Table 1 Summary of construction types

Category	Structure type	Site	Designation	Structure	Wall height (in)	Wall thickness (in)	Overall house dimensions (ft x ft)	Maximum differential elevation (in)
pre-manufactured trailers	single wide	KY2	TS-KY2	no strapping	94	4	65 x 14	3.9
		IN	TS-IN	strapping	90	4	64 x 14	3.8
		AL	TS-AL	strapping	94	6	72 x 16	2.8
		OH	TS-OH	strapping	94	6	73 x 15	3.5
	single wide add-on	VA	TSA-VA	add-on	94	5	54 x 14	3.3
				original trailer	82	4	54 x 12	
		KY2	TSA-KY2	add-on	94	4	56 x 12	8.2
				original trailer	94	4	56 x 12	
	double wide	VW2	TD-WV2	center wall	94	6	64 x 28	2.4
		TN	TD-TN	center wall	104	4	74 x 28	1.8
		PA	TD-PA	basement	117	8	48 x 24	3.8
				first floor	84	4		
mine camp	single-story	AL	C1S-AL	first floor	86	8	50 x 27	4.0
		VA	C1S-VA	first floor	82	2	34 x 28	7.4
	two-story	KY1	C2S-KY1A	first floor	92	4	28 x 28	5.1
				second floor	92	4		
		KY1	C2S-KY1B	first floor	94	5.5	48 x 29	3.3
				second floor	94	5.5	29 x 16	
log	one-story	OH	L1S-OH	basement	91.6	9	38 x 23.5	3.7
				first floor	90.4	9		
		VW1	L1S-WV1	historic log cabin	78	12	24 x 26	5.9
	two-story	TN	L2S-TN	first floor	111.5	6.75	29 x 25	3.5
				second floor loft	93.5	6.75		
		OH	L2S-OH	first floor	great-wall 282 in. mid-wall at 144 in. from base	7	37 x 25	2.0
				second floor	82	7		
		WV2	L2S-WV2	west wall	94	8	46 x 30	2.7
				center post	286	8		
				second floor loft	82	8		
earth, stone, and masonry	one story cinder block	NM	E1S-NMA	ground floor	120	8	60 x 40	1.7
	two-story historic stone	NM	E2S-NM	first floor	108	24	37 x 30	5.0
				second floor	90	15		
	one-story adobe	NM	E1S-NMB	first floor	114	10	70 x 32	3.1
wood-frame	one-story	IN	W1S-IN	basement	92.4	8	40 x 22	3.7
				first floor	96	6		
		PA	W1S-PA	first floor	102	6	66.5 x 35	3.2
	two-story	IN	W2S-IN	basement	90	8	35 x 30	Nm
				first floor	96	6		
	three-story cantilever	WV1	W3S-VW1	garage	101	8	42 x 16	1.9
				first floor	94	5	42 x 20	
				second floor	52	5	42 x 20	

Nm – not measured

Table 2 Site information

Site	Number of Structures	Number of Blasts	Blast-to-Structure Distance (ft)	Charge Weight per Delay (lbs)	Square-Root Scaled Distance Factor ($ft/lbs^{1/2}$)
Alabama	2	4	852-1520	280-550	36-86
Indiana	3	16	816-9219	126-1712	44-223
Kentucky – 1	2	7	1830-5140	404-1044	60-184
Kentucky – 2	2	7	1510-4600	183-808	68-340
New Mexico	3	6	2095-5565	300-13047	23-278
Ohio	3	23	570-6280	284-4130	25-268
Pennsylvania	2	4	1390-1510	612-486	58-68
Tennessee	2	3	1225-6110	885-2809	34-149
Virginia	2	6	1212-1390	313-361	64-77
West Virginia – 1	2	5	4640-2240	126-2076	78-215
West Virginia – 2	2	8	1610-2670	415-973	76-118

Table 3 Ground motion attenuation equations from Figure 9

Site	Equation $[a\ (D/W^{1/2})^{-b}]$	Correlation Coefficient (R^2)
Alabama	$958\ (D/W^{1/2})^{-2.22}$	0.97
Indiana	$64\ (D/W^{1/2})^{-1.34}$	0.91
Ohio	$231\ (D/W^{1/2})^{-1.67}$	0.75
New Mexico – casting	$256\ (D/W^{1/2})^{-1.93}$	0.98
New Mexico – pre-split	$5448\ (D/W^{1/2})^{-2.03}$	0.90
U.S Bureau of Mines coal mine data*	$133\ (D/W^{1/2})^{-1.50}$ (maximum horizontal) $119\ (D/W^{1/2})^{-1.52}$ (all components)	

