately 3, since the longer rock path in the north-south firing appears to have produced greater attenuations. In all cases there is a transfer coefficient of 0.57 at the water-rock interface. This figure is calculated from the transfer equation (Pain, 1968, p.114), assuming densities of 1000 kg/m³ and 2400 kg/m³ and velocities of 1500 m/s and 3000 m/s. The transfer factor may be higher where there is a layer of silt or clay and where the rock is weathered. Thus 0.57 is a minimum value. The transfer factor for the water-pile situation can only be estimated and 0.98 is assumed. Hence the transfer factors alone do not account for the variation in velocity recorded at the rock and pile sites. The attenuation resulting from a minimum path of 5-10 m in the outcrop is presumably the significant feature.

CONCLUSION

This brief and not wholly rigorous observational exercise does enable

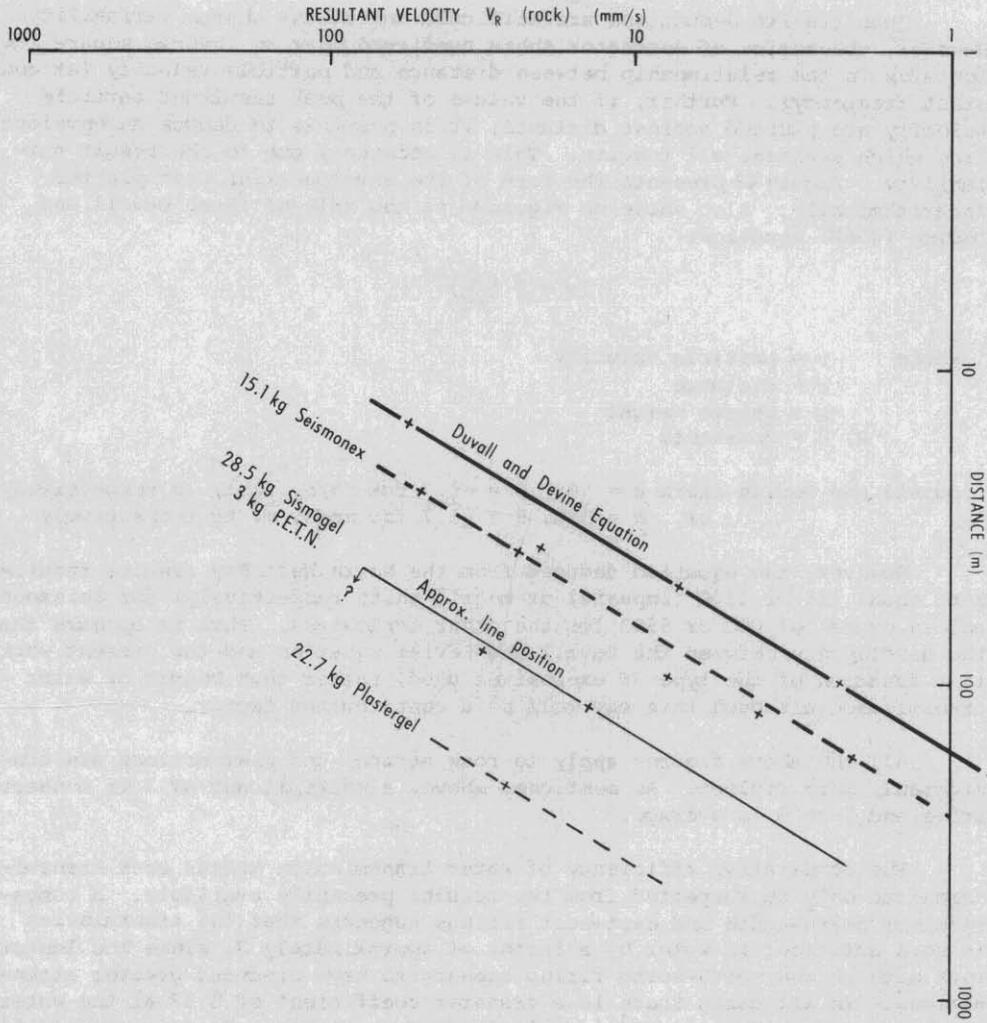
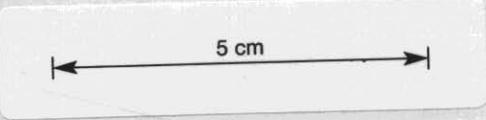


Figure 43. Rock vibration determinations.

a concluding statement concerning damage levels to be made. The actual damage produced is always dependent upon the nature of the structure and the particle velocity incited. The semi-infinite rock mass may be regarded as displaying the minimal damage effects whereas the light wooden piles and jetty could be regarded as showing maximum effects. All normal structures should fall within the range indicated and if of large and solid dimensions, would approach the rock condition.

