Vibrations from Rock Blasting

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Dr Yingxin ZHOU
Senior Principal Engineer, Defence Science & Technology Agency
President, Society for Rock Mechanics & Engineering Geology (Singapore)

Vibration Effects

- Building damage
- Sensitive equipment
- Human annoyance

Characteristics of Blasting Vibration

- Transient events (usu. < than 1 sec)
- Repeated
- Typically high frequency (usu. tens of Hz)
- Effects depend on magnitude and frequency
- Fatigue effects possible (when > thousands of cycles)
- *Beware of short circuiting due to steel piles founded on bed rock*

Blasting Vibrations

$$V = H\left(\frac{R}{Q^{B}}\right)^{-n}$$

H = constant; B = scaling law;

n = attenuation coefficient

Bukit Timah Granite Test:

$$V = 1099\left(\frac{R}{Q^{1/3}}\right)^{-1.44}$$

Typical Values for H, n, and B

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H value, mm/s	Exponent n	Exponent B	Remarks
1109	1.4	1/3	Fully coupled tests in granite
21 - 804	0.88 - 2.8	1/3	Cube Root: China & Japan
1200	1.6	1/2	Square Root: Mining (USBM), Civil engineering
1130	1.77	1/2	Hong Kong granite tunnel blasting
700	1.5	0.467	Average Swedish bedrock
700	2.0	1/3	Granite rock
193-1930	1.6	1/2	Down hole bench blasting
50 - 220	1.10	1/2	Coyote (large chamber) blasting

Empirical Equations from Granite Site

For fully coupled rock free field:	$V = 1099\left(\frac{R}{Q^{1/3}}\right)^{-1.44}$
For decoupled rock free field:	$V = 498\left(\frac{R}{Q^{1/3}}\right)^{-1.45}$
For fully coupled soil overburden:	$V_X * \frac{R_V}{Q^{1/3}} = 212e^{-1.22\left(\frac{R}{Q^{1/3}}\right)}$ $V_Z * \frac{R_V}{Q^{1/3}} = 3876\left(\frac{R}{Q^{1/3}}\right)^{-1.88}$
For decoupled soil overburden:	$V_X * \frac{R_V}{Q^{1/3}} = 53e^{-1.22\left(\frac{R}{Q^{1/3}}\right)}$ $V_Z * \frac{R_V}{Q^{1/3}} = 969\left(\frac{R}{Q^{1/3}}\right)^{-1.88}$

