50 YEARS OF
BLAST VIBRATION
MONITORING & CONTROL

(No, this isn't my retirement speech. There's too much left to do.)

Quick Review of Historical Trends

Deep Dive into RI 8507

NORTHWESTERN UNIVERSITY
1851

HISTORICAL TRENDS

Loss of Contact w/ Primary Studies 8896?

Greater Definition of Blasting Regulations Z

Shrinkage of the Control Crack Nail pops

Comparison of Vibratory and Weather Response of Cracks

Computerization of Instrumentation

Increasing Analytical Ability fdom, FFT

Improving Close-In Blasting Capability

Application of Blasting Research to Construction Vibrations

Increasing Sophistication of Explosive Technology Elect Dets

LOSS OF CONTACT w/ PRIMARY STUDIES

Who Has a Copy of RI 8507, 8896, or 9523 ?

Who Has Read These RI's from USBM

Summarize 10's of Millions of Dollars of Vibration Research

See OSM for complete collection

https://www.osmre.gov/resources/blasting/ARblast.shtm

8507 Structure Response & Damage Produced by Ground Vibrations from Surface Blasting

Siskind classic that introduces the concept of a frequency based vibration control limit;
the Z curve.
These limits are based upon the observation of cosmetic, hair sized cracks

8896 Effects of Repeated Blasting on a Wood-Frame House

Loose ends of RI 8507 are tied up in this report, which contains results of full scale fatigue tests (important for vibratory construction equipment) as well as full scale tests of in-plane shearing of concrete masonry units..

9523 Surface Mine Blasting Near Pressurized Transmission Lines

Reports response of field tests on pressurized pipelines subjected to full-scale surface coal mine blasts. Demonstrates that they can sustain very high particle velocities.

Reprints available from ISEE and OSM ARblast .

Memories of the birth of "Z"
Top 10 from RI 8507

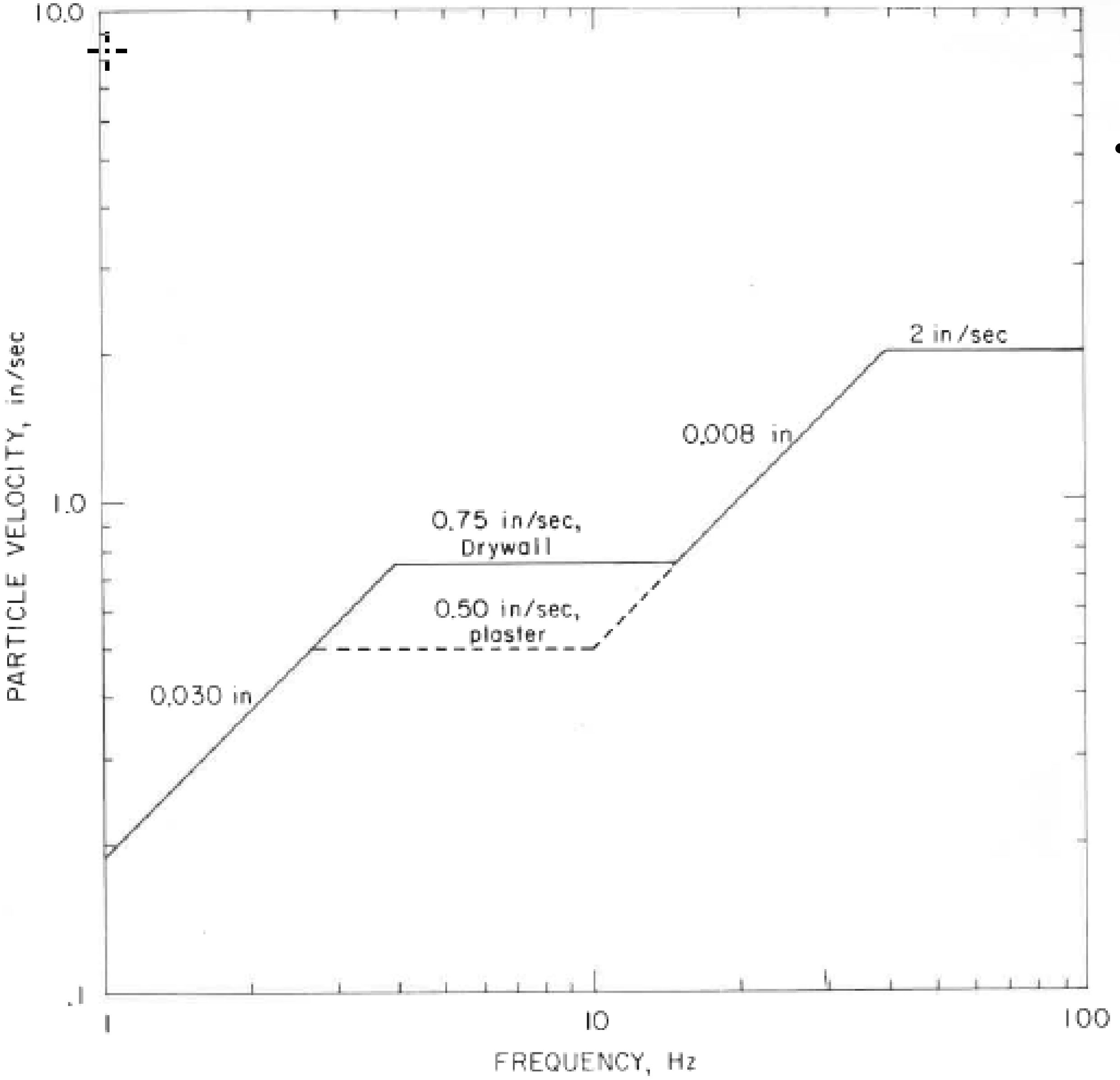


Figure B–1.—Safe levels of blasting vibration for houses using a combination of velocity and displacement.

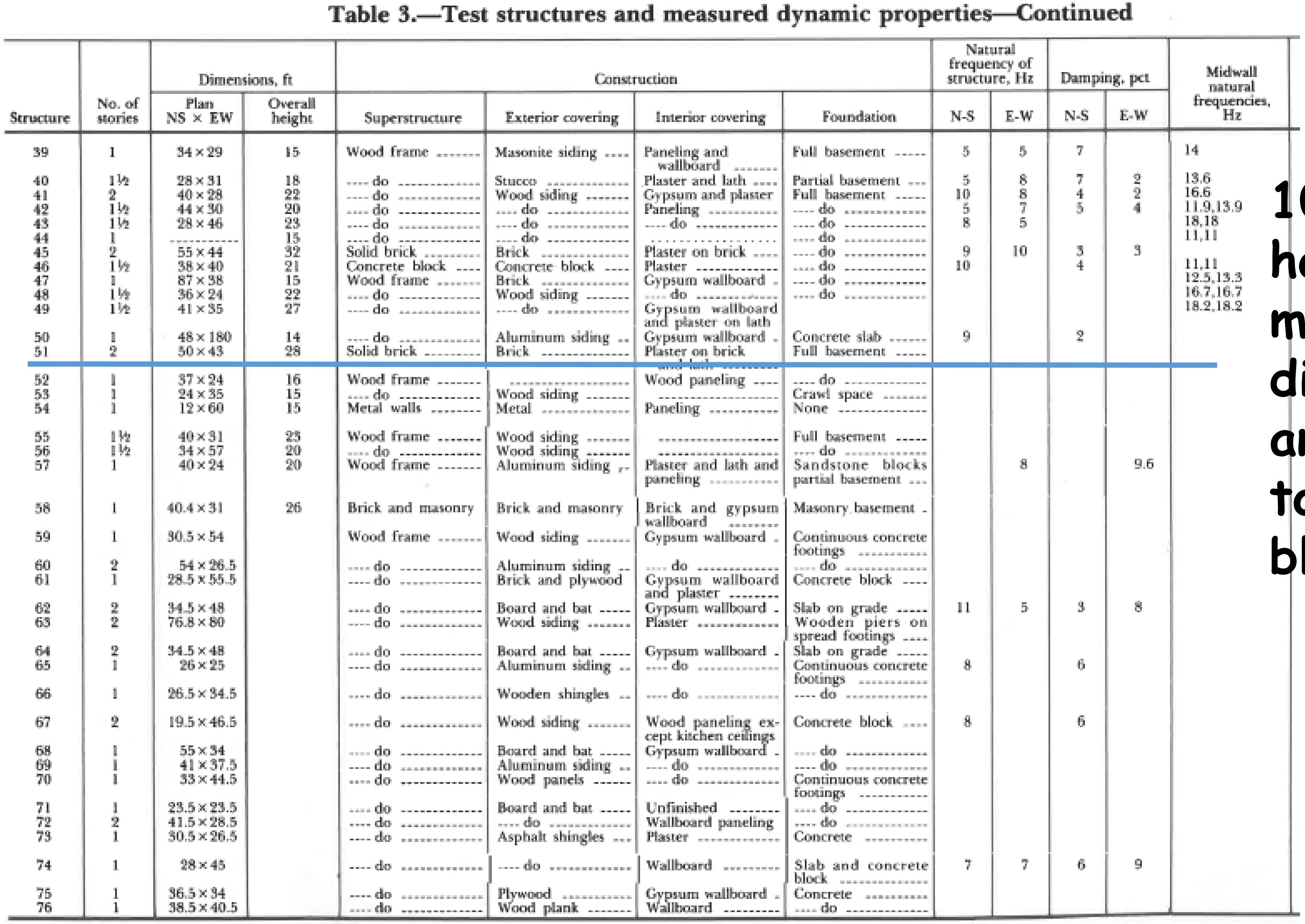


Table 3.—Test structures and measured dynamic properties—Continued

Structure	No. of stories	Dimensions, ft		Construction				Natural frequency of structure, Hz		Damping, pct		Midwall natural frequencies, Hz
		Plan NS × EW	Overall height	Superstructure	Exterior covering	Interior covering	Foundation	N-S	E-W	N-S	E-W	
39	1	34 × 29	15	Wood frame	Masonite siding	Paneling and wallboard	Full basement	5	5	7		14
40	1½	28 × 31	18	do	Stucco	Plaster and lath	Partial basement	5	8	7	2	13.6
41	2	40 × 28	22	do	Wood siding	Gypsum and plaster	Full basement	10	8	4	2	16.6
42	1½	44 × 30	20	do	do	Paneling	do	5	7	5	4	11.9,13.9
43	1½	28 × 46	23	do	do	do	do	8	5			18,18
44	1		15	do	do		do					11,11
45	2	55 × 44	32	Solid brick	Brick	Plaster on brick	do	9	10	3	3	
46	1½	38 × 40	21	Concrete block	Concrete block	Plaster	do	10		4		11,11
47	1	87 × 38	15	Wood frame	Brick	Gypsum wallboard	do					12.5,13.3
48	1½	36 × 24	22	do	Wood siding	do	do					16.7,16.7
49	1½	41 × 35	27	do	do	Gypsum wallboard and plaster on lath						18.2,18.2
50	1	48 × 180	14	do	Aluminum siding	Gypsum wallboard	Concrete slab	9		2		
51	2	50 × 43	28	Solid brick	Brick	Plaster on brick and lath	Full basement					
52	1	37 × 24	16	Wood frame		Wood paneling	do					
53	1	24 × 35	15	do	Wood siding		Crawl space					
54	1	12 × 60	15	Metal walls	Metal	Paneling	None					
55	1½	40 × 31	23	Wood frame	Wood siding		Full basement					
56	1½	34 × 57	20	do	Wood siding		do					
57	1	40 × 24	20	Wood frame	Aluminum siding	Plaster and lath and paneling	Sandstone blocks partial basement		8		9.6	
58	1	40.4 × 31	26	Brick and masonry	Brick and masonry	Brick and gypsum wallboard	Masonry basement					
59	1	30.5 × 54		Wood frame	Wood siding	Gypsum wallboard	Continuous concrete footings					
60	2	54 × 26.5		do	Aluminum siding	do	do					
61	1	28.5 × 55.5		do	Brick and plywood	Gypsum wallboard and plaster	Concrete block					
62	2	34.5 × 48		do	Board and bat	Gypsum wallboard	Slab on grade	11	5	3	8	
63	2	76.8 × 80		do	Wood siding	Plaster	Wooden piers on spread footings					
64	2	34.5 × 48		do	Board and bat	Gypsum wallboard	Slab on grade					
65	1	26 × 25		do	Aluminum siding	do	Continuous concrete footings	8		6		
66	1	26.5 × 34.5		do	Wooden shingles	do	do					
67	2	19.5 × 46.5		do	Wood siding	Wood paneling except kitchen ceilings	Concrete block	8		6		
68	1	55 × 34		do	Board and bat	Gypsum wallboard	do					
69	1	41 × 37.5		do	Aluminum siding	do	do					
70	1	33 × 44.5		do	Wood panels	do	Continuous concrete footings					
71	1	23.5 × 23.5		do	Board and bat	Unfinished	do					
72	2	41.5 × 28.5		do	do	Wallboard paneling	do					
73	1	30.5 × 26.5		do	Asphalt shingles	Plaster	Concrete					
74	1	28 × 45		do	do	Wallboard	Slab and concrete block	7	7	6	9	
75	1	36.5 × 34		do	Plywood	Gypsum wallboard	Concrete					
76	1	38.5 × 40.5		do	Wood plank	Wallboard	do					

10) Of the 76 homes inspected many were distressed:
and subjected a total of 240 blasts

Structure 51 –
plaster and lath walls
Over abandoned coal mine
wall paper stripped to
expose extensive cracking

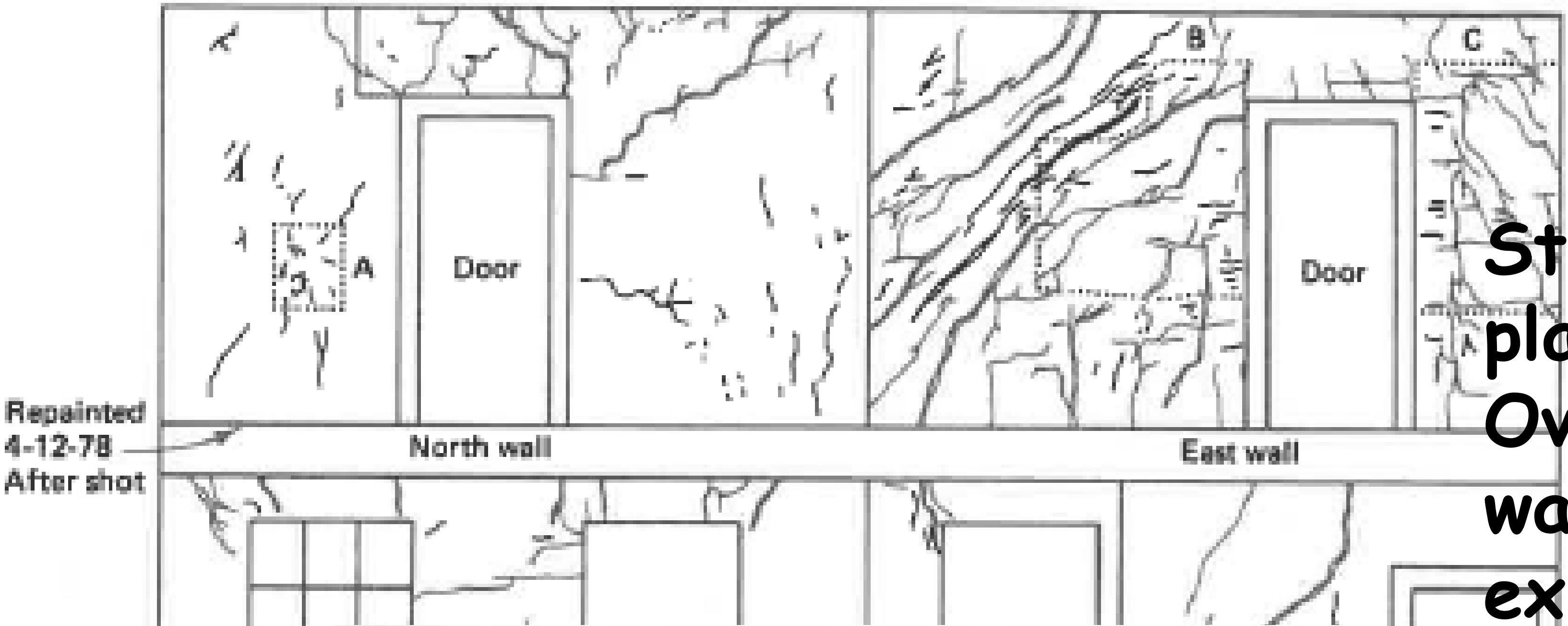


Figure 9-4
Bureau of
.S.

Figure 27.—Test structure 51, near a coal mine.

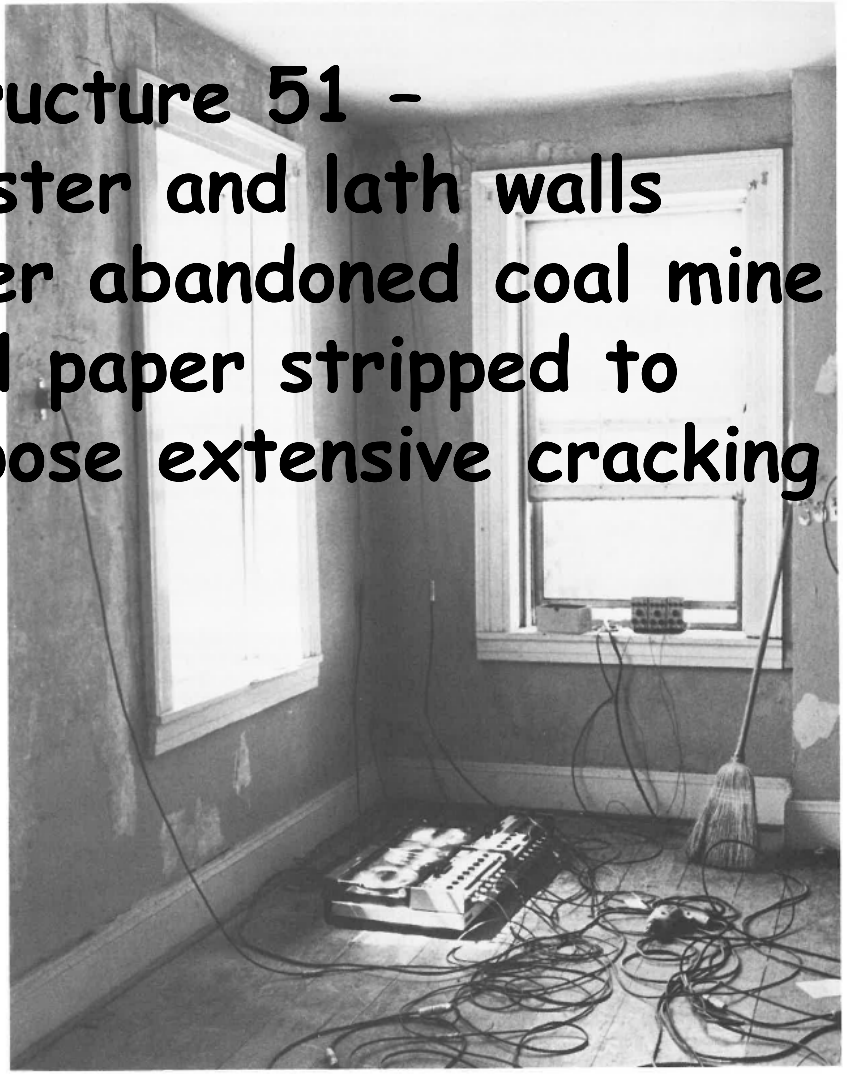
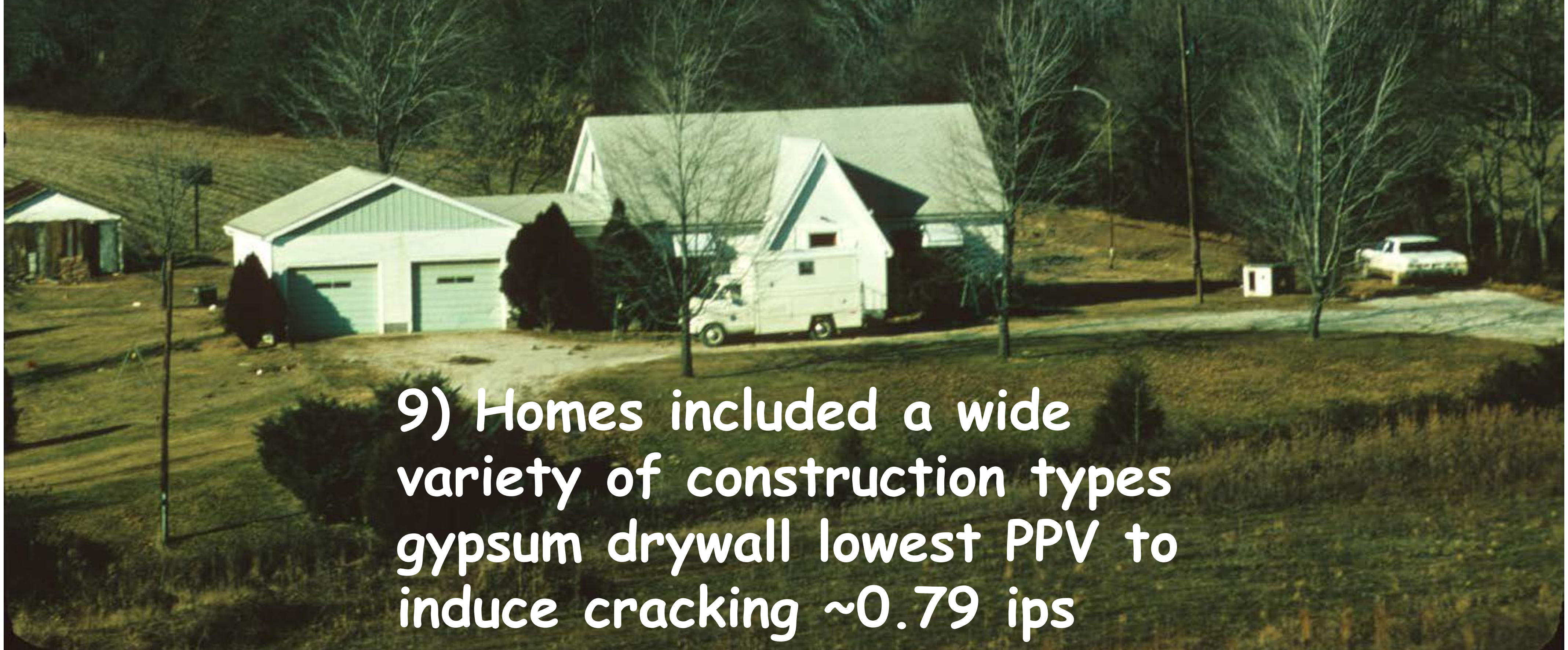


Figure 29.—Vibration gages mounted in corners and on walls for measuring structure response in structure 51.