* U.S. Bureau of Mines RI 8507 (Siskind, et al, 1980a)

Table 4 Airblast overpressure attenuation equations

Site	Equation [a $(D/W^{1/3})^{-b}$]	Correlation Coefficient (R^2)
All sites	0.35 $(D/W^{1/3})^{-0.95}$	0.45
Coal mine data for highwalls *	0.146 $(D/W^{1/3})^{-0.823}$	0.77
Coal mine data for coal parting *	49.6 $(D/W^{1/3})^{-1.62}$	0.50

* U.S. Bureau of Mines RI 8485 (Siskind, et al, 1980b)

Table 5 Comparisons of two methods used to determine frequencies: zero-crossing and FFT methods

Site	Range of Frequencies (Hz)	
	Measured at the PPV using zero-crossing method	Calculated using FFT method
Sites with the great change in frequency between the two methods		
Kentucky – 1	9 – 22	6 – 7
New Mexico	4 – 18	4 – 8
Alabama	10 - 34	8 – 17
Kentucky – 2	18 - 30	15 – 19
Indiana	3 - 28	2 – 19
Sites with little change in frequency between the two methods		
Ohio	4 - 24	3 – 18
Pennsylvania	8 - 22	7 – 20
Virginia	7 - 23	6 – 20
West Virginia – 1	11 - 16	11 – 14
West Virginia – 2	7 - 19	6 – 16
Tennessee	10 - 32	12 – 35

Table 6 Best fit equations relating structure response in terms of whole structure and mid-wall motions to ground motions and air overpressures for different structure designs

Driving force	**Response**	**Structure design**	**Stories or component**	**Best fit equation** slope (a)	**Correlation Coefficient (R^2)**
peak particle velocity ground motion PPV	whole structure WSR = a * PPV	trailers	1	0.66	0.64
		log	1	0.45	0.91
			2	1.54	0.84
		earth, stone, and masonry	1	0.91	0.76
			2	3.22	0.42
		wood-frame and camp	1	1.30	0.88
			2	2.70	0.73
		all structures	1	0.63	0.45
			2	1.43 (1)	0.75
	mid-wall MWR = a * PPV	trailers	R	1.32	0.86
			T	2.09	0.73
		log	R	1.90	0.80
			T	2.98	0.94
		camp	R	2.58	0.87
			T	2.25	0.98
		wood-frame	R	1.83	0.92
			T	2.08	0.67
		earth, stone, and masonry	R	1.52	0.90
			T	1.24 (1)	0.83
airblast overpressure AP	whole structure WSR = a * AP	trailers	1	28.9	0.51
	mid-wall MWR = a * AP	trailers	R	206.1	0.52
			T	155.4	0.55
		camp	R	120.0	0.67
			T	131.0	0.95
		wood-frame	R	175.0	0.74
			T	213.6	0.70

(1) excluding the historic stone structure response

Table 7 Natural frequencies and damping coefficients calculated when ground motions occur at a 90 degrees phase shift from structure response

Structure	Shot Date (time)	PPV	Airblast	Transverse				Radial			
				whole structure		mid-wall		whole structure		mid-wall	
				natural frequency	damping coefficient	natural frequency	damping coefficient	natural frequency	damping coefficient	natural frequency	damping coefficient
		(in/sec)	(dB)	(Hz)	(%)	(Hz)	(%)	(Hz)	(%)	(Hz)	(%)
E2S-NM	6/22/01 (14:16)	0.258	131	4	6.31	4	4.88	4	2.33	4	3.55
	7/17/01 (12:52)	0.46	119	na	na	4	4.91	na	na	4	6.93
	7/23/01 (11:23)	0.23	110	4	3.09	4	5.89	na	na	4	4.58
	7/26/01 (11:05)	0.253	106	4	7.73	4	7.28	4	5.36	4	2.90
	7/26/01 (14:55)	0.21	122	4	4.58	4	3.55	4	3.55	4	6.45
	Average			**4**	**5.43**	**4**	**5.30**	**4**	**3.75**	**4**	**4.88**
TD-WV2	12/04/01 (12:22)	0.095	112	7	3.64	7	3.00	7	3.55	Na	Na
	12/05/01 (16:54)	0.060	116	7	4.89	7	3.55	7	6.45		
	12/06/01 (16:52)	0.085	117	7	1.8	7	5.43	7	11.06		
	average			**7**	**3.44**	**7**	**3.99**	**7**	**7.02**		