** Based on tests in Bukit Timah granite*

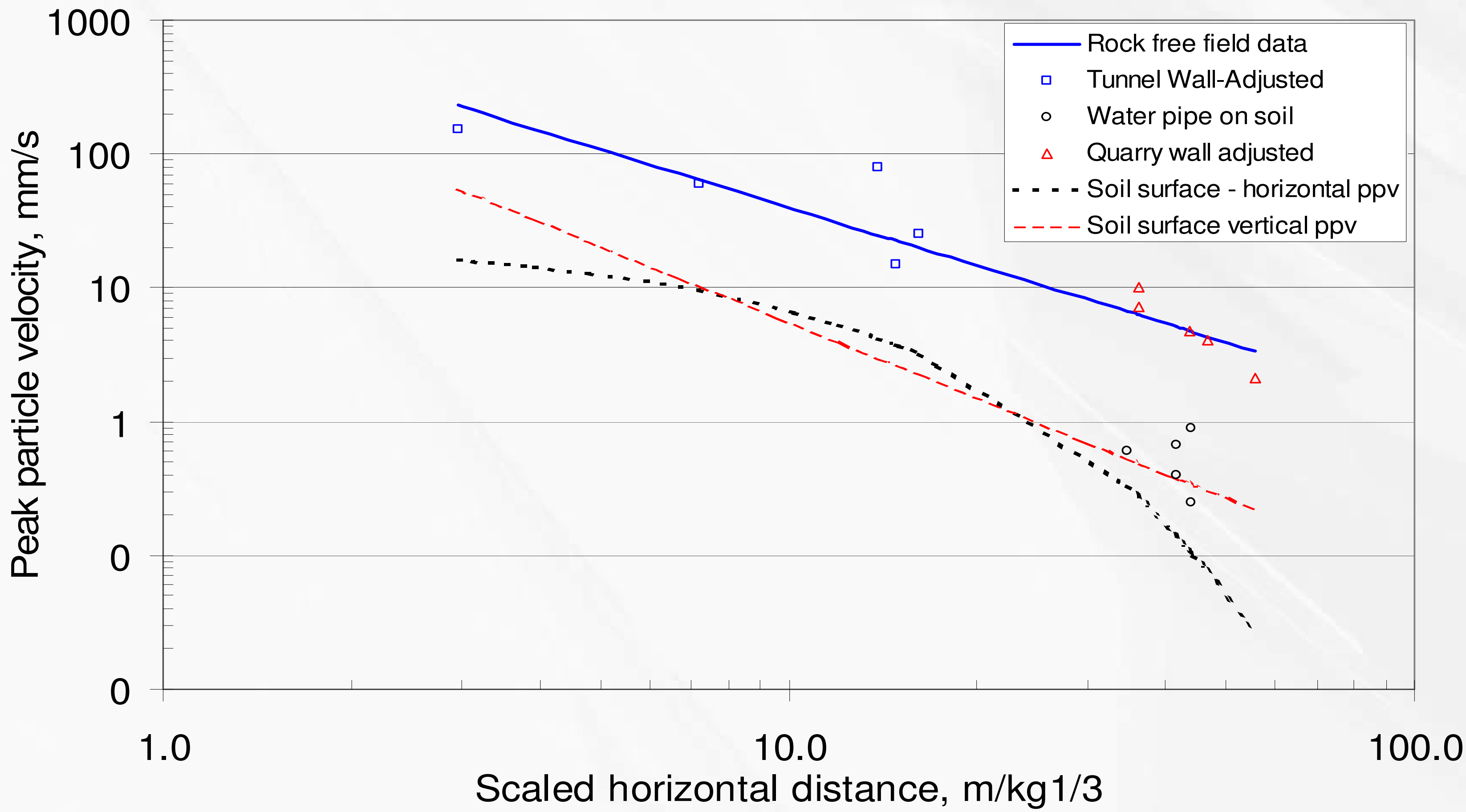
Selected Monitoring Results (1)

Distance to centre of face	Max charge per delay, kg	Scaled distance, $m/kg^{1/3}$	Recorded PPV, mm/s	Adjusted PPV, mm/s
		Tunnel Wall		
13.3	90	3.0	307.0	153.5
14	90	3.1	--	--
17.5	90	3.9		0.0
32.3	90	7.2	118.0	59.0
54	90	12.0		0.0
62.4	90	13.9	161.0	80.5
66.6	90	14.9	30.0	15.0
72.3	90	16.1	50.0	25.0
		Water Pipe		
190	80	44.1	1.8	0.9
190	80	44.1	0.5	0.3
180	80	41.8	1.3	0.7
180	80	41.8	0.8	0.4
150	80	34.8	1.2	0.6

Selected Monitoring Results (2)

Distance to centre of face	Max charge per delay, kg	Scaled distance, $m/kg^{1/3}$	Recorded PPV, mm/s	Adjusted PPV, mm/s
Quarry Wall				
145	64	36.3	14.5	7.3
145	64	36.3	20.1	10.1
190	40	55.6	4.2	2.1
160	40	46.8	8.2	4.1
150	40	43.9	9.4	4.7

Comparison of PPV's



Blasting Vibration Criteria

Country	PPV (mm/s)	Remarks
Norway/Sweden	18-70	Specifically stated for vertical PPV for different geological media. Corrections are made for other factors.
USA	50	Mostly based on US Bureau of Mines studies relating to surface mines
UK	50	
Switzerland	30	