Structure 20

Figure 16.—Test structure 20, near a coal mine.



9) Homes included a wide variety of construction types gypsum drywall lowest PPV to induce cracking ~0.79 ips

Structure 27
Lowest PPV – 0.72 ips to produce cosmetic cracking in plaster and lath

Figure 21.—Test structure 27, near a coal mine.

Example foundation support

Structure 19 Plaster and Lath Cracking: PPV-Fdom plots along Line of constant displacement on the Z curve

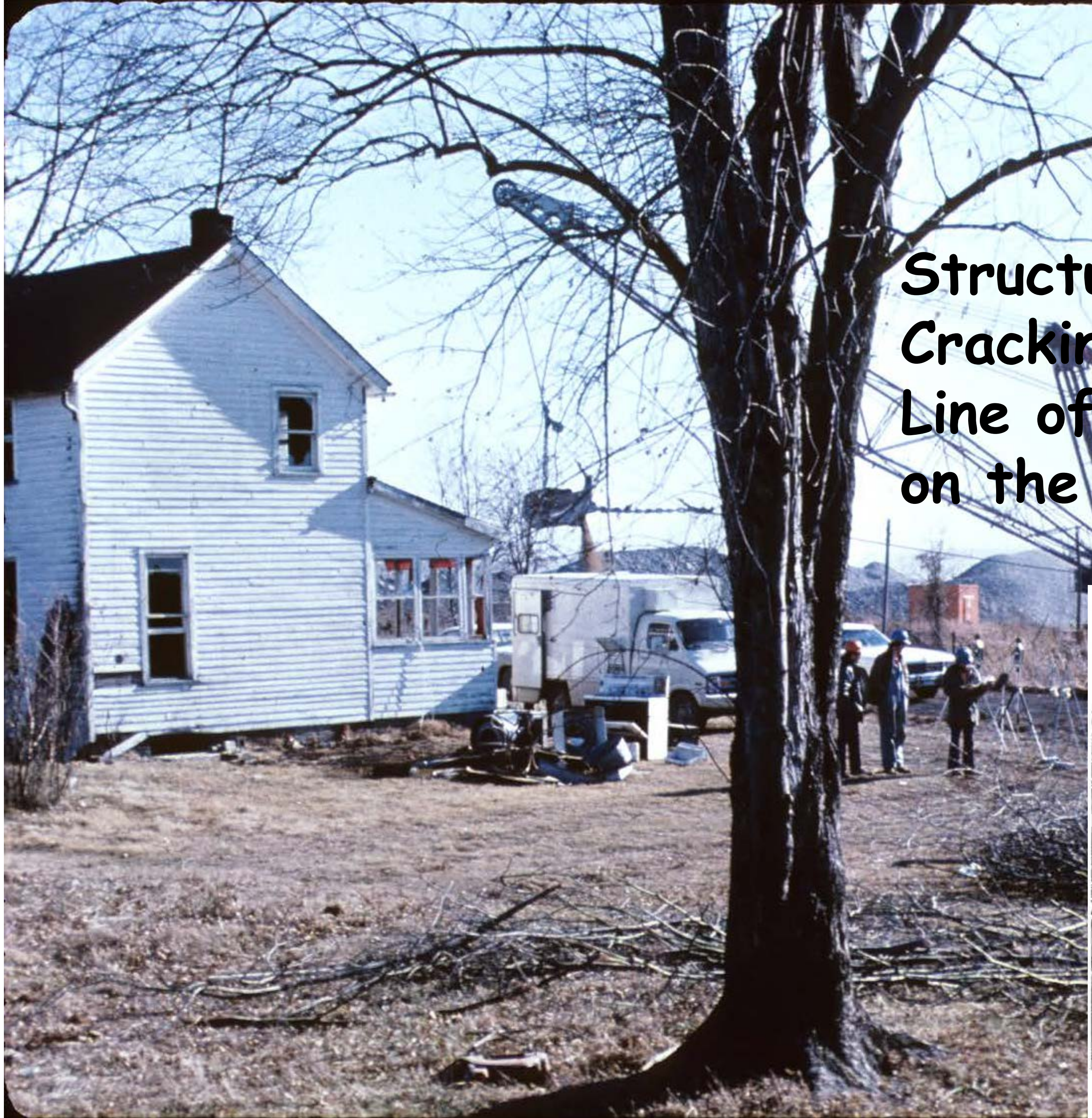
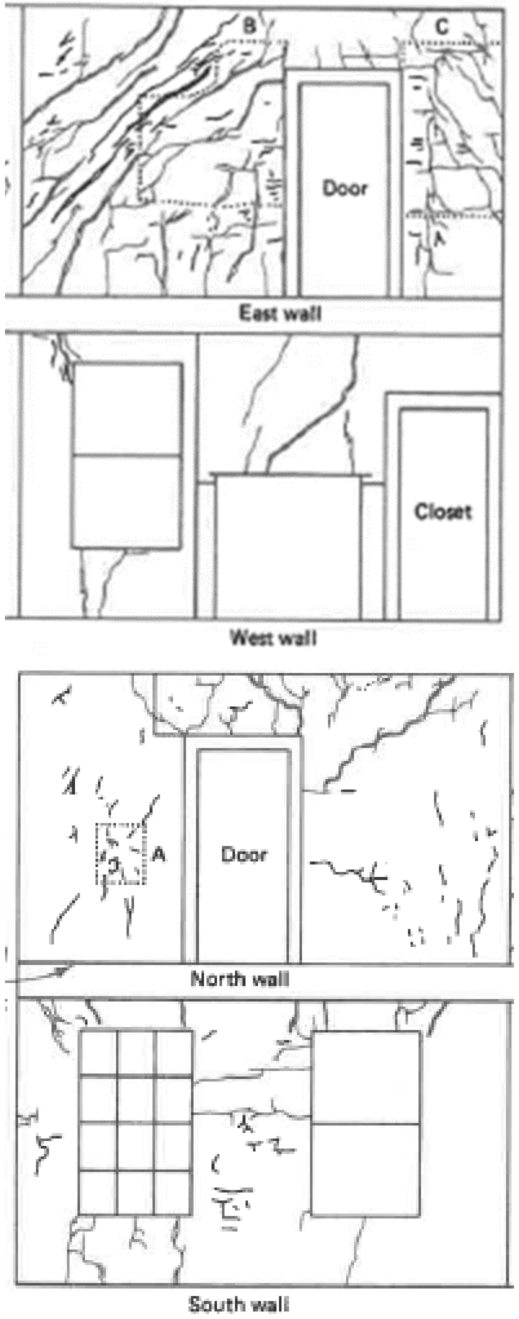



Figure 15.—Test structure 19, near a coal mine.



Shots 173, 174, and 175 caused cracking, but 167 did not. Observed walls in the southwest bedroom were stripped of all wall covering and inspected carefully before and after each blast. With respect to the crack pattern in Figure 9-4, inspection after shot 173 showed

PPV = 25.6 mm/s ~ 1.05 ips

> Nothing very significant. Test area A's few cracks (in Figure 9-4) are more evident. A few extensions and connections in area B. One new crack in B.

After shot 173 the right-half side of north wall was painted and cracks large enough to show through paint were marked. After shot 174 the inspection showed

PPV = 47.2 mm/s ~ 1.85 ips

> New cracks in area A and preexisting ones more evident. Nothing new in other areas.

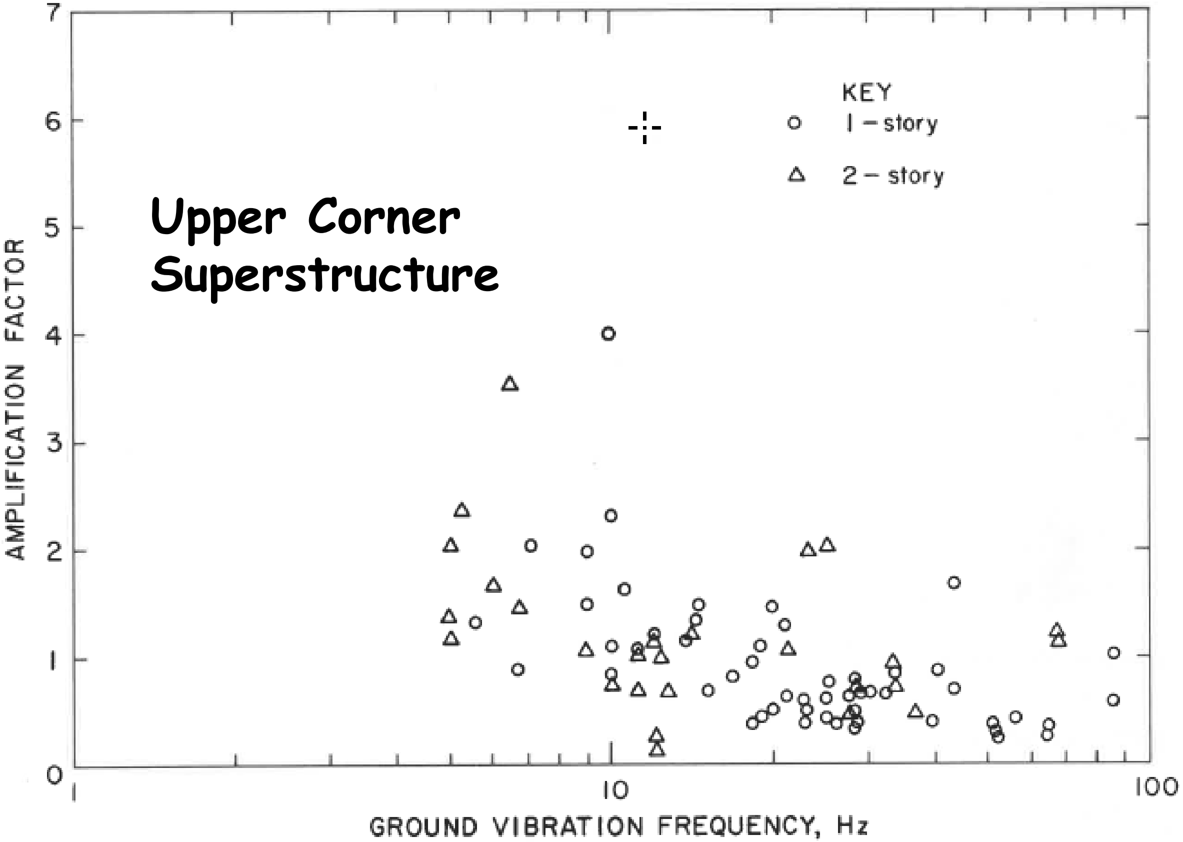
After shot 175 the inspection revealed

PPV = 216.9 mm/s ~ 8.53 ips

> "major" cracking in north and south walls—"major" diagonal crack through new paint on north wall, connecting hairline cracks existing previously, and widening considerably. Crack over door is quite wide. Previous condition not known. Very light horizontal crack near door. Nothing significant on east wall. New and wider cracks on south wall near window. Horizontal cracks between windows. Crack below window on west wall. Quite evident crack widths measured. Cement block addition developed a vertical crack through three blocks lower northeast corner east wall through mortar and block.

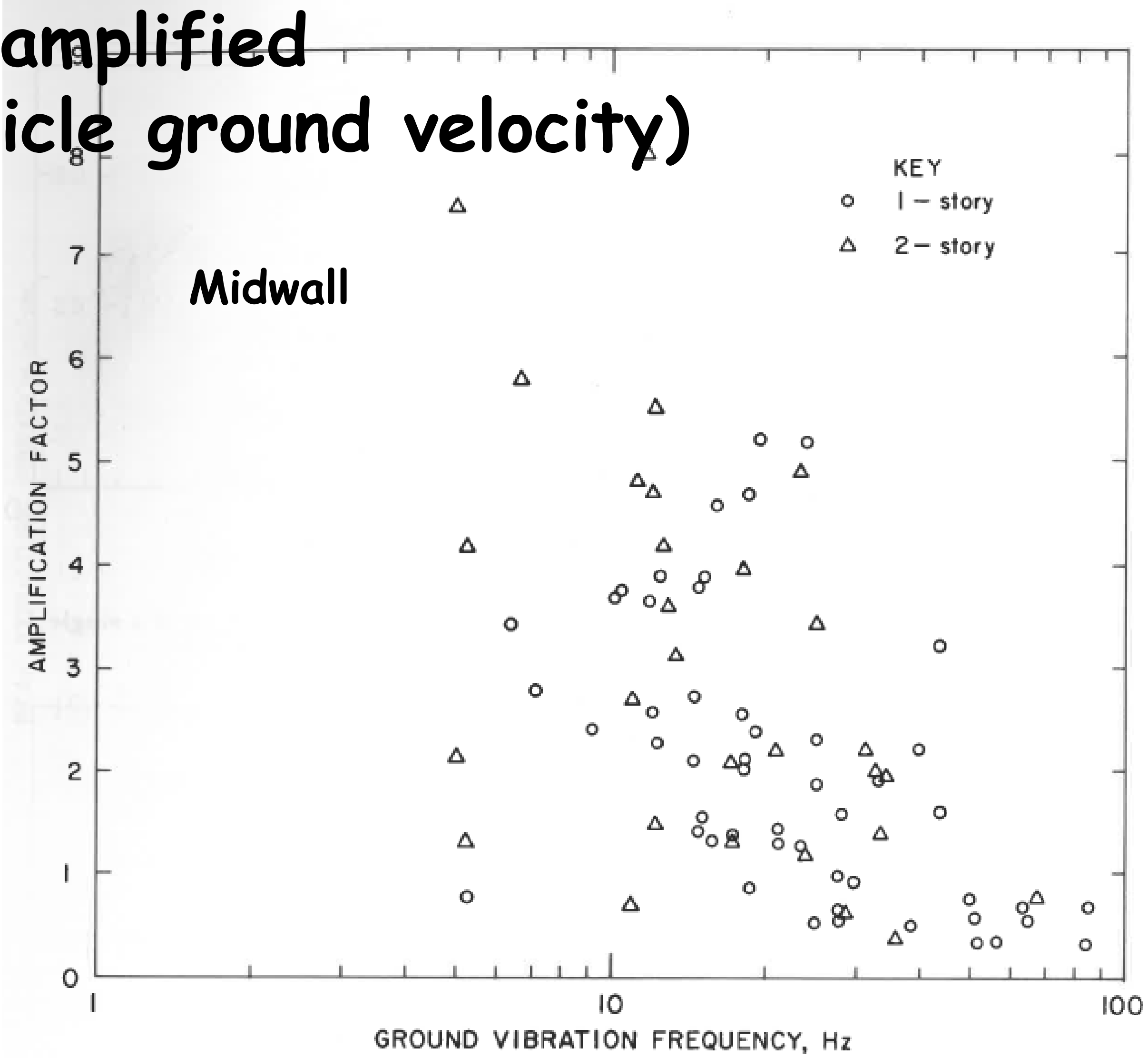
8) Interior wall coverings were inspected immediately before and after each blast

7) Home velocity response was amplified (eg was greater than peak particle ground velocity)



Upper Corner Superstructure

Figure 39.—Amplification factors for blast-produced structure vibration (corners), all homes.