REFERENCES

- DUVALL, W.I.; DEVINE, J.F. 1968. Avoiding damage by air-blasts and ground vibrations from blasting, in E.P. Pfeleider, (ed.). *Surface mining*: 398-412. American Institute of Mining, Metallurgical & Petroleum Engineers : New York.
- PAIN, H.J. 1968. *The Physics of vibrations and waves*. Wiley : New York.
- TYNAN, A.E. 1973. Ground vibrations. Damaging effects to buildings. *Spec. Rep. Aust. Rd Res. Bd.* 11.

APPENDIX I

In order to indicate some of the practical implications of the observations detailed in this report, a hypothetical but potentially real question, at the time of writing, may be asked.

On 5 January 1975, the bulk carrier Lake Illawarra collided with piers on the eastern side of the Tasman Bridge and collapsed three spans. The vessel sank with at least one span on or in the ship, and other span and pier material settled in river silt around the pile foundations. Efficient, economic and rapid salvage of the vessel or repair of the bridge may depend upon the removal of bridge span material. Since each span consisted of pre-stressed beams and pavements weighing a total of approximately 1100 t, some breaking up of this material may be required. The use of explosives is an obvious method for the separation of a span into its constituent parts, or even a breakdown of parts. Similar consideration applies to the dismantling of the ship when it is realised that normal cutting and diver operations must be retarded at the depth of water involved.

Two factors must be taken into account. The use of any explosives, unless totally confined or of extremely low weight and, or of low speed of detonation, must incite a vertical motion in the remaining piles and piers of the bridge. Unless there is an assurance that all piles are firmly and consistently founded, some settlement is inevitable. No such confidence can be presumed for the whole length of the bridge although it may be possible east of Pier 12. The cracking of piers and cap or span displacement are also possible.

Secondly, low velocity explosives for use in concrete may well minimise the effect, but the value of such explosives on reinforced or pre-stressed concrete must be demonstrated. Explosive charge weights less than 10 kg are unlikely to be useful in any of the applications mentioned, and as the report shows, total confinement and careful direction of the energy will be essential. A radiation of energy, even at a relatively low speed of detonation, from 10 kg of explosive is likely to produce particle velocities in the nearest piles well in excess of the Australian Standard CA23-1967 limit. Obviously the output of the particular explosive is critical and 3 kg of Petn at 25-40 m (distance minimum) will exceed this limit by a factor of 7 to 8. Petn is a very high explosive but these figures do indicate something of the caution necessary. Use of explosives in 30 m of water and in low visibility conditions must presume careful installation and adequate inspection, if the

safety of the remaining piers is to be assured. It is also possible, at the moderate charge weight suggested, that the CA23-1967 limit could be exceeded at distances of 60-100 m.

The vibrations induced in a piled concrete structure are likely to be more akin to the rock values due to rigidity, density and mass factors. However, there is a long column for each pile-pier unit and the motions at the roadway may be very severe with the moment factor thus increasing the risk. The actual motions are likely to be in the range of rock to pile as described in this report and should be assumed to be closer to those of the piles so as to give an adequate factor of safety.

This discussion has been based on Figure 43 (rock vibration determination) and is therefore a discussion of *absolute* minima. The real situation could be worse by a factor of 3 to 10, and in view of the risks to the bridge and practical problems of charge setting, confinement and accidents, the use of high explosives within 400 m of the bridge and low explosives within 100 m cannot be recommended. Clauses stating that the use of explosives within these limits are at the firer or firing contractors risk and that the same person(s) be liable for any resultant damage should be inserted in any agreement. Piers east of Pier 13 should be monitored during any firing, and also Piers 5 or 6 if possible.

The potentially explosive detonation of a pre-stressed beam poses a further risk should any attempt be made to cut or shatter the cords (intentionally or accidentally). The impulsive output of such an occurrence and the potentially destructive effect of considerable energy being radiated directly into deep water where losses are minimised can only be conjectured, but must be guarded against.

[10 April 1975]