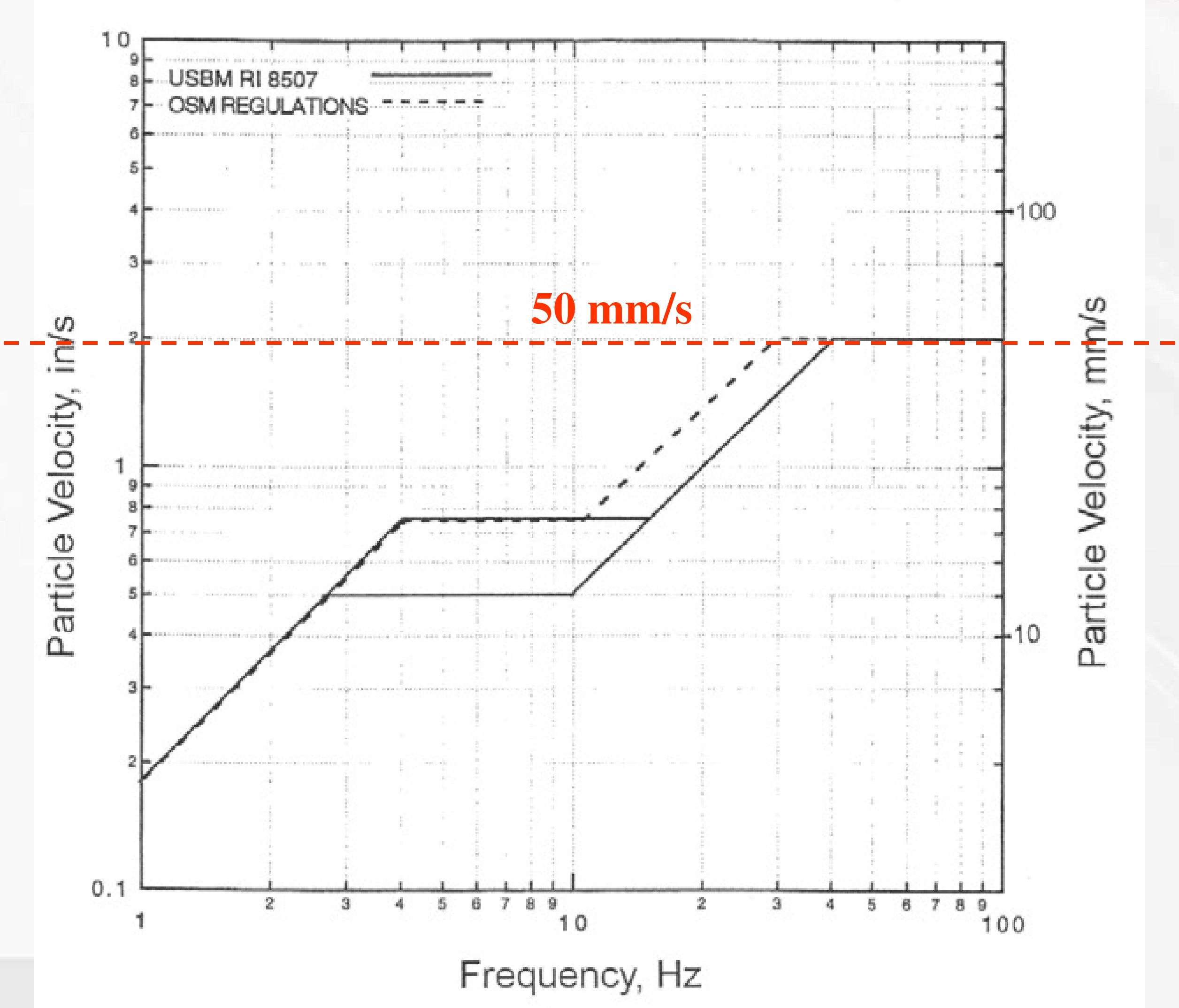
Singapore: 15 mm/s

Common Residential Effects and Criteria (USA)

PPV, mm/s	Effects and Criteria
12.5	Threshold damage for plaster construction near long-term large-scale surface mines
25.4	OSM regulatory limits for residences near long-term large scale surface mine operations
50.8	Widely accepted vibration limits for residences near construction and quarry blasting. Allowed by OSM for frequencies above 30 Hz
137	Threshold effects to the average house subjected to construction or quarry blasting
229	About 90% probability of threshold damage from construction or quarry blasting
508	For close-in construction blasting, minor damage to most houses and structural damage to some. For low frequencies, structural damage to most houses

Source: Frank J. Lucca, 2003

Frequency-based Criteria



Observed Threshold Values For RC Structures

Material	Building Type	PPV (mm/s)	Remarks
Light concrete	Residential	110	Swedish study of concrete house
Old concrete	Industrial	254	Structures expected to crack at 5-18 cm/s in ACI predictions
Concrete with masonry foundations	Industrial	150-250	USBM field studies on Initial concrete block cracks
Concrete	Industrial	300	Tests showing lowest level corresponding to cracking
Native stone with mortar joints & rubble foundation	1 1/2-storey residential	180-510	Subjected to progressively more intense blast vibrations until damage was observed.