Midwall

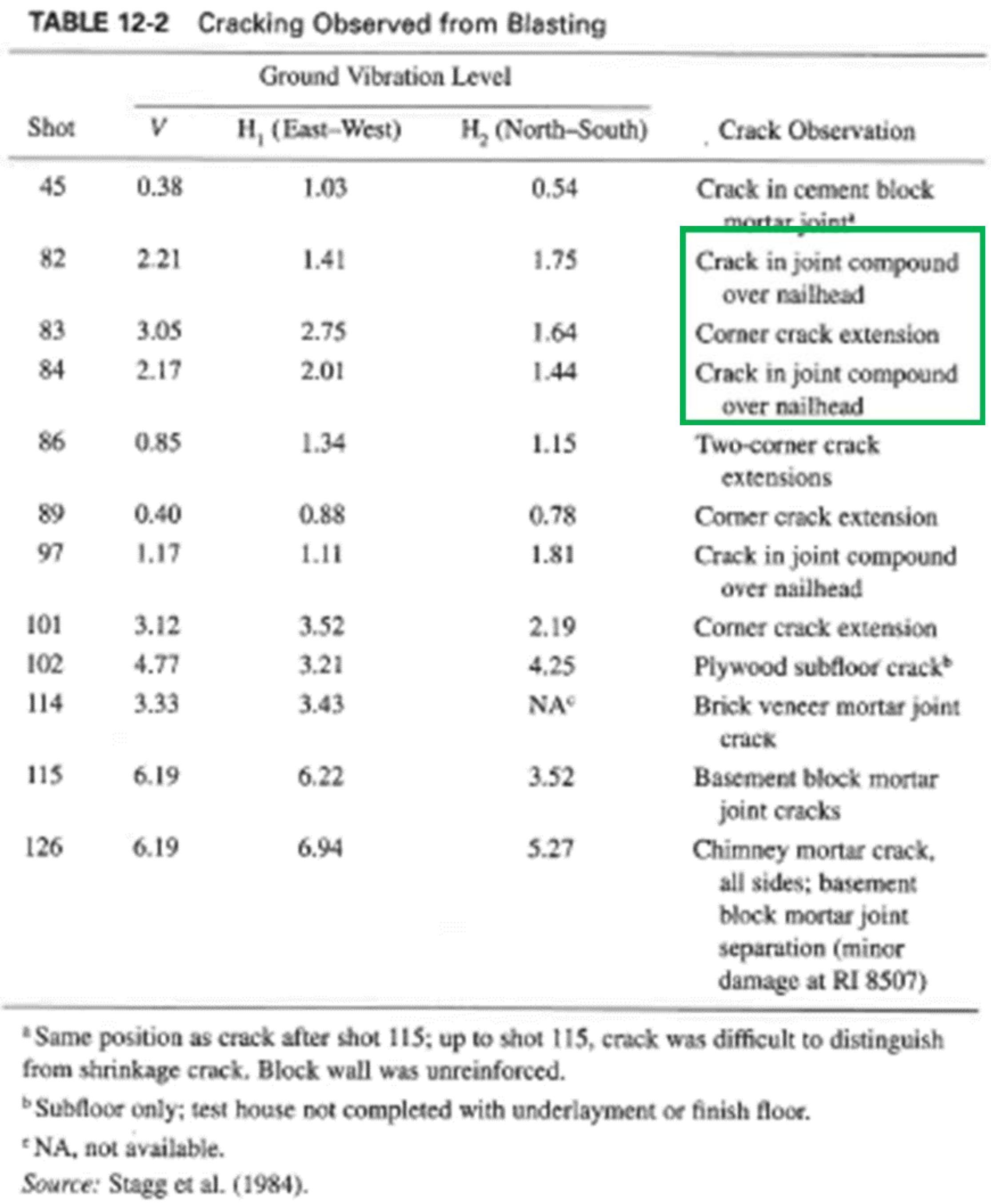


TABLE 12-2 Cracking Observed from Blasting

Shot	Ground Vibration Level V	H₁ (East–West)	H₂ (North–South)	Crack Observation
45	0.38	1.03	0.54	Crack in cement block mortar joint[a]
82	2.21	1.41	1.75	Crack in joint compound over nailhead
83	3.05	2.75	1.64	Corner crack extension
84	2.17	2.01	1.44	Crack in joint compound over nailhead
86	0.85	1.34	1.15	Two-corner crack extensions
89	0.40	0.88	0.78	Corner crack extension
97	1.17	1.11	1.81	Crack in joint compound over nailhead
101	3.12	3.52	2.19	Corner crack extension
102	4.77	3.21	4.25	Plywood subfloor crack[b]
114	3.33	3.43	NA[c]	Brick veneer mortar joint crack
115	6.19	6.22	3.52	Basement block mortar joint cracks
126	6.19	6.94	5.27	Chimney mortar crack, all sides; basement block mortar joint separation (minor damage at RI 8507)

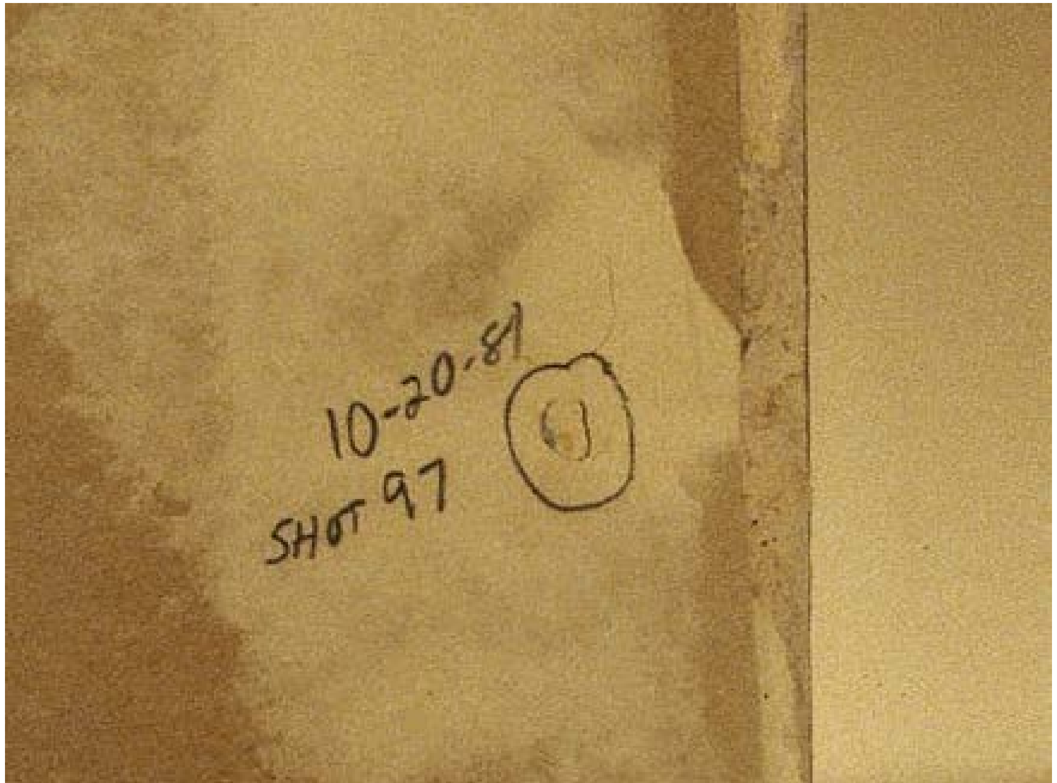
[a] Same position as crack after shot 115; up to shot 115, crack was difficult to distinguish from shrinkage crack. Block wall was unreinforced.

[b] Subfloor only; test house not completed with underlayment or finish floor.

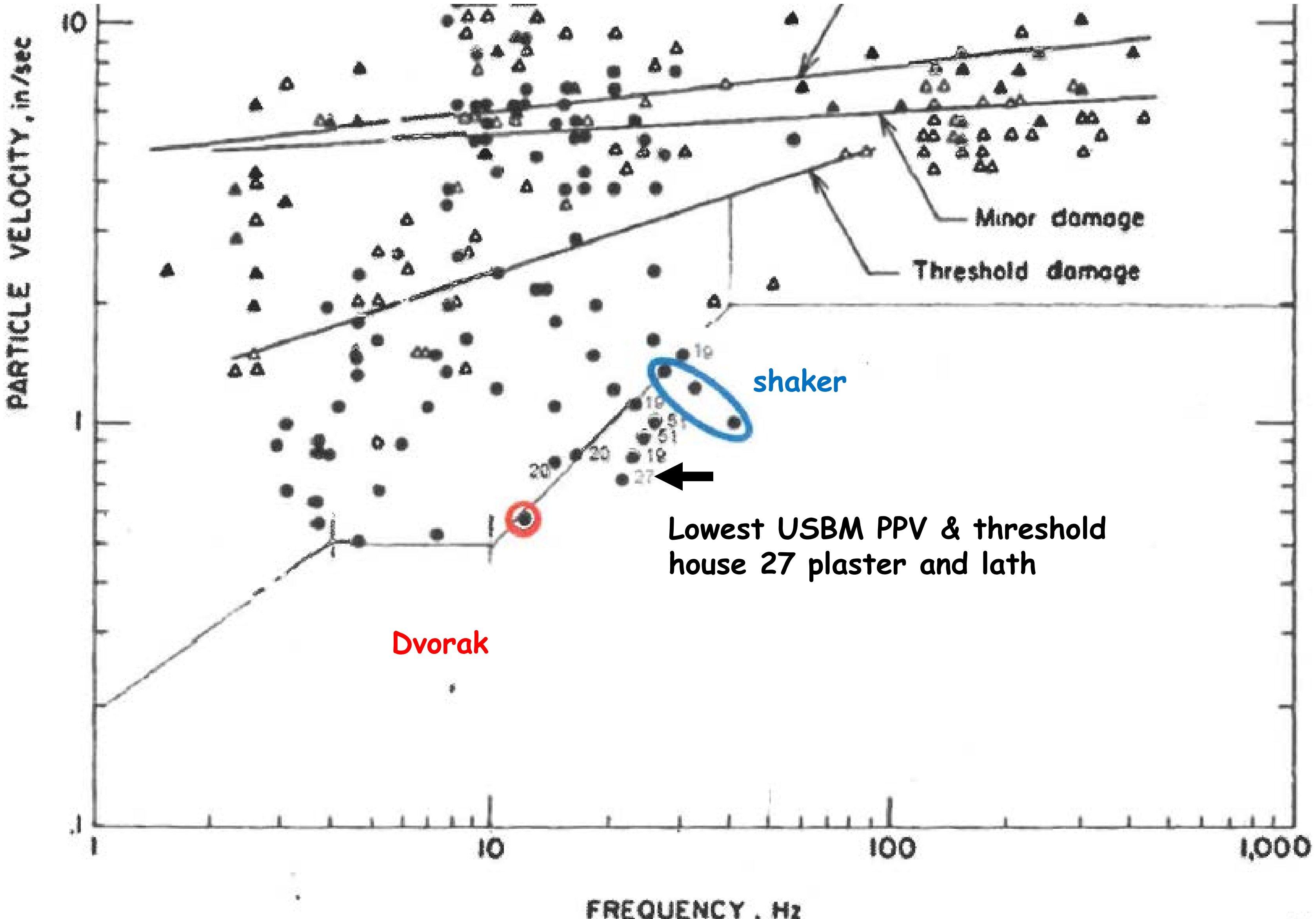
[c] NA, not available.

Source: Stagg et al. (1984).

6) Observations of blast –induced cracking were based on threshold of cosmetic cracking lower than previous



5) 0.72 ips -- lowest single axis, peak particle velocity associated w/ blast induced cosmetic cracking observed by USBM personnel.



shaker

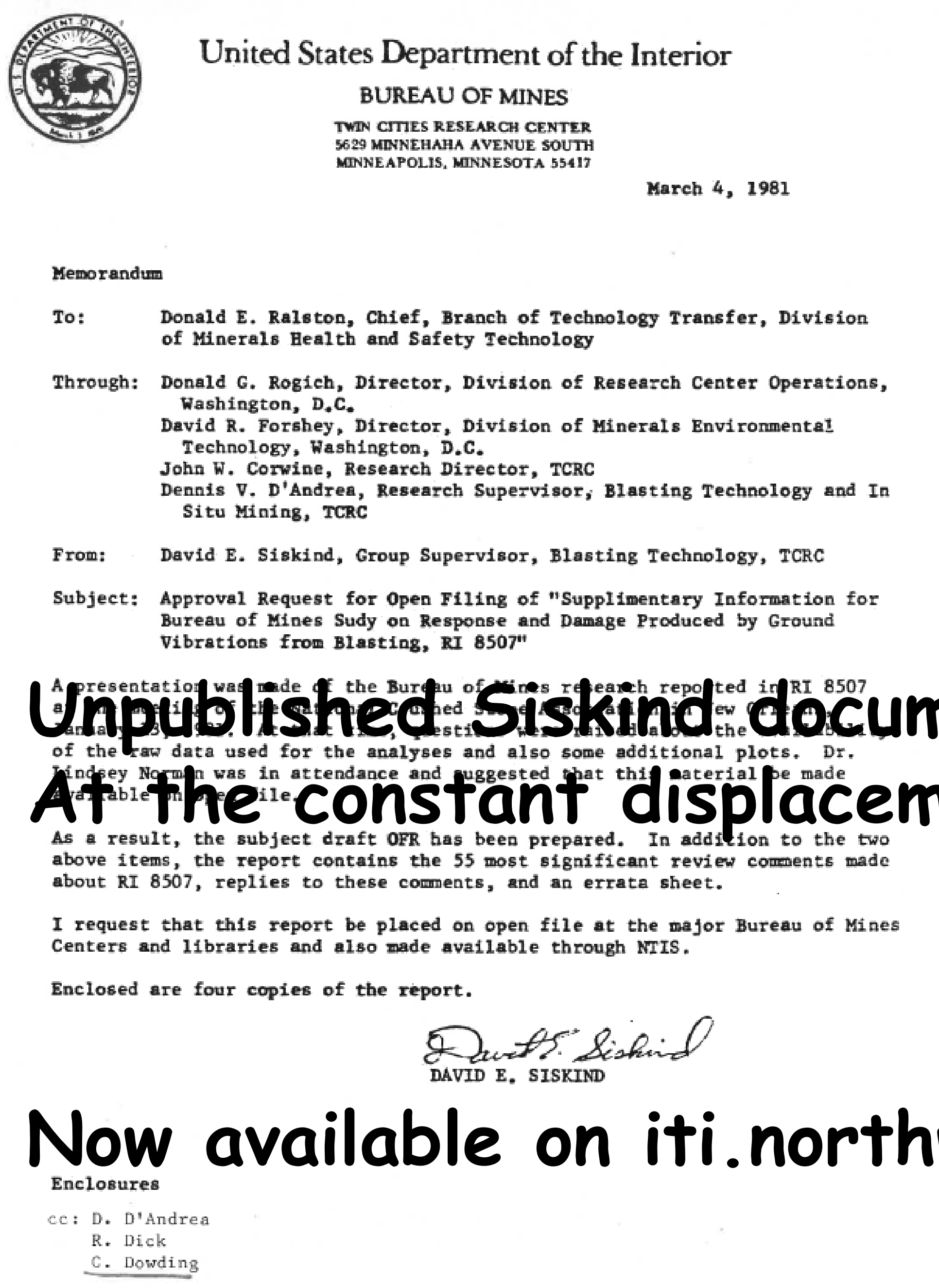
Lowest USBM PPV & threshold
house 27 plaster and lath

Dvorak

Structures 19, 27, 51
Plaster & Lath, Old, Distressed
Old in the late 1970's
Lowest PPV = 0.72 ips (18.2 mm/s)
Threshold Crack

Structure 20
Newer, Gypsum Wallboard
Lowest PPV = 0.79 ips (20 mm/s)
Threshold Crack

Unpublished Siskind document in Dowding files identifies points
At the constant displacement line in the Z curve



United States Department of the Interior
BUREAU OF MINES
TWIN CITIES RESEARCH CENTER
5629 MINNEHAHA AVENUE SOUTH
MINNEAPOLIS, MINNESOTA 55417

March 4, 1981

Memorandum

To: Donald E. Ralston, Chief, Branch of Technology Transfer, Division of Minerals Health and Safety Technology

Through: Donald G. Rogich, Director, Division of Research Center Operations, Washington, D.C.
David R. Forshey, Director, Division of Minerals Environmental Technology, Washington, D.C.
John W. Corwine, Research Director, TCRC
Dennis V. D'Andrea, Research Supervisor, Blasting Technology and In Situ Mining, TCRC

From: David E. Siskind, Group Supervisor, Blasting Technology, TCRC

Subject: Approval Request for Open Filing of "Supplimentary Information for Bureau of Mines Sudy on Response and Damage Produced by Ground Vibrations from Blasting, RI 8507"

A presentation was made of the Bureau of Mines research reported in RI 8507 a[illegible] meeting of the Nat[illegible] Crushed S[illegible] Association in New Orleans, January [illegible]. At that time, questions were raised about the [illegible] of the raw data used for the analyses and also some additional plots. Dr. Lindsey Norman was in attendance and suggested that this material be made available on open file.

As a result, the subject draft OFR has been prepared. In addition to the two above items, the report contains the 55 most significant review comments made about RI 8507, replies to these comments, and an errata sheet.

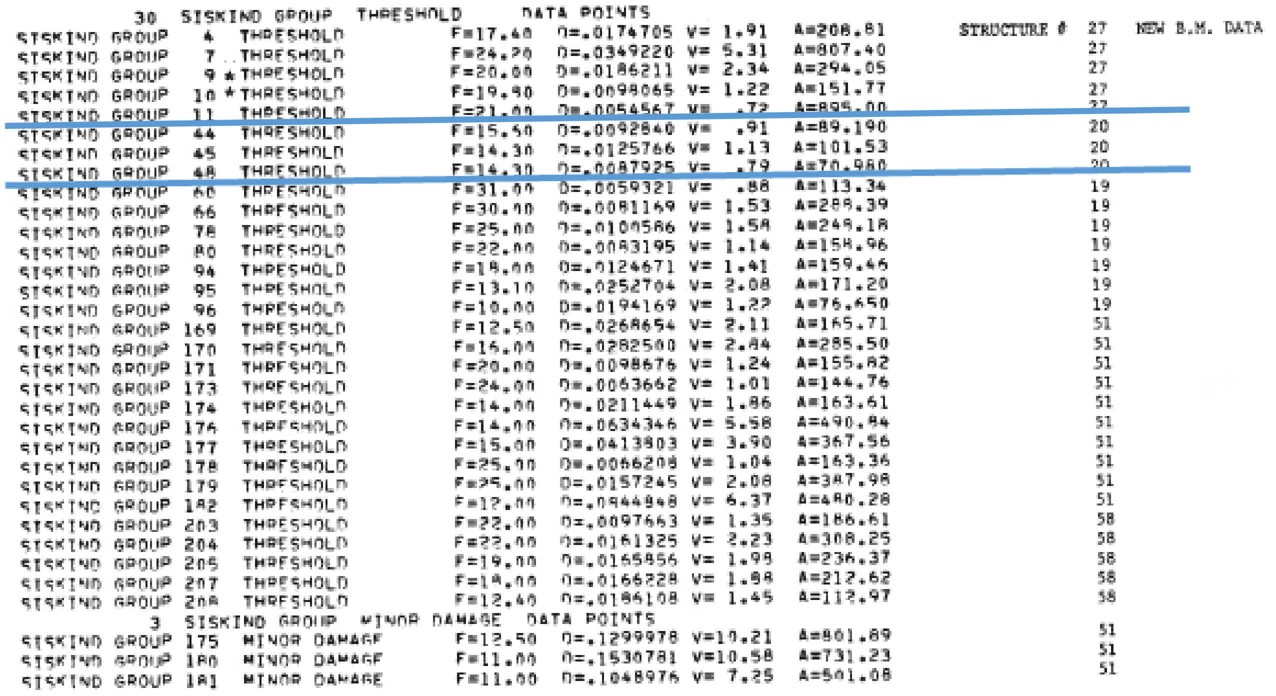
I request that this report be placed on open file at the major Bureau of Mines Centers and libraries and also made available through NTIS.

Enclosed are four copies of the report.