Na – not applicable as response is not detected

Table 8 Average and range (minimum to maximum) of natural frequencies computed during free response after ground motions have arrested

Design	Transverse (Hz)		Radial (Hz)	
	whole structure	mid-wall	whole structure	mid-wall
Trailer	6.9 (3.5 – 13.5)	9.5 (4.3 – 29.3)	6.3 (4.3 – 6.8)	19.9 (6 – 29)
Log	6.5 (6 – 8)	15.8 (8 – 24)	6.4 (5 – 7.5)	13.8 (6 – 27.5)
Earth, stone, and masonry	4.4 (4 – 4.8)	4.3 (3.8 – 4.8)	4.3 (4 – 4.5)	4.3 (3.8 – 4..5)
Camp	5.3 (3 – 7.5)	3.4 (3 – 3.8)	6.9 (6.5 – 7.5)	6.9 (6.5 – 7.5)
Wood-frame	7.6 (3 – 13)	8.9 (4 – 13.5)	Nd	23.9 (22 – 25.5)
Average for all structures	6.1	8.4	6.0	13.8
U.S.B.M. RI 8507 (Table 3)	7.1 (4 – 10)		7.8 (4 – 11)	16.4 (8.3 – 36)(1)

(1) The U.S.B.M. instrumented only the mid-wall facing the blast to measure air pressure effects

Table 9 Average damping coefficients for free response computed in Table 7

Design	Transverse (% of critical)		Radial (% of critical)	
	whole structure	mid-wall	whole structure	mid-wall
Trailer	8.9	9.5	9.6	8.7
Log	8.5	8.5	9.7	6.8
Earth, stone, and masonry(1)	3.9	6.4	6.6	8.7
Camp	9.2	6.2	5.5	8.2
Wood-frame	8.2	5.8	Nd	8.5
Average for all sites	7.7	7.3	7.9	8.2
U.S.B.M. RI 8507 (Table 3)	5.0	2.3	4.4	1.8

Nd – not detected

(1) excluding CMU block structure

Table 10 Amplification factors

Design	Description	Time-correlated Amplification Factors	
		average	minimum-maximum
Trailers	Single-wide	1.0	1.0 – 3.6
	Double-wide	2.4	1.1 – 4.0
	Add-on	1.9	0.4 – 3.3
Log	One story	1.4	0.4 – 3.0
	Two story	2.1	0.9 – 3.0
Earth, stone, and masonry	One story	1.1	0.6 – 1.6
	Two story	3.5	1.7 – 5.0
Camp	One story	2.1	1.5 – 3.5
	Two story	3.3	1.5 – 4.6
Wood-frame	One story	1.7	1.0 – 2.5
	Two story	1.3	1.1 – 1.5
	Three story	1.6	1.3 – 1.9

Table 11 Blast-induced strains for the radial, R, and transverse, T, walls

Design		In-plane tensile strains[1] (μ-strains)		Wall bending strains (μ-strains)	
		Average (maximum)		Average (maximum)	
		R	T	R	T
Trailer	single wide	5.0 (23.5)	6.7 (38.3)	1.5 (11.5)	2.9 (25.7)
	double wide	3.5 (33.2)	8.9 (23.4)	9.2 (18.9)	1.8 (16.0)
	add-on	8.0 (30.0)	4.9 (10.1)	0.9 (3.9)	6.0 (11.1)
Log	one-story	2.7 (41.7)	4.8 (95.5)	10.5 (13.3)	8.9 (15.5)
	two-story	3.0 (24.5)	4.1 (66.6)	0.2 (1.6)	Na
Earth, stone, and masonry	cinder block	7.4 (10.4)	11.6 (13.4)	Na	3.6 (11.7)
	adobe	4.2 (4.9)	3.9 (7.3)	8.8 (12.1)	5.1 (9.0)
	2-story stone	49.0 (98.9)	55.1 (113.1)	5.2 (18.3)[2]	18.9 (46.6)[3]
Camp	one-story	11.6 (27.4)	9.5 (18.7)	4.5 (8.0)	5.4 (9.2)
	two-story	2.9 (6.6)	1.7 (13.2)	0.03 (1.4)	0.1 (0.3)
Wood-frame	one-story	11.0 (39.4)	12.5 (33.7)	5.2 (13.0)	3.1 (9.6)
	two-story	2.0 (15.2)	2.7 (13.7)	Na	7.5 (13.0)[3]