Vibration Effects - Some Perspectives

Loading	Induced micro-strain	Equivalent Vibration Level, mm/s
Daily environmental changes	149	30.0
	385	76.0
Walking	9.1	0.8
Heel drops	16.0	0.8
Jumping	37.3	7.1
Door slams	48.8	12.7
Pounding nails	88.7	22.4

Source: Dowding, in "Comprehensive Rock Engineering"

Norwegian Standard

- Guidance level for vertical ppv:

$$V = V_0 * F_k * F_d * F_t$$

V_0 - uncorrected vertical PPV

F_k = construction quality factor

F_d = distance factor

F_t = project time factor

Norwegian Standard

Uncorrected vertical PPV:

Type of Ground	**V_0 (mm/s)**	**Eq seismic velocity C_p (m/s)**
Loose moraine, sand, gravel, clay (seismic velocity < 2000 m/s)	18	1170
Firm moraine, shale, soft limestone (seismic velocity 2000-4000 m/s	35	2275
Hard rocks like granite, gneiss, limestone, quatzite, sandstone (seismic velocity > 4000 ms)	70	4550

$V_0 = C_p/65$ *(mm/s)*; C_p *- seismic velocity, m/s,*

$$V = V_0 * F_k * F_d * F_t$$

Norwegian Standard

Construction Quality Factor:

$$F_k = F_b \; x \; F_m$$

F_b = *Building factor;*

F_b = *Construction material factor.*

$$V = V_0 * F_k * F_d * F_t$$

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Building Factor

$$F_k = F_b \times F_m$$

Class	Type of Structure	F_b
1	Heavy structures, bridges, quay, civil defence structures	1.70
2	Industrial and office buildings	1.20
3	Residential buildings	1.00
4	Sensitive buildings with high arches or large spans, churches and museums	0.65
5	Historical buildings in poor conditions	0.5

Norwegian Standard

Construction Material Factor $F_k = F_b \times F_m$

Class	Type of Structure	F_m
1	Reinforced concrete, steel	1.20
2	Non-reinforced concrete, brick	1.00
3	Aerated concrete	0.75
4	Mexi-brick (artificial limestone brick)	0.65

Norwegian Standard

Distance Factor

Distance from blasting, d	F_d
d < 5 m	To be defined individually
5m < d < 200 m	0.5+0.5(200-d)/195
D > 200m	0.5

** The distance factor compensates for the decreased frequency with increasing distance*

$$V = V_0 * F_k * F_d * F_t$$

Norwegian Standard

- Project time factor, F_t

Type of blasting activity	F_t
Construction works such as tunnels, caverns, surface blasting	1.0
Stationary works, quarries, and mines	0.75 – 1.00