David E. Siskind
DAVID E. SISKIND

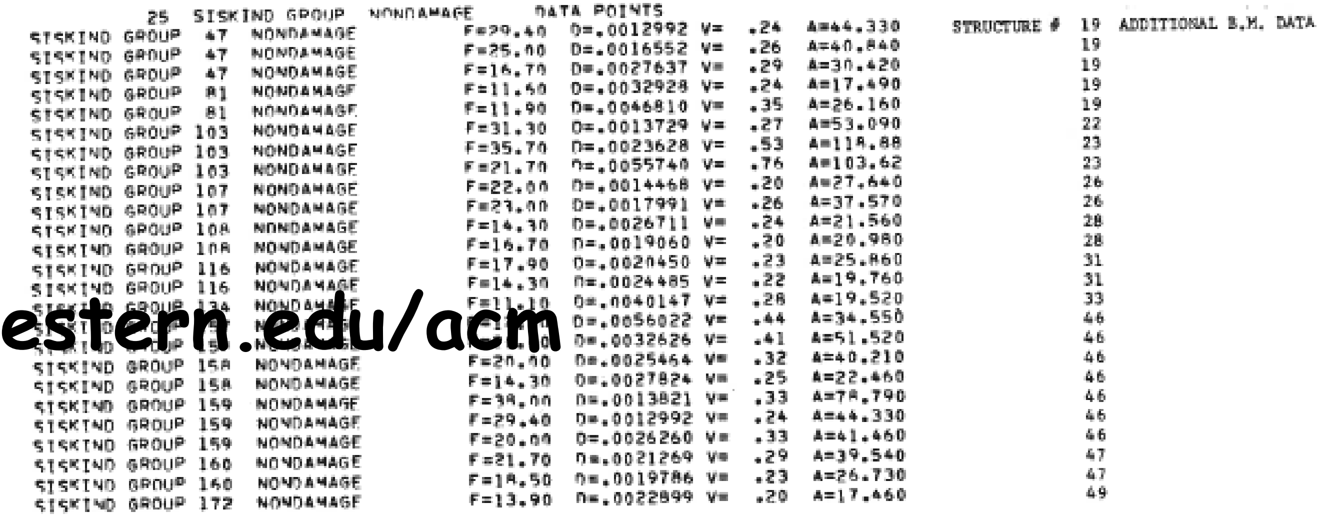
Enclosures

cc: D. D'Andrea
R. Dick
C. Dowding



```
           30  SISKIND GROUP  THRESHOLD     DATA POINTS
SISKIND GROUP   4   THRESHOLD          F=17.40  D=.0174705 V= 1.91  A=208.81      STRUCTURE #  27   NEW B.M. DATA
SISKIND GROUP   7 ..THRESHOLD          F=24.20  D=.0349220 V= 5.31  A=807.40                   27
SISKIND GROUP   9 * THRESHOLD          F=20.00  D=.0186211 V= 2.34  A=294.05                   27
SISKIND GROUP  10 * THRESHOLD          F=19.90  D=.0098065 V= 1.22  A=151.77                   27
SISKIND GROUP  11   THRESHOLD          F=21.00  D=.0054567 V=  .72  A=895.00                   27
SISKIND GROUP  44   THRESHOLD          F=15.50  D=.0092840 V=  .91  A=89.190                   20
SISKIND GROUP  45   THRESHOLD          F=14.30  D=.0125766 V= 1.13  A=101.53                   20
SISKIND GROUP  48   THRESHOLD          F=14.30  D=.0087925 V=  .79  A=70.980                   20
SISKIND GROUP  60   THRESHOLD          F=31.00  D=.0059321 V=  .88  A=113.34                   19
SISKIND GROUP  66   THRESHOLD          F=30.00  D=.0081169 V= 1.53  A=288.39                   19
SISKIND GROUP  78   THRESHOLD          F=25.00  D=.0100586 V= 1.58  A=249.18                   19
SISKIND GROUP  80   THRESHOLD          F=22.00  D=.0083195 V= 1.14  A=158.96                   19
SISKIND GROUP  94   THRESHOLD          F=18.00  D=.0124671 V= 1.41  A=159.46                   19
SISKIND GROUP  95   THRESHOLD          F=13.10  D=.0252704 V= 2.08  A=171.20                   19
SISKIND GROUP  96   THRESHOLD          F=10.00  D=.0194169 V= 1.22  A=76.650                   19
SISKIND GROUP 169   THRESHOLD          F=12.50  D=.0268654 V= 2.11  A=165.71                   51
SISKIND GROUP 170   THRESHOLD          F=16.00  D=.0282500 V= 2.84  A=285.50                   51
SISKIND GROUP 171   THRESHOLD          F=20.00  D=.0098676 V= 1.24  A=155.82                   51
SISKIND GROUP 173   THRESHOLD          F=24.00  D=.0063662 V= 1.01  A=144.76                   51
SISKIND GROUP 174   THRESHOLD          F=14.00  D=.0211449 V= 1.86  A=163.61                   51
SISKIND GROUP 176   THRESHOLD          F=14.00  D=.0634346 V= 5.58  A=490.84                   51
SISKIND GROUP 177   THRESHOLD          F=15.00  D=.0413803 V= 3.90  A=367.56                   51
SISKIND GROUP 178   THRESHOLD          F=25.00  D=.0066208 V= 1.04  A=163.36                   51
SISKIND GROUP 179   THRESHOLD          F=25.00  D=.0157245 V= 2.08  A=387.98                   51
SISKIND GROUP 182   THRESHOLD          F=12.00  D=.0844848 V= 6.37  A=480.28                   51
SISKIND GROUP 203   THRESHOLD          F=22.00  D=.0097663 V= 1.35  A=186.61                   58
SISKIND GROUP 204   THRESHOLD          F=22.00  D=.0161325 V= 2.23  A=308.25                   58
SISKIND GROUP 205   THRESHOLD          F=19.00  D=.0165856 V= 1.98  A=236.37                   58
SISKIND GROUP 207   THRESHOLD          F=18.00  D=.0166228 V= 1.88  A=212.62                   58
SISKIND GROUP 208   THRESHOLD          F=12.40  D=.0186108 V= 1.45  A=112.97                   58
            3  SISKIND GROUP  MINOR DAMAGE  DATA POINTS
SISKIND GROUP 175   MINOR DAMAGE       F=12.50  D=.1299978 V=10.21  A=801.89                   51
SISKIND GROUP 180   MINOR DAMAGE       F=11.00  D=.1530781 V=10.58  A=731.23                   51
SISKIND GROUP 181   MINOR DAMAGE       F=11.00  D=.1048976 V= 7.25  A=501.08                   51

                * NOT USED IN AN[illegible]
```



```
           25  SISKIND GROUP  NONDAMAGE     DATA POINTS
SISKIND GROUP  47   NONDAMAGE          F=29.40  D=.0012992 V=  .24  A=44.330     STRUCTURE #  19  ADDITIONAL B.M. DATA
SISKIND GROUP  47   NONDAMAGE          F=25.00  D=.0016552 V=  .26  A=40.840                  19
SISKIND GROUP  47   NONDAMAGE          F=16.70  D=.0027637 V=  .29  A=30.420                  19
SISKIND GROUP  81   NONDAMAGE          F=11.60  D=.0032928 V=  .24  A=17.490                  19
SISKIND GROUP  81   NONDAMAGE          F=11.90  D=.0046810 V=  .35  A=26.160                  19
SISKIND GROUP 103   NONDAMAGE          F=31.30  D=.0013729 V=  .27  A=53.090                  22
SISKIND GROUP 103   NONDAMAGE          F=35.70  D=.0023628 V=  .53  A=118.88                  23
SISKIND GROUP 103   NONDAMAGE          F=21.70  D=.0055740 V=  .76  A=103.62                  23
SISKIND GROUP 107   NONDAMAGE          F=22.00  D=.0014468 V=  .20  A=27.640                  26
SISKIND GROUP 107   NONDAMAGE          F=23.00  D=.0017991 V=  .26  A=37.570                  26
SISKIND GROUP 108   NONDAMAGE          F=14.30  D=.0026711 V=  .24  A=21.560                  28
SISKIND GROUP 108   NONDAMAGE          F=16.70  D=.0019060 V=  .20  A=20.980                  28
SISKIND GROUP 116   NONDAMAGE          F=17.90  D=.0020450 V=  .23  A=25.860                  31
SISKIND GROUP 116   NONDAMAGE          F=14.30  D=.0024485 V=  .22  A=19.760                  31
SISKIND GROUP 134   NONDAMAGE          F=11.10  D=.0040147 V=  .28  A=19.520                  33
[illegible]                                     D=.0056022 V=  .44  A=34.550                  46
[illegible]                                     D=.0032626 V=  .41  A=51.520                  46
SISKIND GROUP 158   NONDAMAGE          F=20.00  D=.0025464 V=  .32  A=40.210                  46
SISKIND GROUP 158   NONDAMAGE          F=14.30  D=.0027824 V=  .25  A=22.460                  46
SISKIND GROUP 159   NONDAMAGE          F=39.00  D=.0013821 V=  .33  A=78.790                  46
SISKIND GROUP 159   NONDAMAGE          F=29.40  D=.0012992 V=  .24  A=44.330                  46
SISKIND GROUP 159   NONDAMAGE          F=20.00  D=.0026260 V=  .33  A=41.460                  46
SISKIND GROUP 160   NONDAMAGE          F=21.70  D=.0021269 V=  .29  A=39.540                  47
SISKIND GROUP 160   NONDAMAGE          F=18.50  D=.0019786 V=  .23  A=26.730                  47
SISKIND GROUP 172   NONDAMAGE          F=13.90  D=.0022899 V=  .20  A=17.460                  49
```

Now available on iti.northwestern.edu/acm

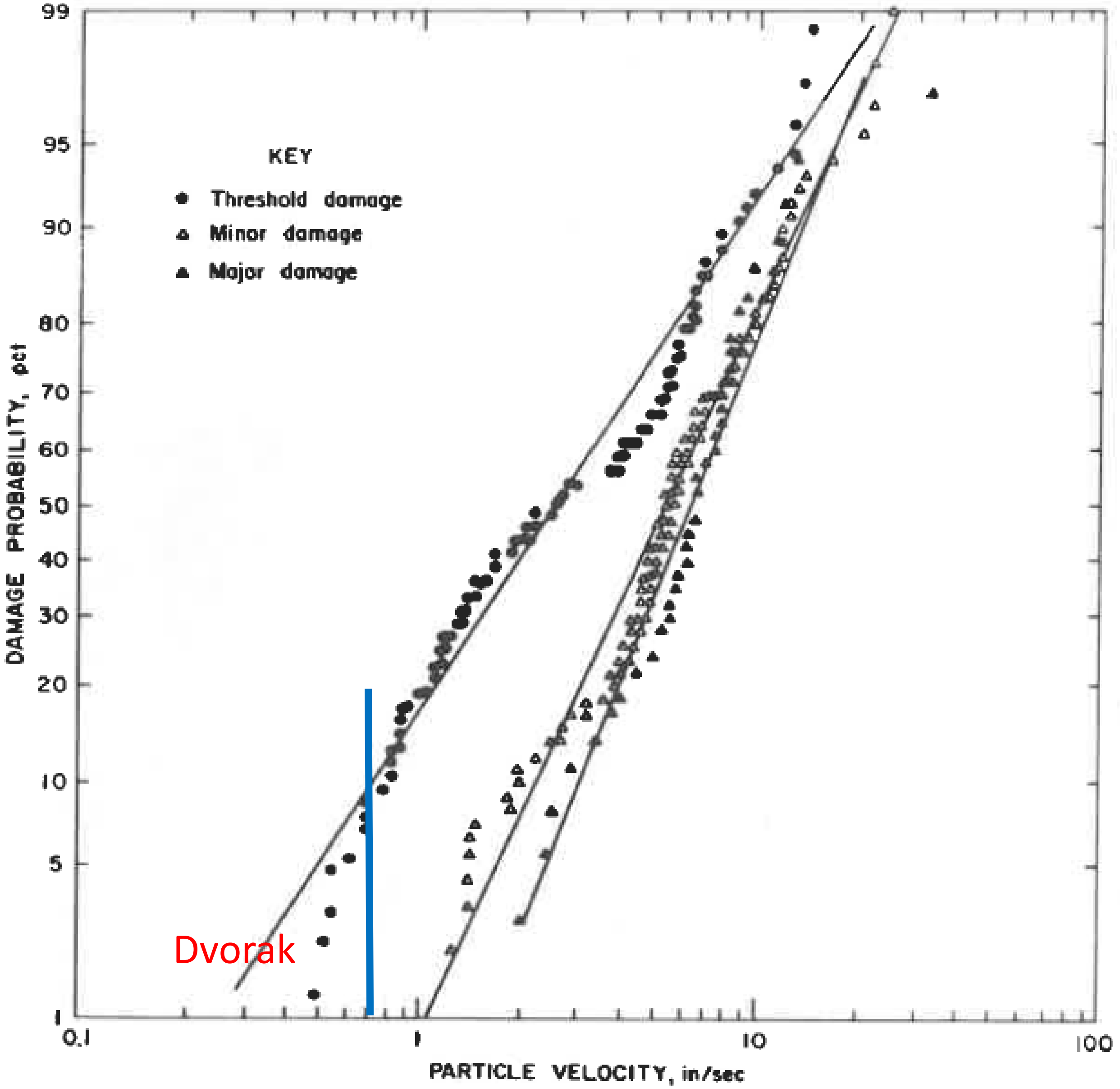


Figure 59.—Probability damage analysis summary, set 7.

4) Probability of blast induced cosmetic cracking is zero below 0.5 ips

DOT block grant allowed accumulation of crack measurement in some 20 (now ~ 30) different homes

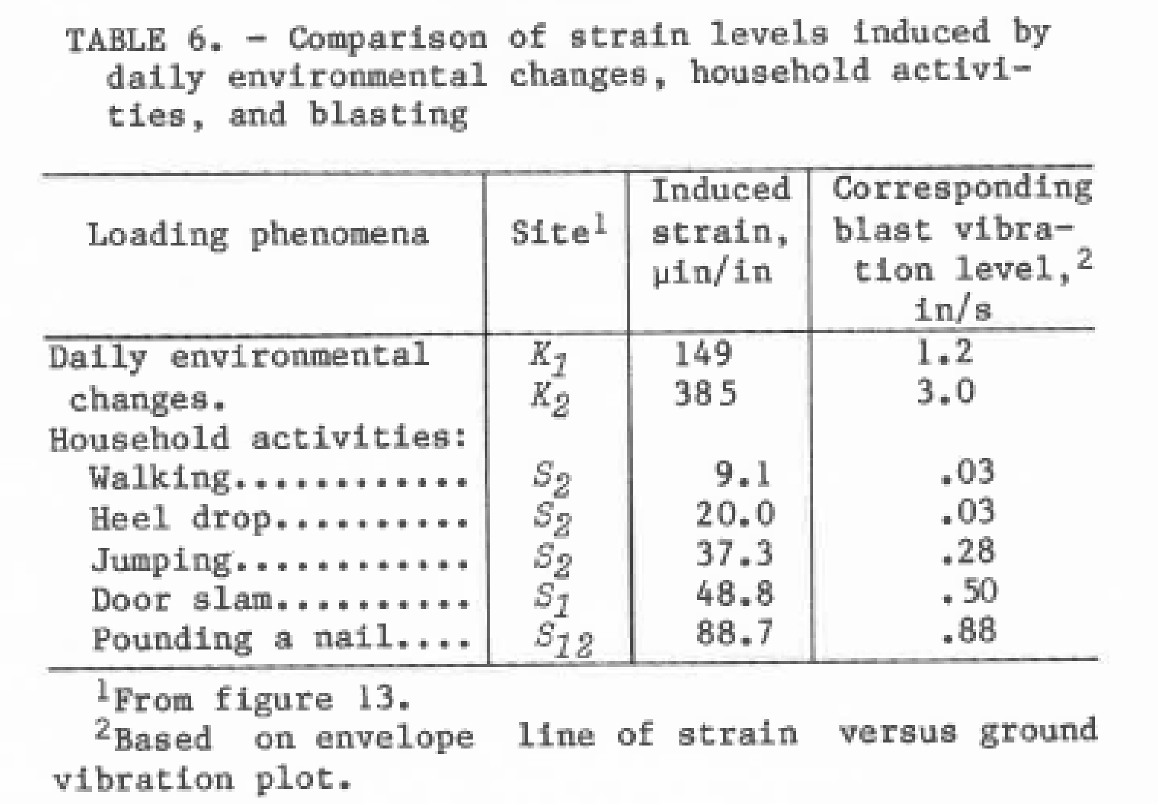
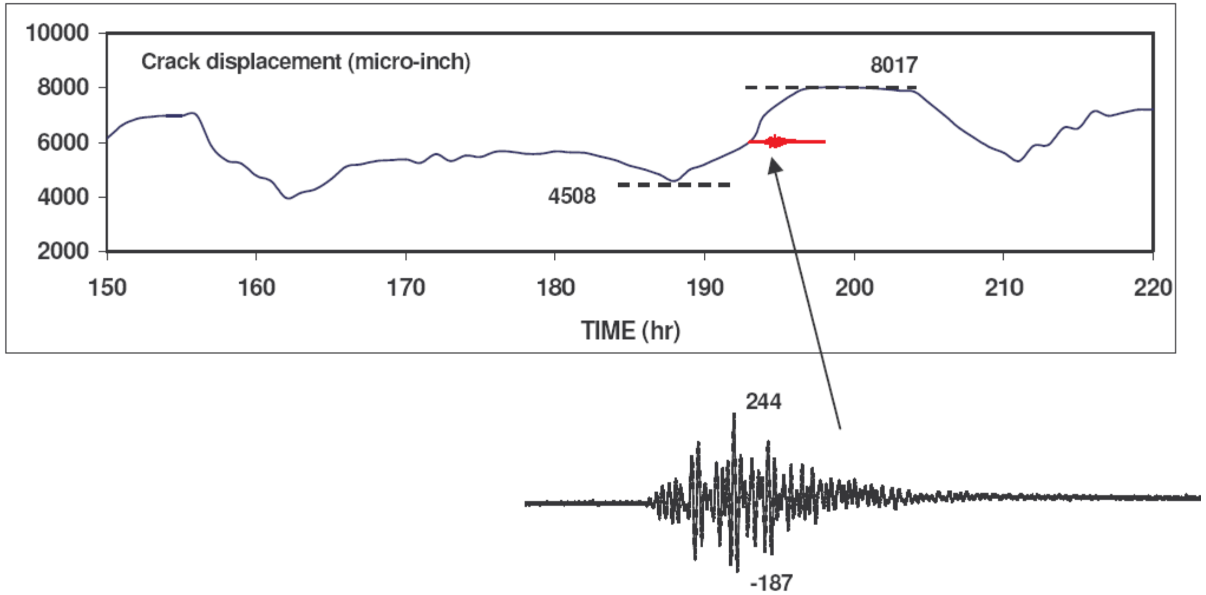


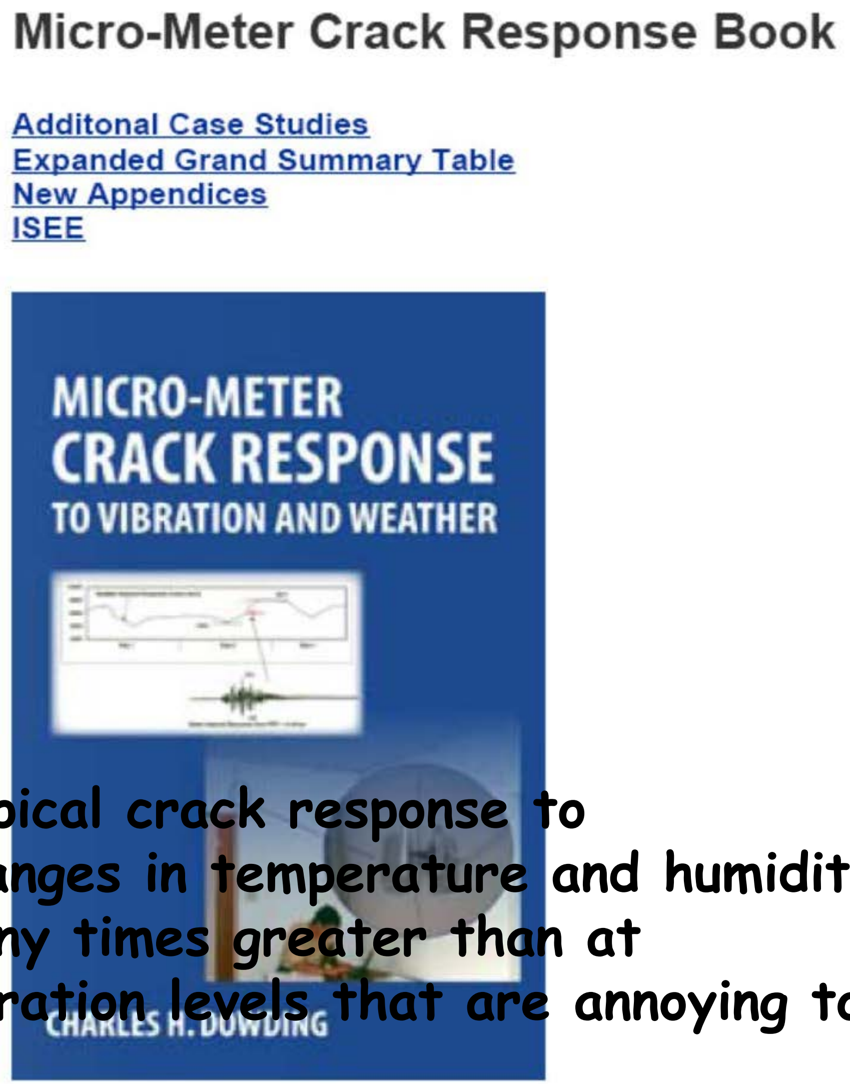
TABLE 6. – Comparison of strain levels induced by daily environmental changes, household activities, and blasting

Loading phenomena	Site[1]	Induced strain, μin/in	Corresponding blast vibration level,[2] in/s
Daily environmental changes.	K_1	149	1.2
	K_2	385	3.0
Household activities:			
Walking..........	S_2	9.1	.03
Heel drop..........	S_2	20.0	.03
Jumping..........	S_2	37.3	.28
Door slam..........	S_1	48.8	.50
Pounding a nail....	S_{12}	88.7	.88

[1] From figure 13.

[2] Based on envelope line of strain versus ground vibration plot.