$$V = V_0 * F_k * F_d * F_t$$

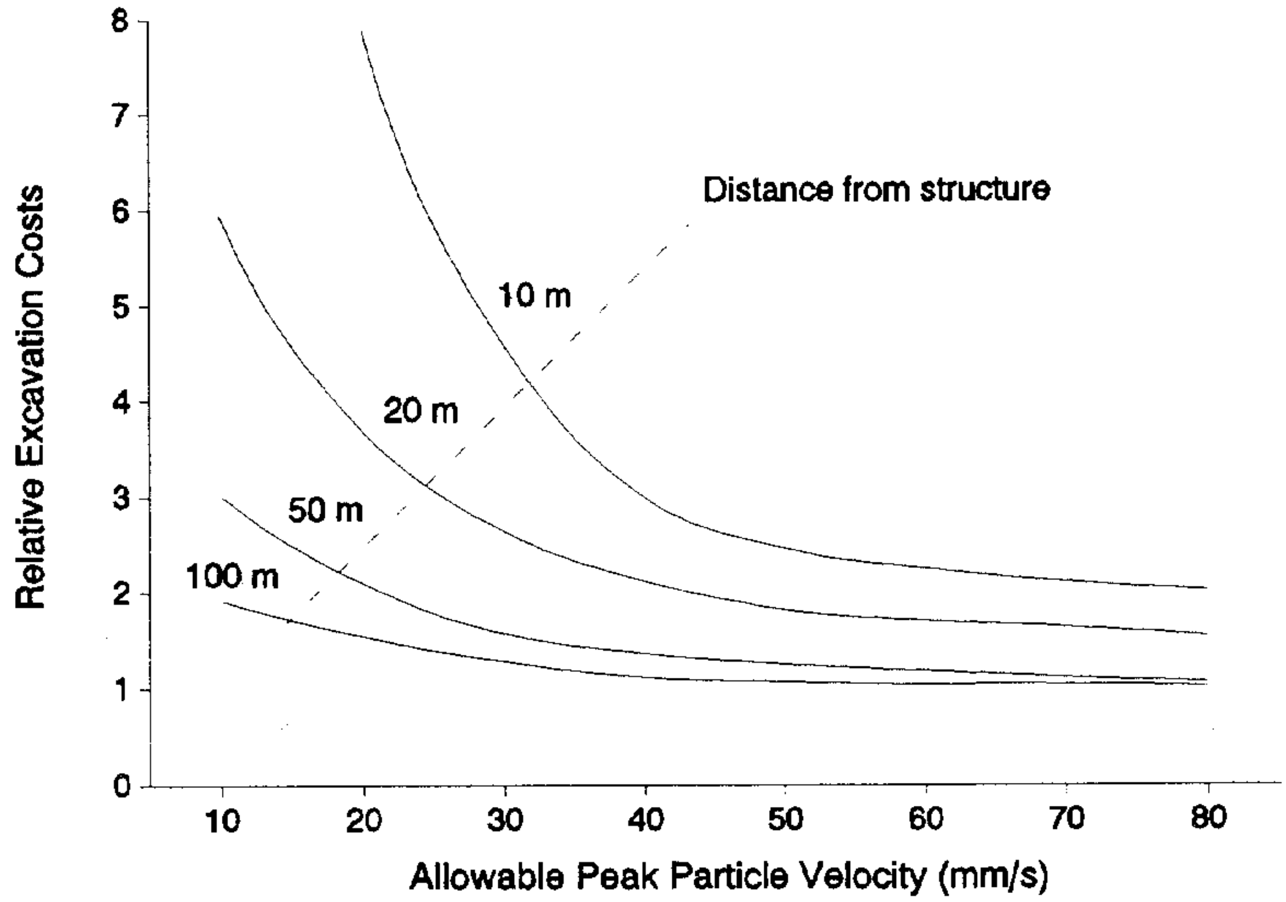
Norwegian Standard

An example:

- 10 month blasting work at 60 m from a residential building made of concrete
- Allowable vertical PPV:
  - 60 mm/s if building is founded on hard rock
  - 15 mm/s if building is founded on clay

Source: NFF, Handbook No 2, 2000

Cost Related to Vibration Control



Note: The curves are indicative only.

** Relative cost based on study for cavern excavation in Hong Kong*

Source: Berthelsen, 1992

Costs Related to Vibration Control

Distance to structure	Allowable Peak Particle Velocity, mm/s		
	20 mm/s	40 mm/s	60 mm/s
10 m	750	300	240
20 m	350	220	175
50 m	200	175	120
100 m	150	125	100

** Relative cost based on study for cavern excavation in Hong Kong*

Source: Berthelsen, 1992

Final Comments

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- Empirical equations based on local geology reasonable for prediction of ground vibrations
- Distinct difference between ground motions in soil and rock media
- Existing criteria for vibration control generally conservative
- Overly conservative criteria can result in unnecessary cost increases in blasting
- Best approach is to study geology, structure, and characteristics of ground shock propagation

Thank you!