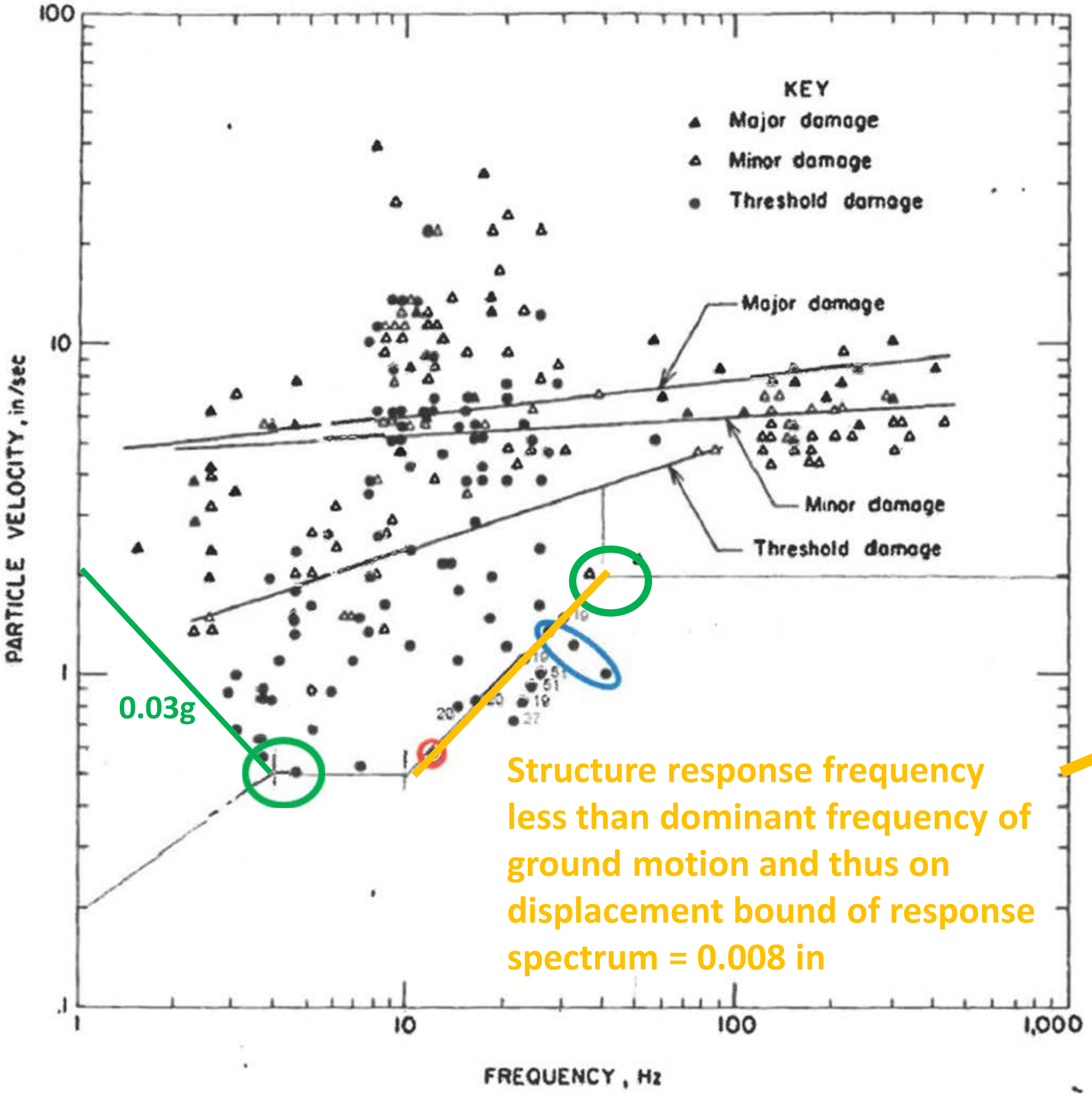


Micro-Meter Crack Response Book

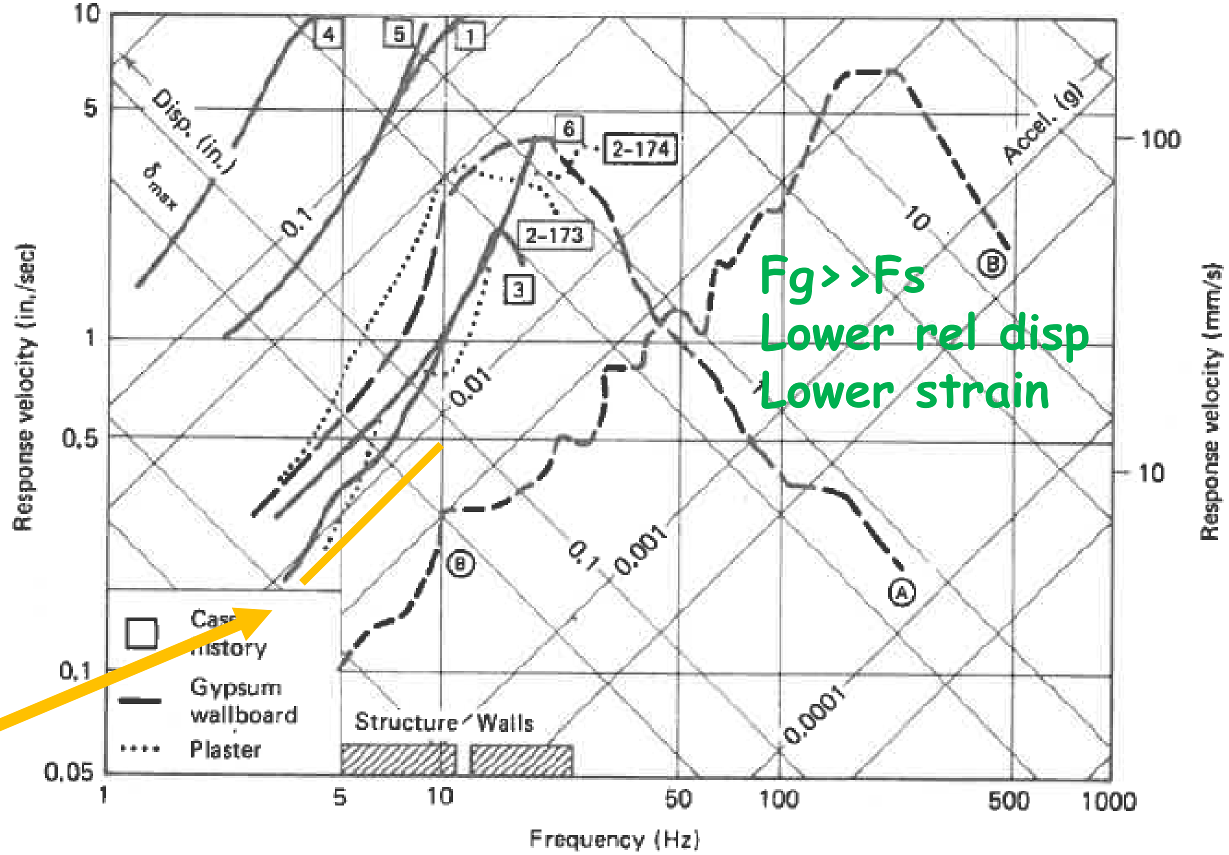
- Additonal Case Studies
- Expanded Grand Summary Table
- New Appendices
- ISEE

Typical crack response to changes in temperature and humidity are many times greater than at vibration levels that are annoying to humans

3) The Z curve integrates structural dynamics principles with the control of blast induced ground motions to prevent cosmetic cracking.



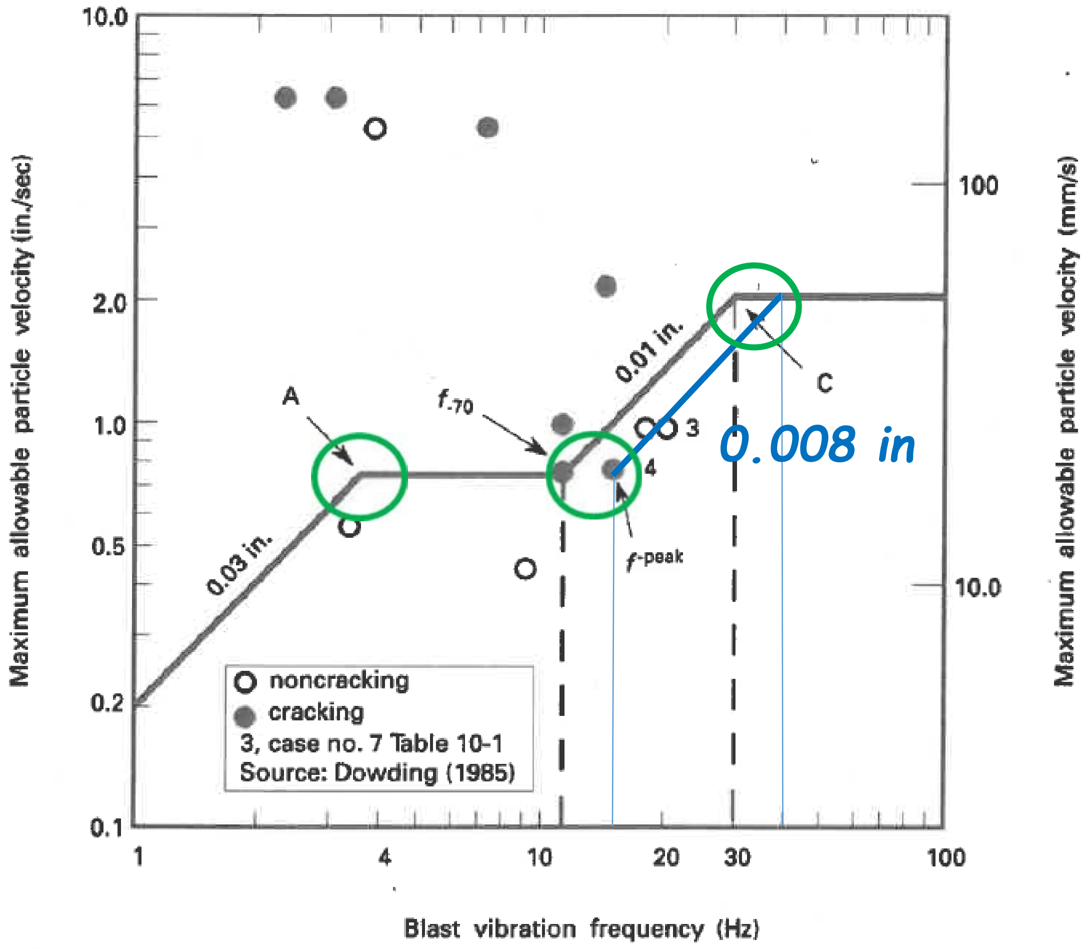
Structure response frequency less than dominant frequency of ground motion and thus on displacement bound of response spectrum = 0.008 in



Fg>>Fs
Lower rel disp
Lower strain

Figure 9-13 Difference between spectra of cracking bounds and high- and low-frequency motions.

2) Dominant frequency for development of the Z curve was based upon data presented in Figure 54 and Figure 10-2 in CV



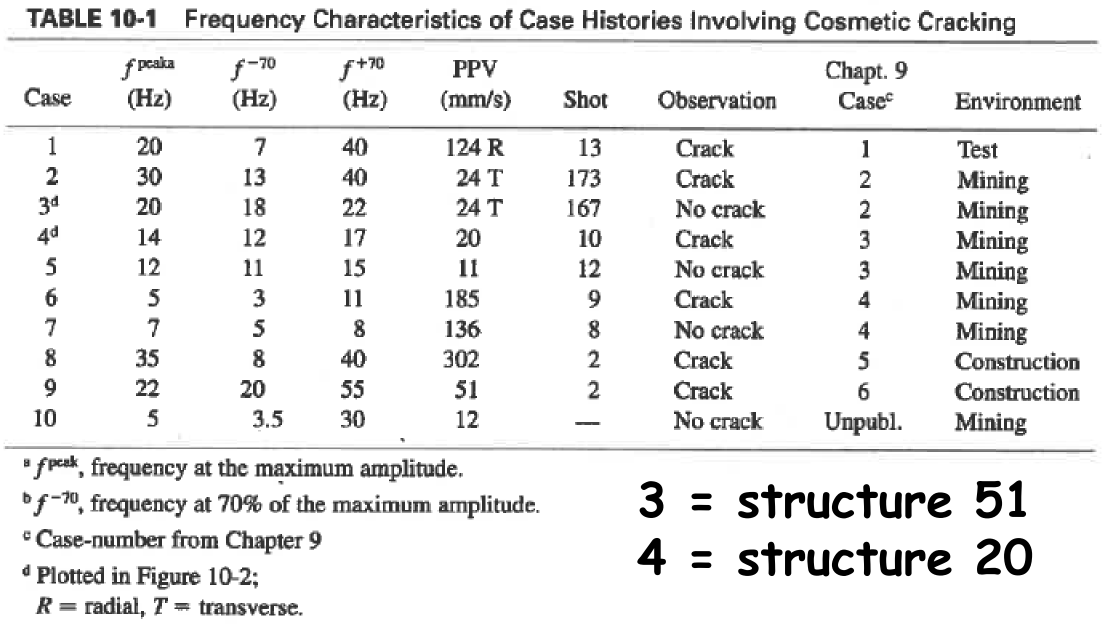


TABLE 10-1 Frequency Characteristics of Case Histories Involving Cosmetic Cracking

Case	$f^{peak a}$ (Hz)	f^{-70} (Hz)	f^{+70} (Hz)	PPV (mm/s)	Shot	Observation	Chapt. 9 Case[c]	Environment
1	20	7	40	124 R	13	Crack	1	Test
2	30	13	40	24 T	173	Crack	2	Mining
3[d]	20	18	22	24 T	167	No crack	2	Mining
4[d]	14	12	17	20	10	Crack	3	Mining
5	12	11	15	11	12	No crack	3	Mining
6	5	3	11	185	9	Crack	4	Mining
7	7	5	8	136	8	No crack	4	Mining
8	35	8	40	302	2	Crack	5	Construction
9	22	20	55	51	2	Crack	6	Construction
10	5	3.5	30	12	—	No crack	Unpubl.	Mining

[a] f^{peak}, frequency at the maximum amplitude.

[b] f^{-70}, frequency at 70% of the maximum amplitude.

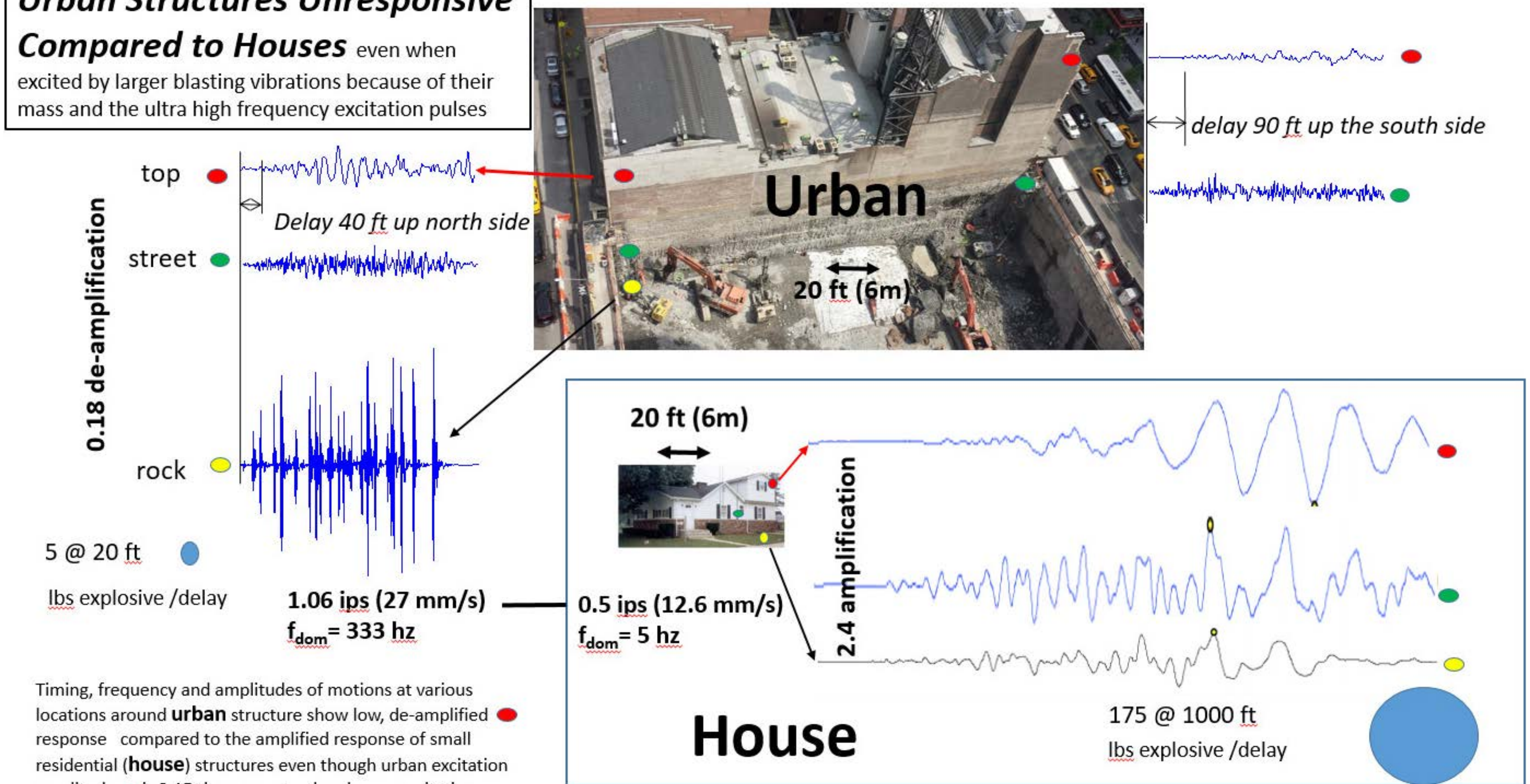
[c] Case-number from Chapter 9

[d] Plotted in Figure 10-2;
R = radial, T = transverse.

3 = structure 51
4 = structure 20

1) To extend 8507 experience beyond residential structures measurement of velocity time histories can be supplemented with calculation of response spectra and strain from measured structure velocity response

Urban Structures Unresponsive Compared to Houses even when excited by larger blasting vibrations because of their mass and the ultra high frequency excitation pulses

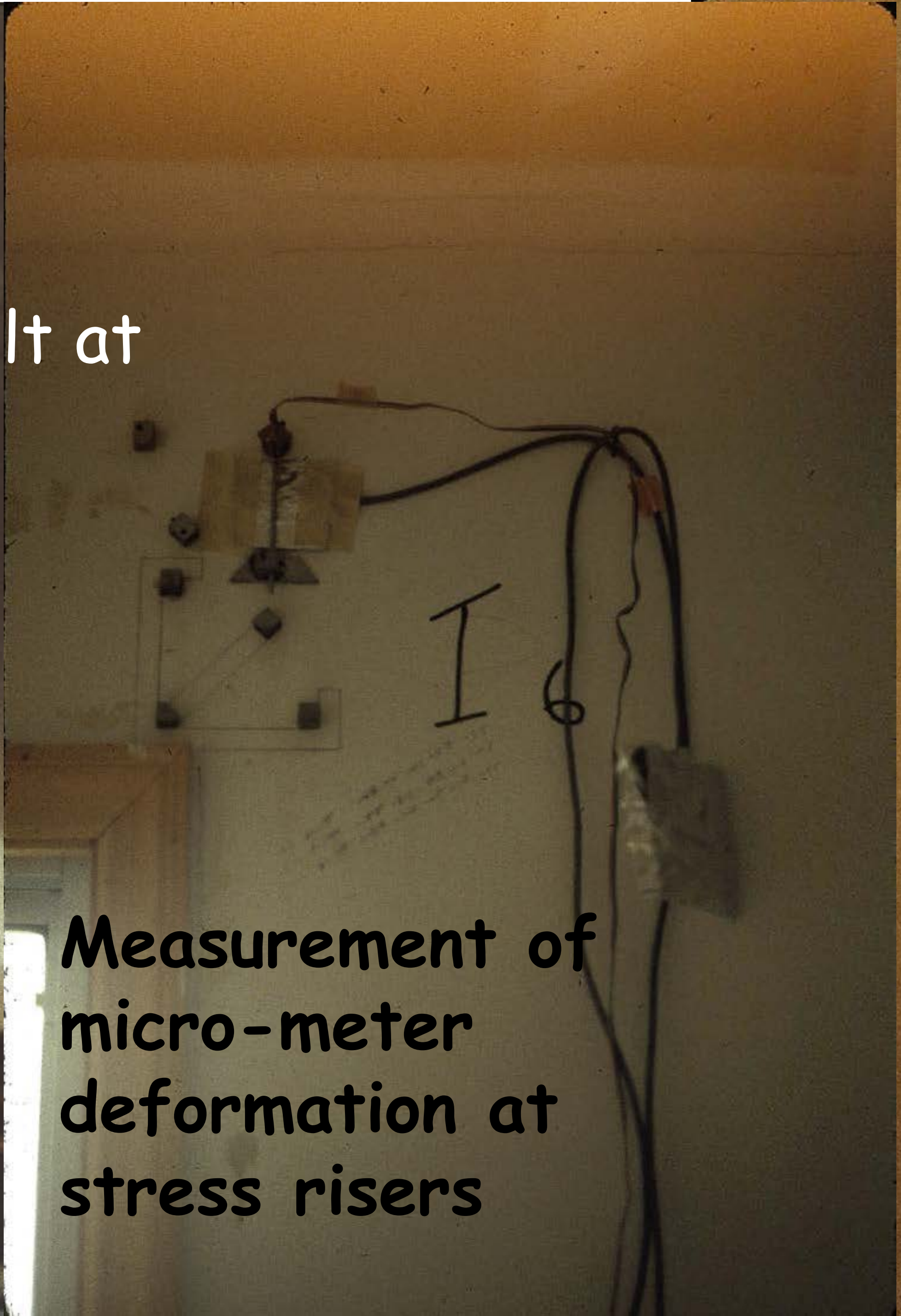


Timing, frequency and amplitudes of motions at various locations around **urban** structure show low, de-amplified ● response compared to the amplified response of small residential (**house**) structures even though urban excitation

RI 8896 Test House
companion document to 8507

Addresses cracking
from multiple events and
of stronger materials
first use of micrometer
crack response

Instrumentation difficult at dawn of digital age



Measurement of micro-meter deformation at stress risers

Lower level of threshold of cosmetic cracking plaster popping over nail heads

5) Micro-inch response of cracks to weather and occupant activity are larger than typical blast excitation

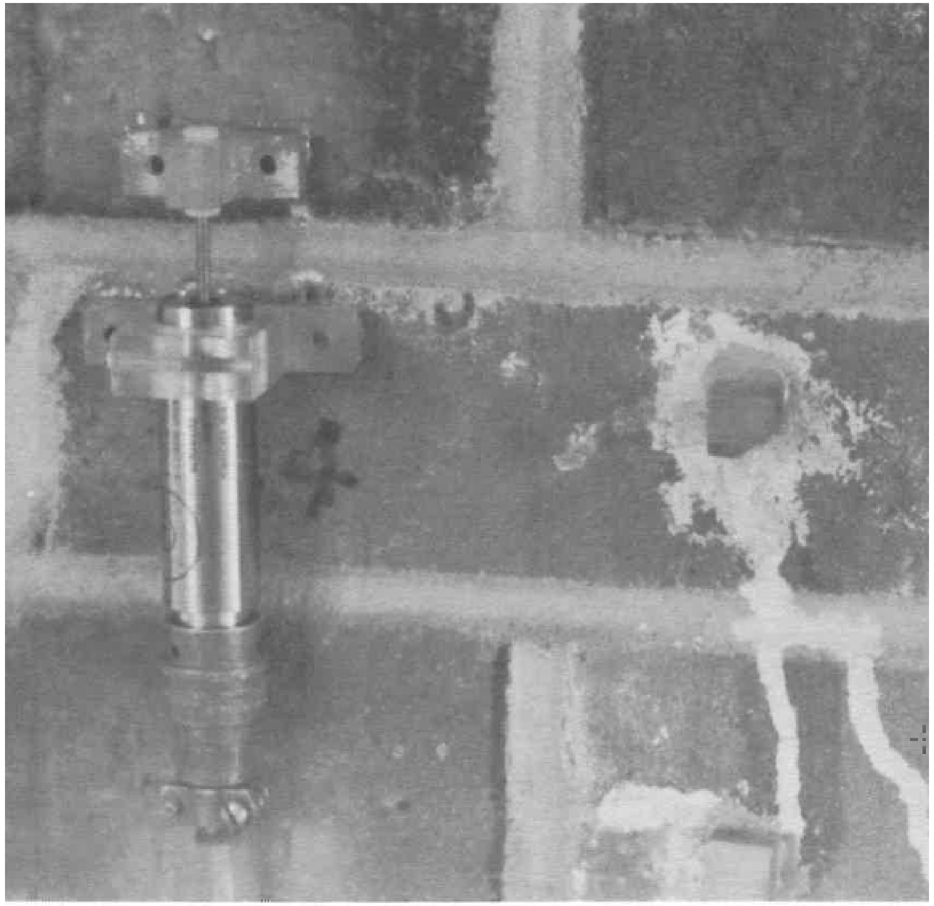


FIGURE 20. - LVDT.

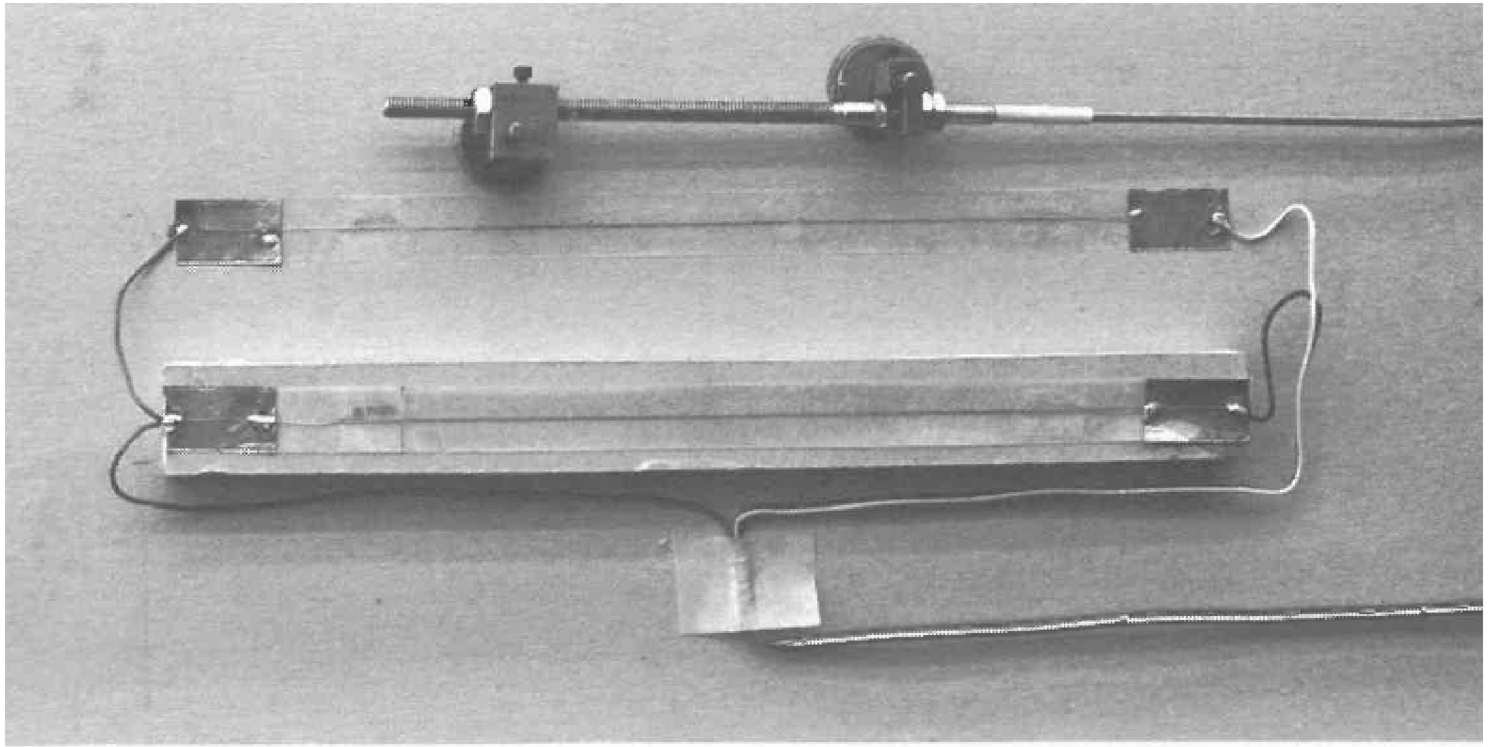


FIGURE 19. - Kaman displacement system (top) and 124-mm strain gauge.

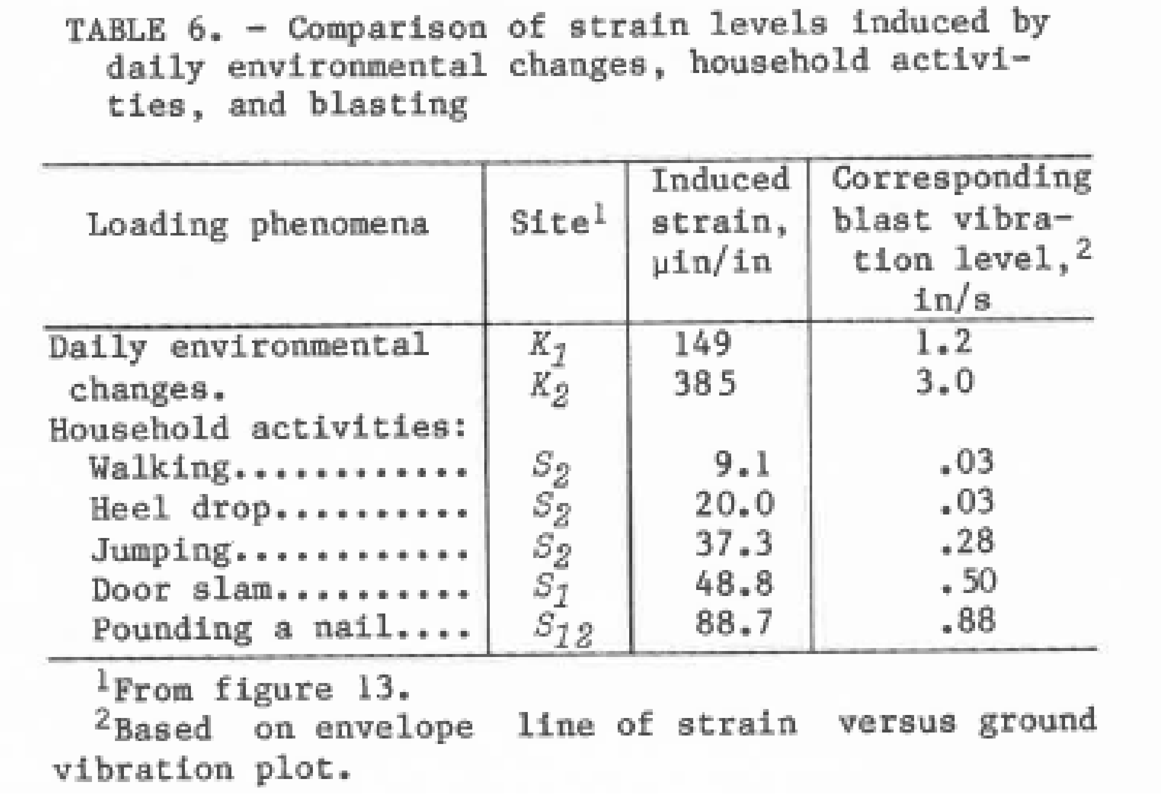
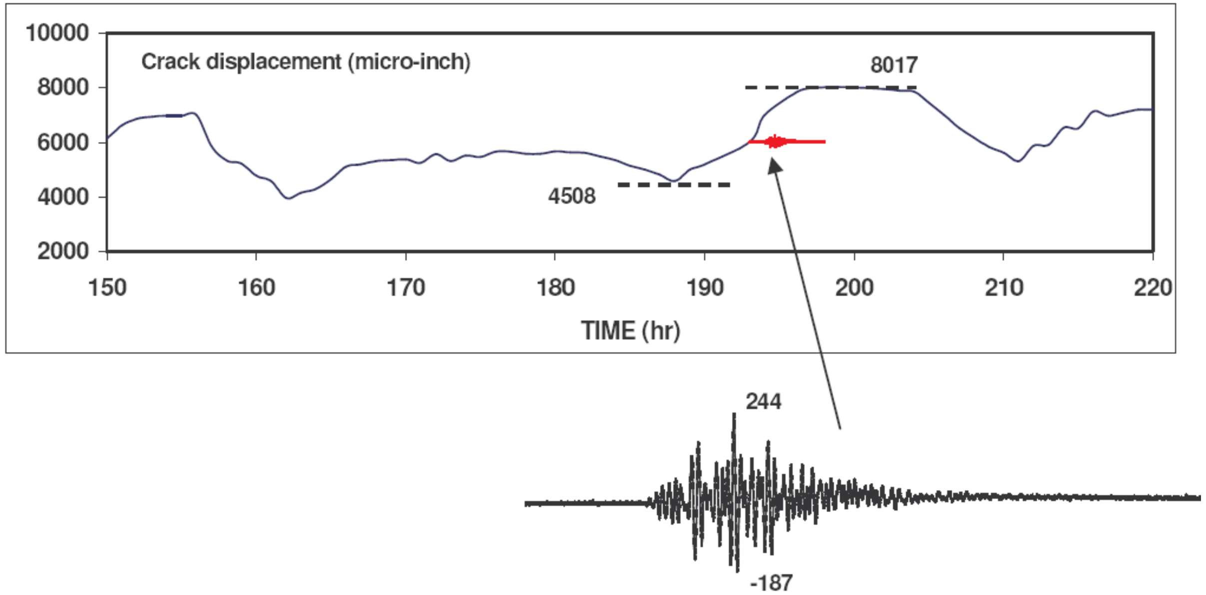


TABLE 6. - Comparison of strain levels induced by daily environmental changes, household activities, and blasting

Loading phenomena	Site[1]	Induced strain, µin/in	Corresponding blast vibration level,[2] in/s
Daily environmental changes.	K_1	149	1.2
	K_2	385	3.0
Household activities:			
Walking...........	S_2	9.1	.03
Heel drop.........	S_2	20.0	.03
Jumping...........	S_2	37.3	.28
Door slam.........	S_1	48.8	.50
Pounding a nail....	S_{12}	88.7	.88

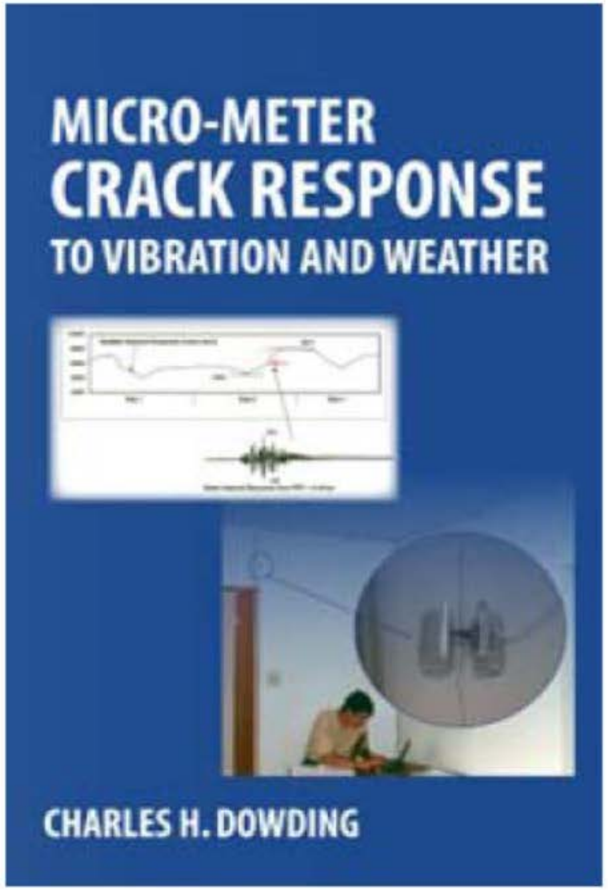
[1] From figure 13.

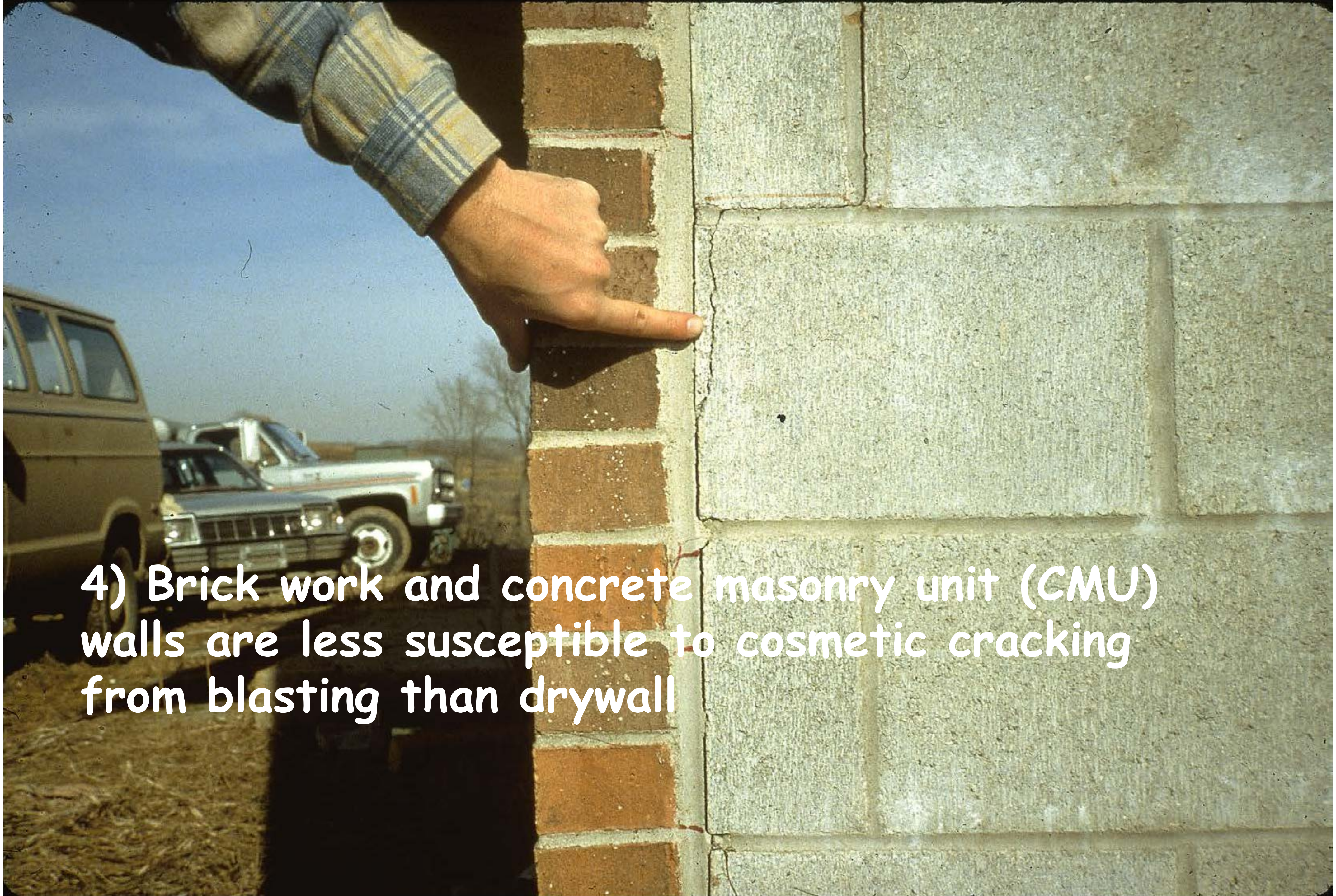
[2] Based on envelope line of strain versus ground vibration plot.



Micro-Meter Crack Response Book

- Additonal Case Studies
- Expanded Grand Summary Table
- New Appendices
- ISEE





4) Brick work and concrete masonry unit (CMU) walls are less susceptible to cosmetic cracking from blasting than drywall

3) Thus engineered structures are stronger

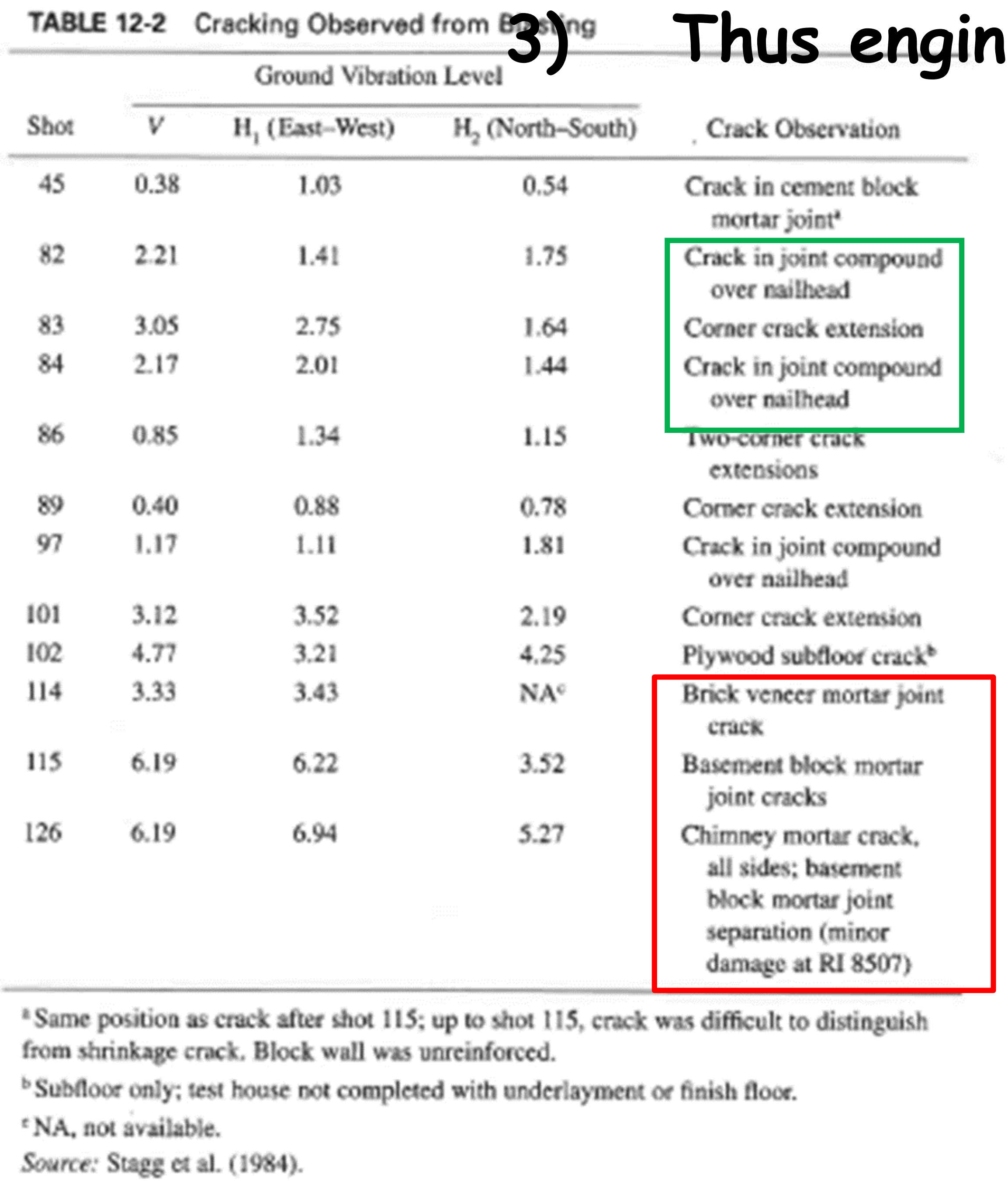


TABLE 12-2 Cracking Observed from Blasting

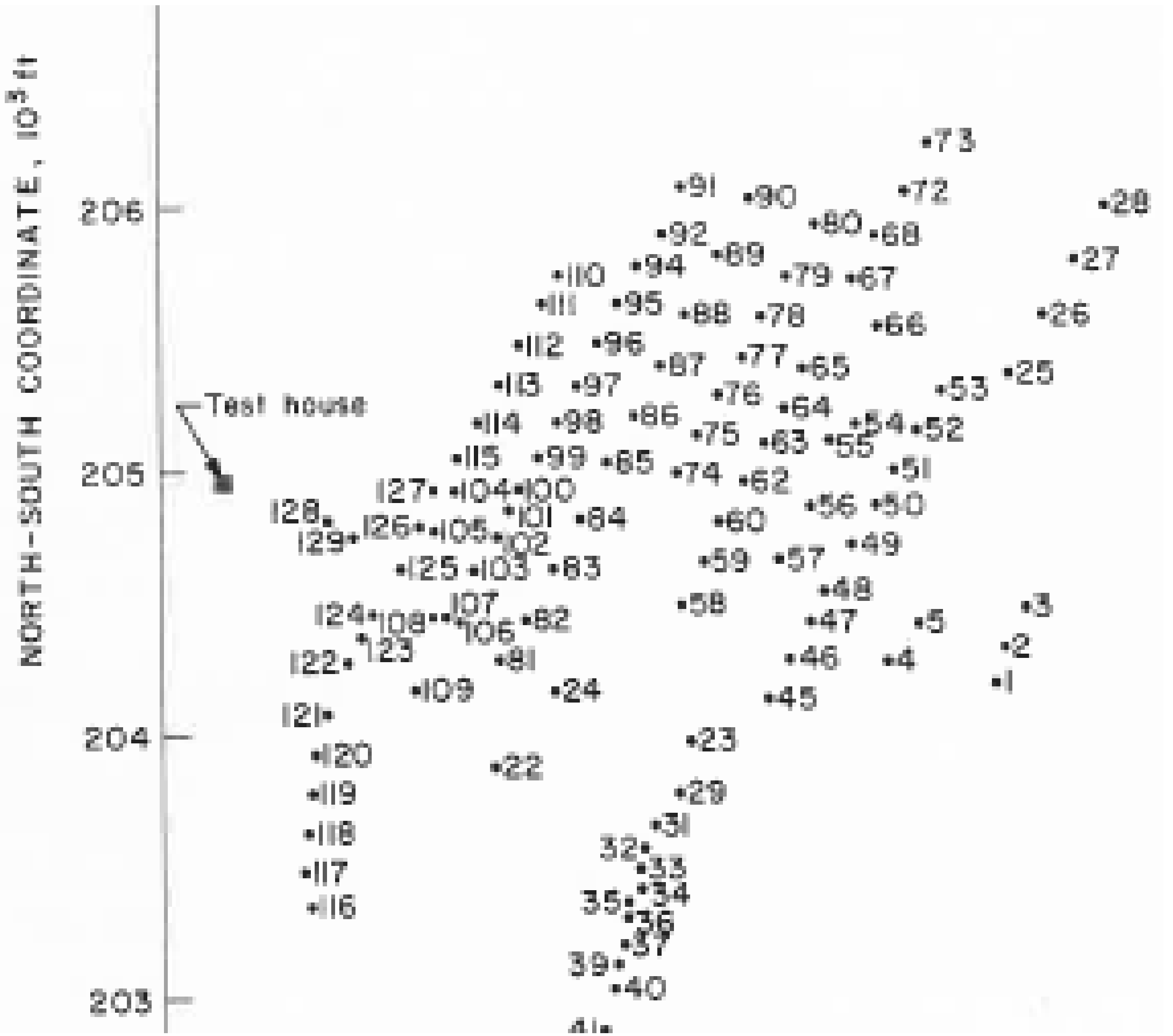
Shot	Ground Vibration Level			Crack Observation
	V	H_1 (East–West)	H_2 (North–South)	
45	0.38	1.03	0.54	Crack in cement block mortar joint[a]
82	2.21	1.41	1.75	Crack in joint compound over nailhead
83	3.05	2.75	1.64	Corner crack extension
84	2.17	2.01	1.44	Crack in joint compound over nailhead
86	0.85	1.34	1.15	Two-corner crack extensions
89	0.40	0.88	0.78	Corner crack extension
97	1.17	1.11	1.81	Crack in joint compound over nailhead
101	3.12	3.52	2.19	Corner crack extension
102	4.77	3.21	4.25	Plywood subfloor crack[b]
114	3.33	3.43	NA[c]	Brick veneer mortar joint crack
115	6.19	6.22	3.52	Basement block mortar joint cracks
126	6.19	6.94	5.27	Chimney mortar crack, all sides; basement block mortar joint separation (minor damage at RI 8507)

[a] Same position as crack after shot 115; up to shot 115, crack was difficult to distinguish from shrinkage crack. Block wall was unreinforced.

[b] Subfloor only; test house not completed with underlayment or finish floor.

[c] NA, not available.

Source: Stagg et al. (1984).



2) NBS tests confirm the high strain resistance of CMU walls

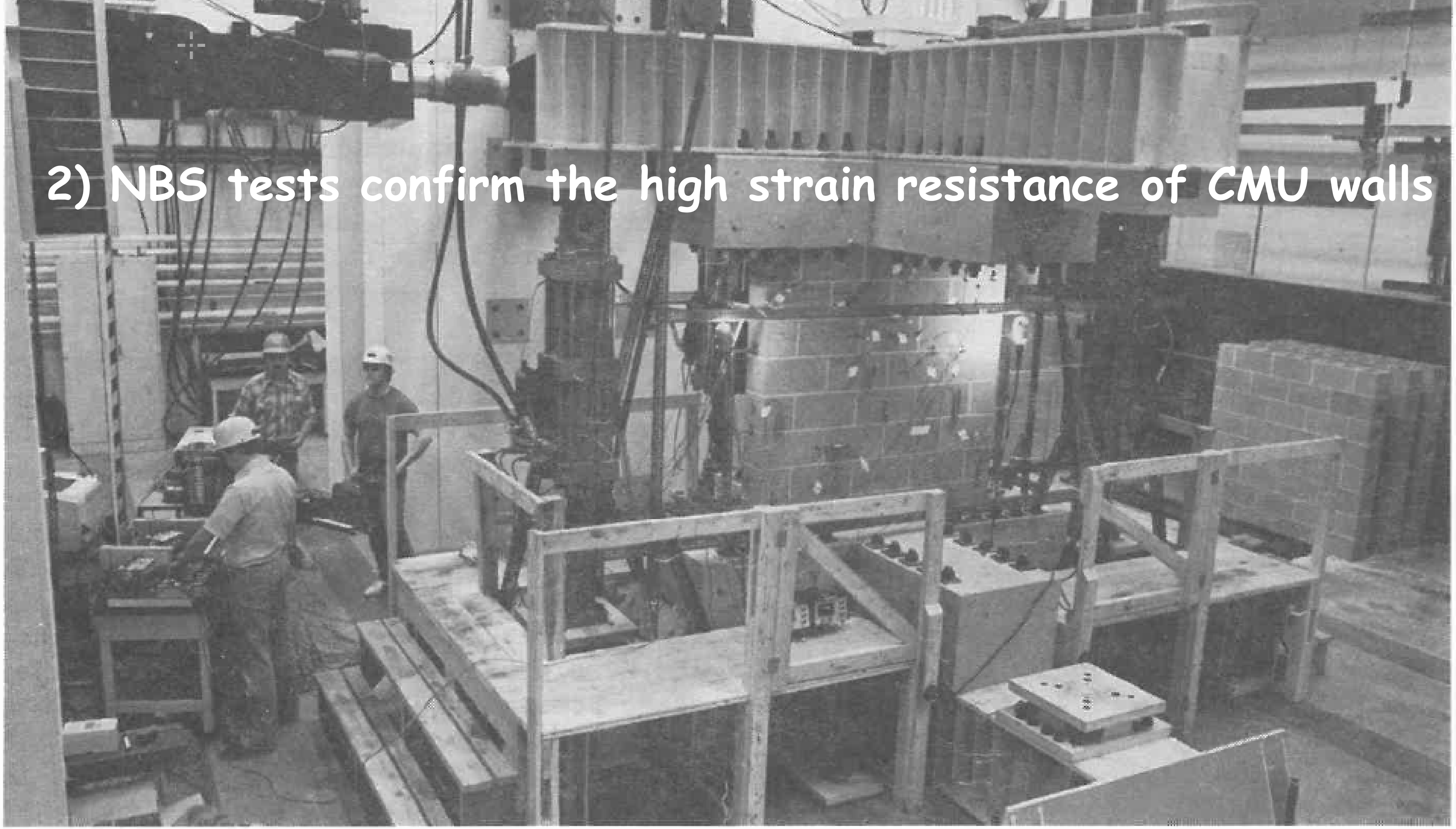


FIGURE A-11. - In-place 5- by 5-ft masonry block wall at NBS Tridirectional Test Facility.

Deep dive into low frequency excitation leads to Discussion of the meaning of CMU response to cyclic shearing

United States Department of the Interior

BUREAU OF MINES
Twin Cities Research Center
5629 Minnehaha Avenue South
Minneapolis, MN 55417-3099

November 9, 1993

Ken Eltschlager
OSMRE
Ten Parkway Center
Pittsburgh, PA 15220

Dear Ken:

Along with Willard Pierce and Mark Stagg, I have reviewed the latest version of Vince Chiarito's report, dated Sept. 1993. The report appears to have some major inconsitancies. I also have a serious problem with paragraph 93 in the conclusions which states that mortar joint cracks are expected in the impacted communities (P.95). The analysis upon which this is based is a misinterpretation of Stagg's data on masonry strain, cracking, and associated vibration amplitudes. I also believe your worst case vibration amplitude scenario is being carelessly applied and the numbers themselves may be unrealistic.

Concerning the strains, there are two problems: 1) strains associated with cracking and identification of whether they are global or local strains and 2) vibration amplitudes associated with specific strains.

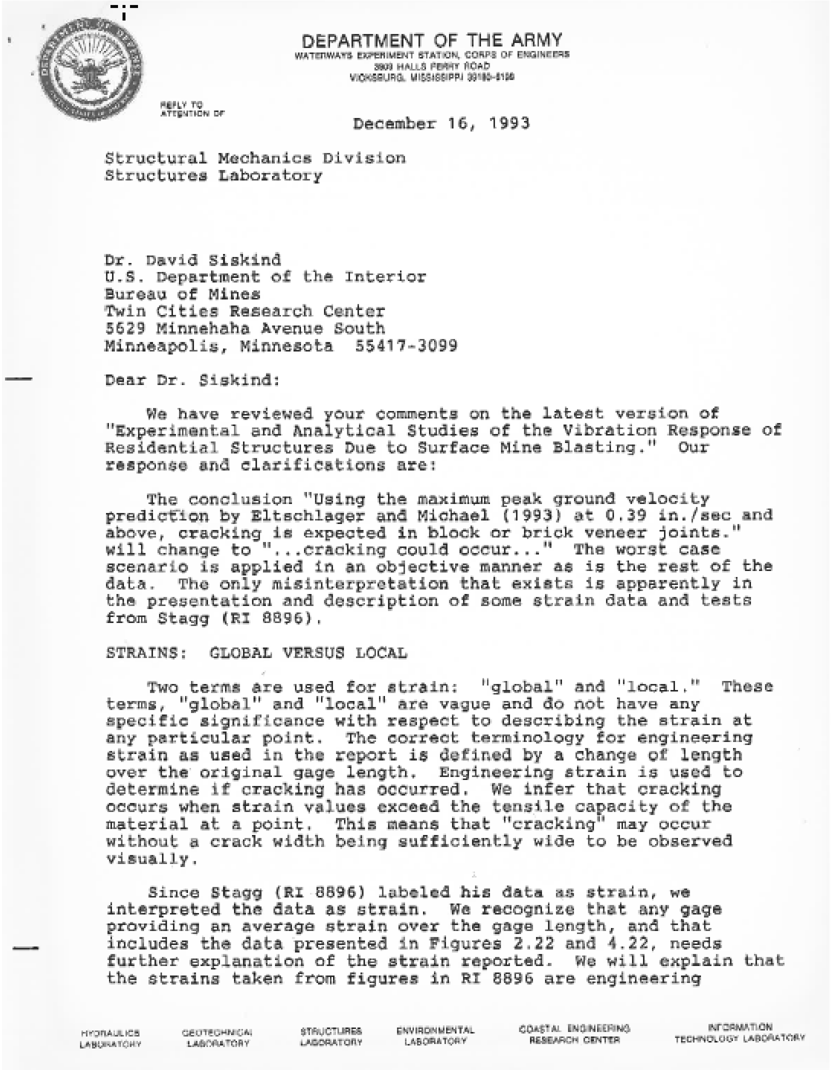
STRAINS: GLOBAL VERSUS LOCAL:

Chiarito uses selected strain values from Stagg's figures 35-37 (RI 8896) in his figures 2.22 and 4.22 and associated them with both threshold cracking and specific vibration amplitudes. In discussion with Stagg, he regrets labeling these "strains" when some are actually displacements between already-separated block segments. The coarse texture in the mortar made hairline joints difficult to see and, more importantly, it was impossible to differentiate between drying surface cracks in the mortar and true separations. Only in the wall section tests with NBS was it possible to constantly monitor load and accurately determine global strains at failure. The general frustration of trying to differentiate between structural and non-structural hairline cracks led to Stagg adopting a crack-width criteria with corresponding local strains of 770-7700$\mu\epsilon$ (P.50). All Stagg's strain values for the test house are local strains.

From Stagg's and Woodward's reports, I offer the following 5 items concerning strains and cracking from the NBS tests:

1. Load-controlled test at NBS showed an inflection point at about .013-in wall displacement, or 100$\mu\epsilon$, suggesting the beginning of

---



DEPARTMENT OF THE ARMY
WATERWAYS EXPERIMENT STATION, CORPS OF ENGINEERS
3909 HALLS FERRY ROAD
VICKSBURG, MISSISSIPPI 39180-6199

REPLY TO
ATTENTION OF

December 16, 1993

Structural Mechanics Division
Structures Laboratory

Dr. David Siskind
U.S. Department of the Interior
Bureau of Mines
Twin Cities Research Center
5629 Minnehaha Avenue South
Minneapolis, Minnesota 55417-3099

Dear Dr. Siskind:

We have reviewed your comments on the latest version of "Experimental and Analytical Studies of the Vibration Response of Residential Structures Due to Surface Mine Blasting." Our response and clarifications are:

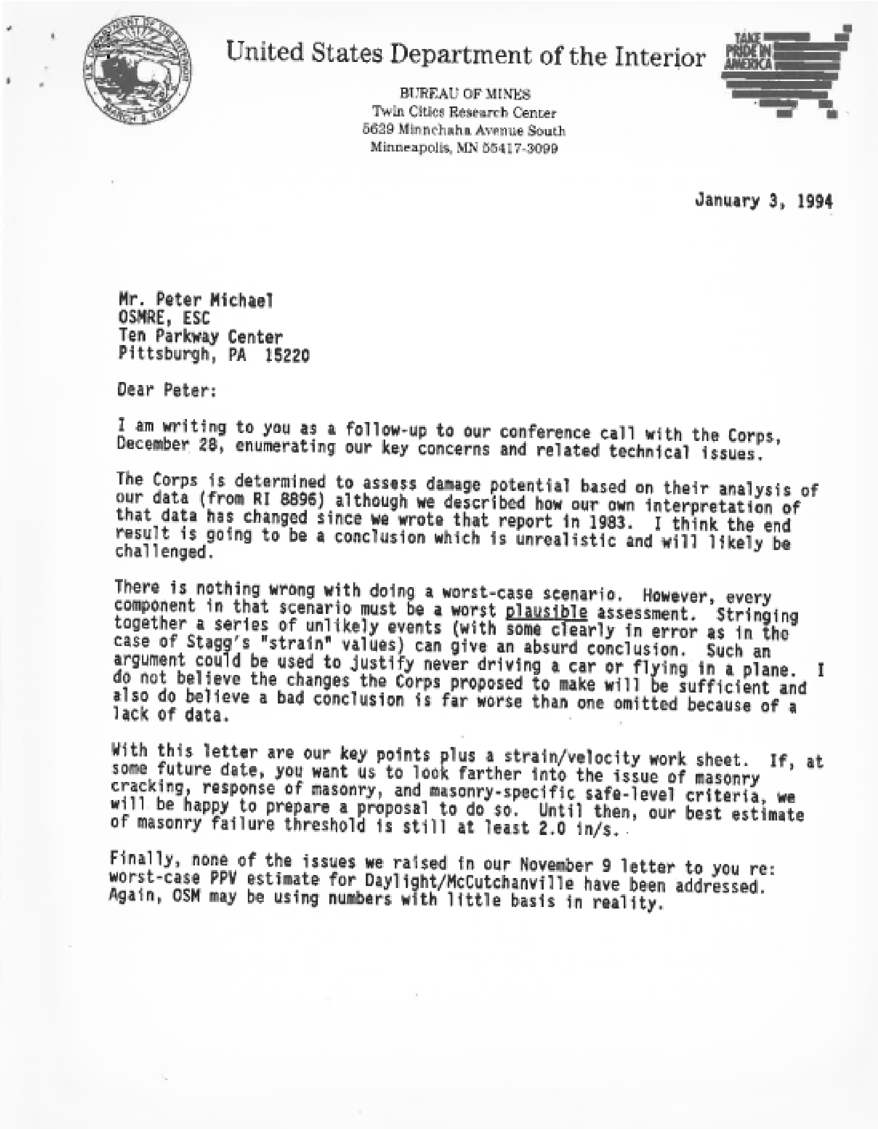
The conclusion "Using the maximum peak ground velocity prediction by Eltschlager and Michael (1993) at 0.39 in./sec and above, cracking is expected in block or brick veneer joints." will change to "...cracking could occur..." The worst case scenario is applied in an objective manner as is the rest of the data. The only misinterpretation that exists is apparently in the presentation and description of some strain data and tests from Stagg (RI 8896).

STRAINS: GLOBAL VERSUS LOCAL

Two terms are used for strain: "global" and "local." These terms, "global" and "local" are vague and do not have any specific significance with respect to describing the strain at any particular point. The correct terminology for engineering strain as used in the report is defined by a change of length over the original gage length. Engineering strain is used to determine if cracking has occurred. We infer that cracking occurs when strain values exceed the tensile capacity of the material at a point. This means that "cracking" may occur without a crack width being sufficiently wide to be observed visually.

Since Stagg (RI 8896) labeled his data as strain, we interpreted the data as strain. We recognize that any gage providing an average strain over the gage length, and that includes the data presented in Figures 2.22 and 4.22, needs further explanation of the strain reported. We will explain that the strains taken from figures in RI 8896 are engineering

---



United States Department of the Interior

BUREAU OF MINES
Twin Cities Research Center
5629 Minnehaha Avenue South
Minneapolis, MN 55417-3099

January 3, 1994

Mr. Peter Michael
OSMRE, ESC
Ten Parkway Center
Pittsburgh, PA 15220

Dear Peter:

I am writing to you as a follow-up to our conference call with the Corps, December 28, enumerating our key concerns and related technical issues.

The Corps is determined to assess damage potential based on their analysis of our data (from RI 8896) although we described how our own interpretation of that data has changed since we wrote that report in 1983. I think the end result is going to be a conclusion which is unrealistic and will likely be challenged.

There is nothing wrong with doing a worst-case scenario. However, every component in that scenario must be a worst plausible assessment. Stringing together a series of unlikely events (with some clearly in error as in the case of Stagg's "strain" values) can give an absurd conclusion. Such an argument could be used to justify never driving a car or flying in a plane. I do not believe the changes the Corps proposed to make will be sufficient and also do believe a bad conclusion is far worse than one omitted because of a lack of data.

With this letter are our key points plus a strain/velocity work sheet. If, at some future date, you want us to look farther into the issue of masonry cracking, response of masonry, and masonry-specific safe-level criteria, we will be happy to prepare a proposal to do so. Until then, our best estimate of masonry failure threshold is still at least 2.0 in/s.

Finally, none of the issues we raised in our November 9 letter to you re: worst-case PPV estimate for Daylight/McCutchanville have been addressed. Again, OSM may be using numbers with little basis in reality.

Lateral displacement of top of 64 inch high CMU wall

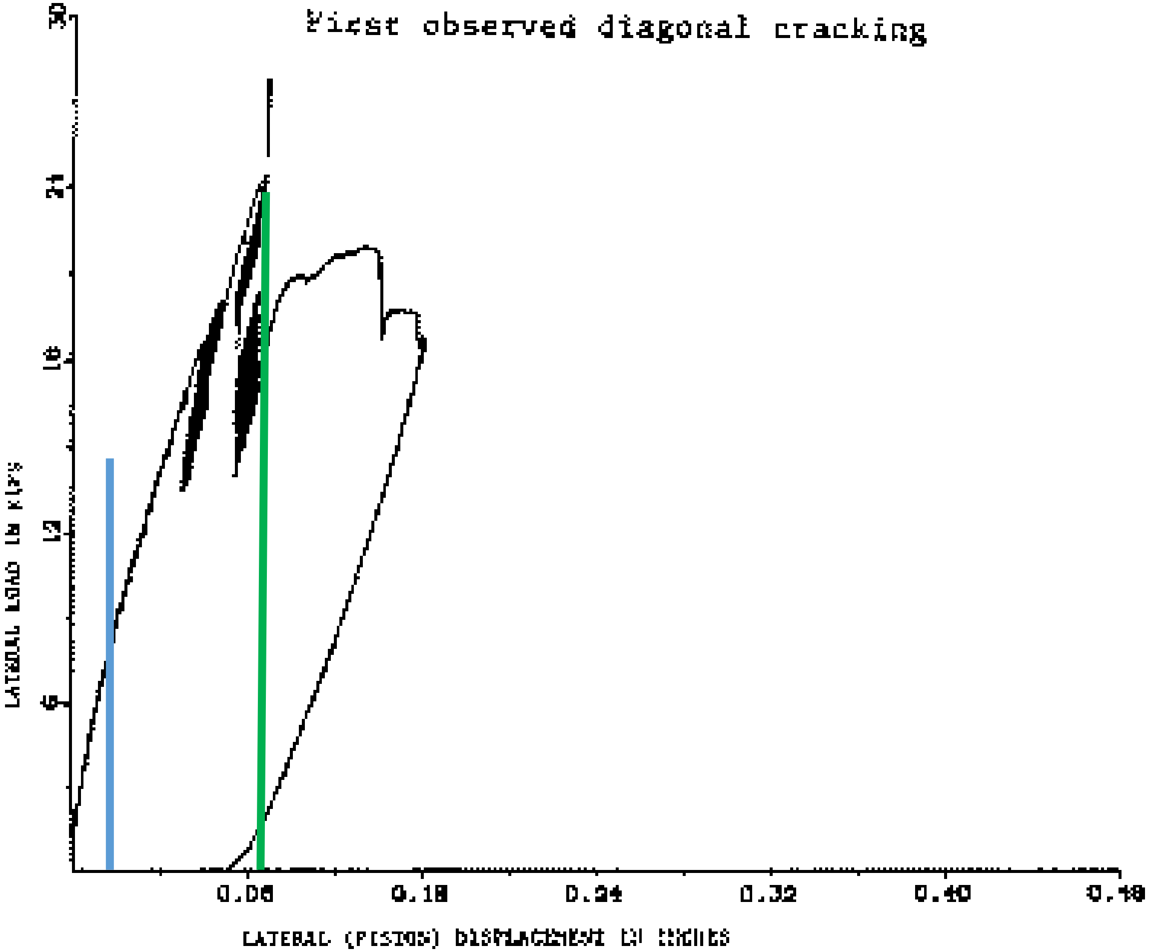
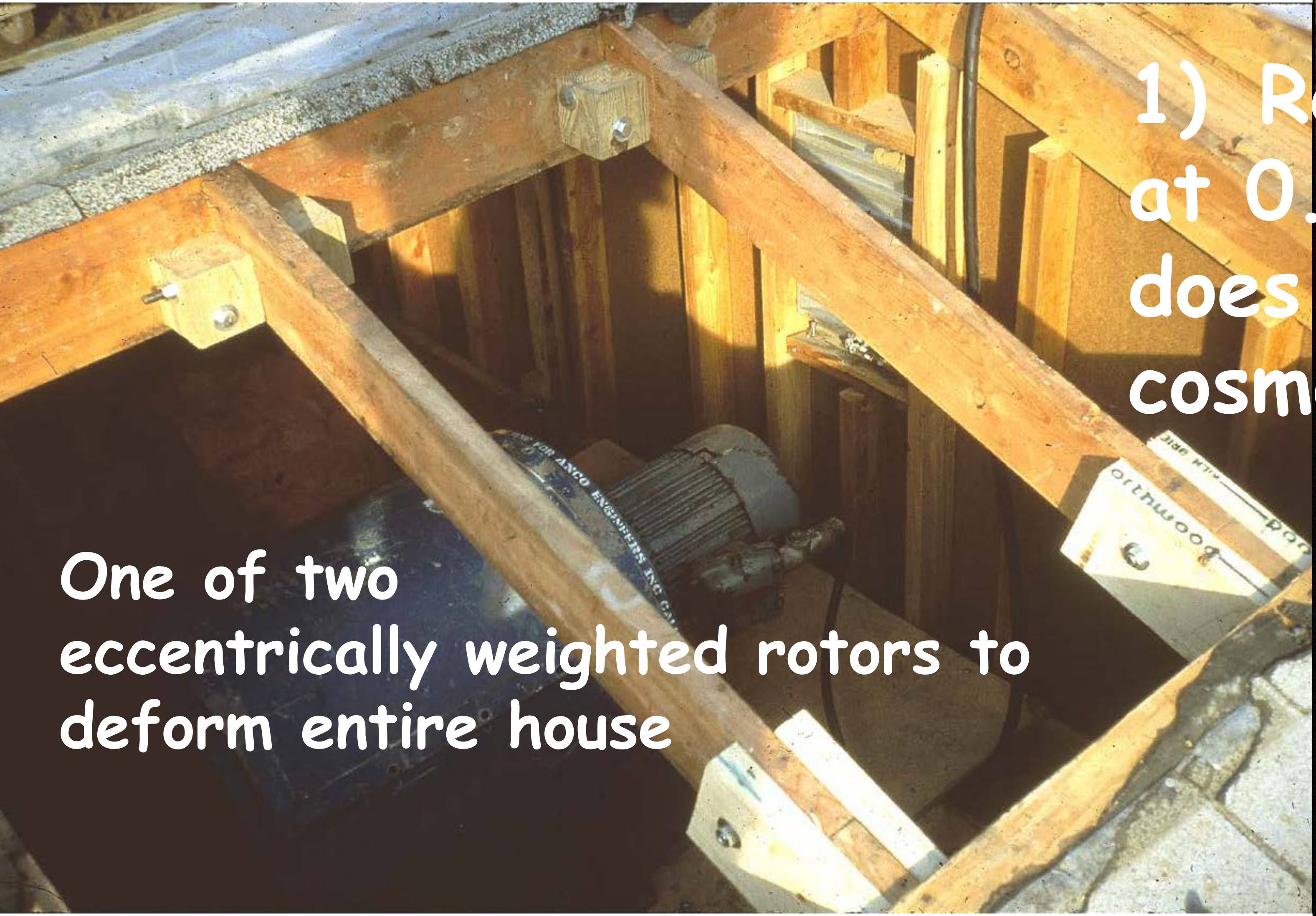


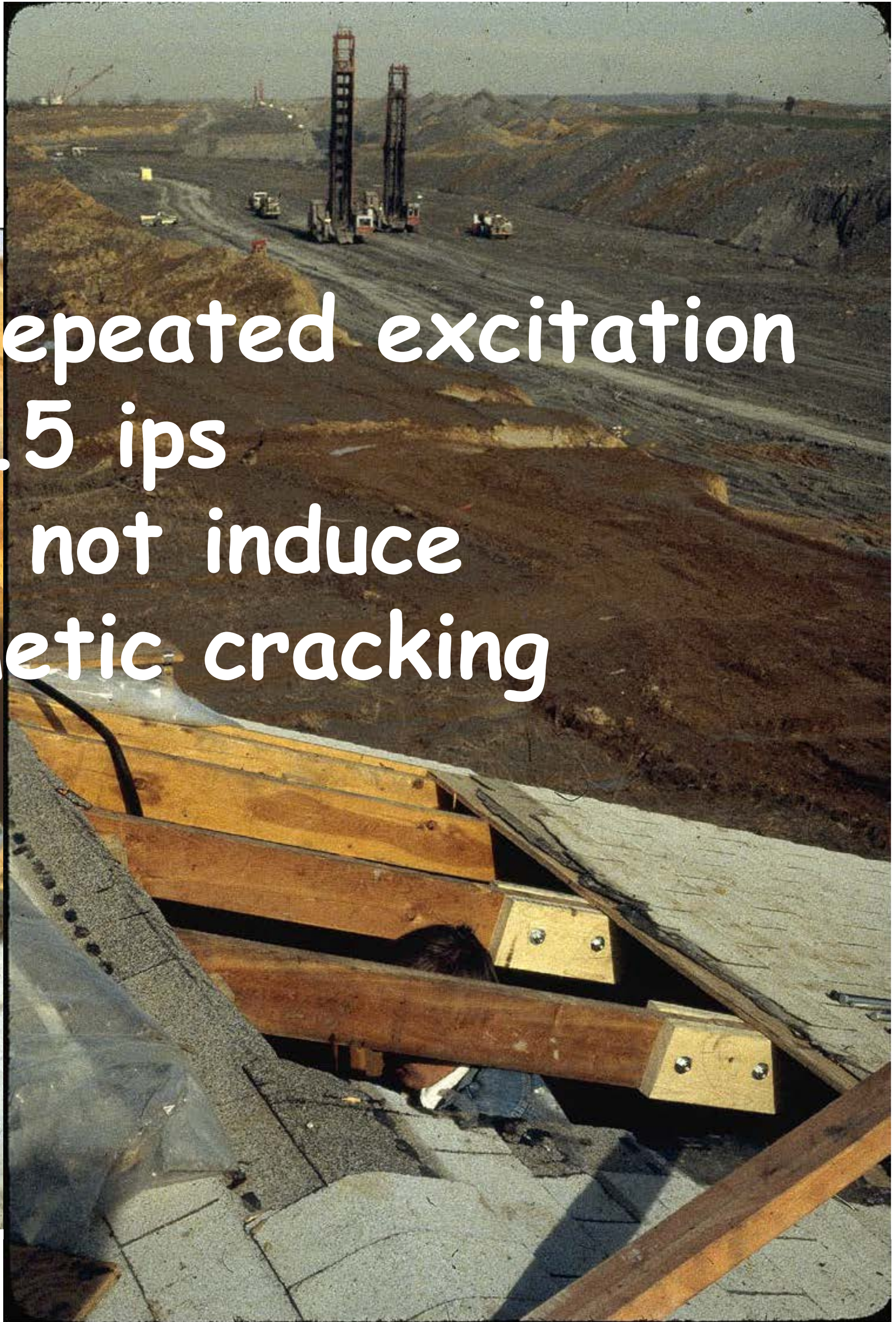
Figure 7.9. Load displacement curve for test P1

Siskind Conservative interpretation
Δy = 0.013 in =>
“global” shear strain, ʎ, = Δy/H =
0.013/64 = 0.000200 = 200μʎ
with no visible cracking
only slight change elastic behavior

CMU could withstand global shear strain of 1000 μʎ,
cycle 100,000 times
increase the load (follows same slope => elastic)
To reach ~ 1300 μʎ
before cyclic loading would produce a diagonal crack



One of two eccentrically weighted rotors to deform entire house



1) Repeated excitation at 0.5 ips does not induce cosmetic cracking

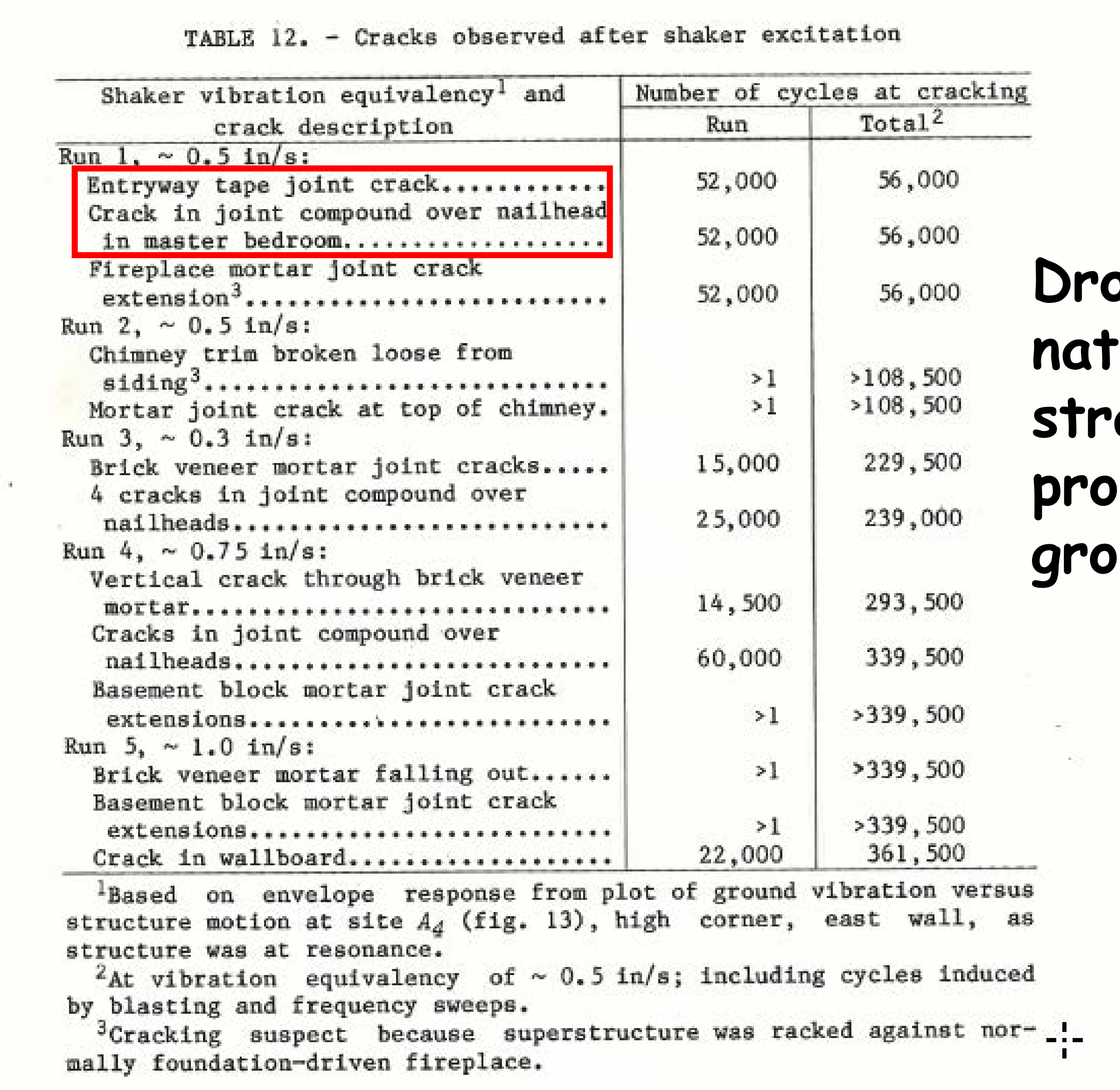


TABLE 12. - Cracks observed after shaker excitation

Shaker vibration equivalency[1] and crack description	Number of cycles at cracking	
	Run	Total[2]
Run 1, ~ 0.5 in/s:		
Entryway tape joint crack............	52,000	56,000
Crack in joint compound over nailhead in master bedroom..................	52,000	56,000
Fireplace mortar joint crack extension[3]..........................	52,000	56,000
Run 2, ~ 0.5 in/s:		
Chimney trim broken loose from siding[3]............................	>1	>108,500
Mortar joint crack at top of chimney.	>1	>108,500
Run 3, ~ 0.3 in/s:		
Brick veneer mortar joint cracks.....	15,000	229,500
4 cracks in joint compound over nailheads...........................	25,000	239,000
Run 4, ~ 0.75 in/s:		
Vertical crack through brick veneer mortar.............................	14,500	293,500
Cracks in joint compound over nailheads...........................	60,000	339,500
Basement block mortar joint crack extensions.........................	>1	>339,500
Run 5, ~ 1.0 in/s:		
Brick veneer mortar falling out......	>1	>339,500
Basement block mortar joint crack extensions.........................	>1	>339,500
Crack in wallboard..................	22,000	361,500

[1] Based on envelope response from plot of ground vibration versus structure motion at site A_4 (fig. 13), high corner, east wall, as structure was at resonance.

[2] At vibration equivalency of ~ 0.5 in/s; including cycles induced by blasting and frequency sweeps.

[3] Cracking suspect because superstructure was racked against normally foundation-driven fireplace.

Drove test house at its natural frequency (~ 7 hz) at strains (response) ~ those produced by ground motions at 0.5 ips