(1) Note that the wall being strained is 90-degrees from the motion sensor recording velocity (e.g., the radial sensor records motion of the transverse walls while the transverse sensor records motion of the radial wall)

(2) first floor

(3) second floor

Na – no sensor used in this location

Table 12 Structure responses to non-blasting activities

Structure Design	Designation	Activity	Maximum velocity (in/sec)			
			upper structure response		mid-wall response	
			R	T	R	T
single wide trailer	TS-IN	shut north bedroom door	0.10	0.06	0.98	0.29
		child running	0.04	0.02	0.07	0.13
		close north window	0.51	0.40	1.08	0.42
		shut room closet door	0.10	0.50	0.78	0.74
		children playing in family room	0.07	0.04	0.14	0.10
		shut family room outside door	0.05	0.07	0.70	0.22
Double wide trailer	TD-PA	shut west bedroom door	0.05	0.03	0.17	0.34
		slam west bedroom door	0.16	0.10	0.49	1.46
		shut west bathroom door	0.20	0.30	0.50	2.14
		shut exterior kitchen door	0.06	0.12	0.23	0.34
		close west bedroom window	0.15	0.15	0.16	0.74
		jump in bedroom	0.02	0.05	0.16	0.42
		chair fall back in dining room	0.05	0.04	0.06	0.09
one-story wood frame	W1S-IN	shut front door	0.065	0.10	1.58	0.14
		walk in living room	0.02	0.01	0.38	0.17
		child bouncing a ball in living room	0.03	0.05	0.38	0.10
two-story wood frame	W2S-IN	jump in living room	0.03	0.06	Na	Na
		running down stairs	0.04	0.03		
		drop sofa end in living room	0.03	0.05		
		close kitchen window	0.01	0.06		
one-story earth, stone, and masonry	E1S-NMA	shut garage door	0.01	0.02	Na	0.03
	E1S-NMB	shut patio door	0.05	0.12	0.08	0.07
		bump wall with shoulder	0.02	0.04	0.02	0.15
		bump wall with a broom	0.01	0.02	0.01	0.14
two-story earth, stone, and masonry	E2S-NM	Backhoe dropping flagstone near house	0.05	0.04	Na	0.03
			0.03	0.04		0.06
			0.02	0.02		0.03
			0.02	0.02		0.03

Na – no mid-wall sensors mounted

Table 13 Comparison of structure responses for household activities with blasting

Structure designation	Structure response velocity (in/sec)							
	Maximum from household activities				Maximum from blasting activities			
	whole structure		mid-walls		whole structure		mid-walls	
	R	T	R	T	R	T	R	T
TS-IN	0.51	0.40	1.08	0.42	0.52	0.41	1.24	0.64
TD-PA	0.20	0.30	0.50	2.14	0.19	0.20	1.08	0.535
W1S-IN	0.065	0.10	1.58	0.14	0.82	0.55	0.16	0.15
W2S-IN	0.03	0.06	Na	Na	0.24	0.25	Na	Na
E1S-NMA	0.01	0.02	Na	0.03	0.66	0.31	Na	0.78
E1S-NMB	0.05	0.12	0.08	0.07	0.15	0.22	0.27	0.305
E2S-NM	0.05	0.04	Na	0.03	1.52	1.24	0.63	2.64

Na – sensor not mounted in location

Table 14 Velocities and calculated strains in trailers produced by wind for wind speeds ranging from 12 to 32 miles/hour

Structure Design	Designation	Component or wall	Maximum upper structure response	Whole structure transverse shear strain	Maximum mid-wall response	Mid-wall bending strains
			(in/sec)	(μ-strains)	(in/sec)	(μ-strains)
Single wide trailer	TS-KY2	T	0.055	1.5	0.090	1.1
		R	0.035	3.5	0.055	1.2
		T	0.040	1.2	0.060	0.7
		R	0.025	3.4	0.060	0.8
	TS-AL	R	0.010	Na	0.030	1.8
		T	0.030	Na	Na	1.6
Double wide trailer	TD-PA	R	0.005	1.1	0.010	0.6
		T	0.010	1.0	0.025	0.3

Na – strain could not be computed as sensors were not placed in lower corners or not on radial mid-walls

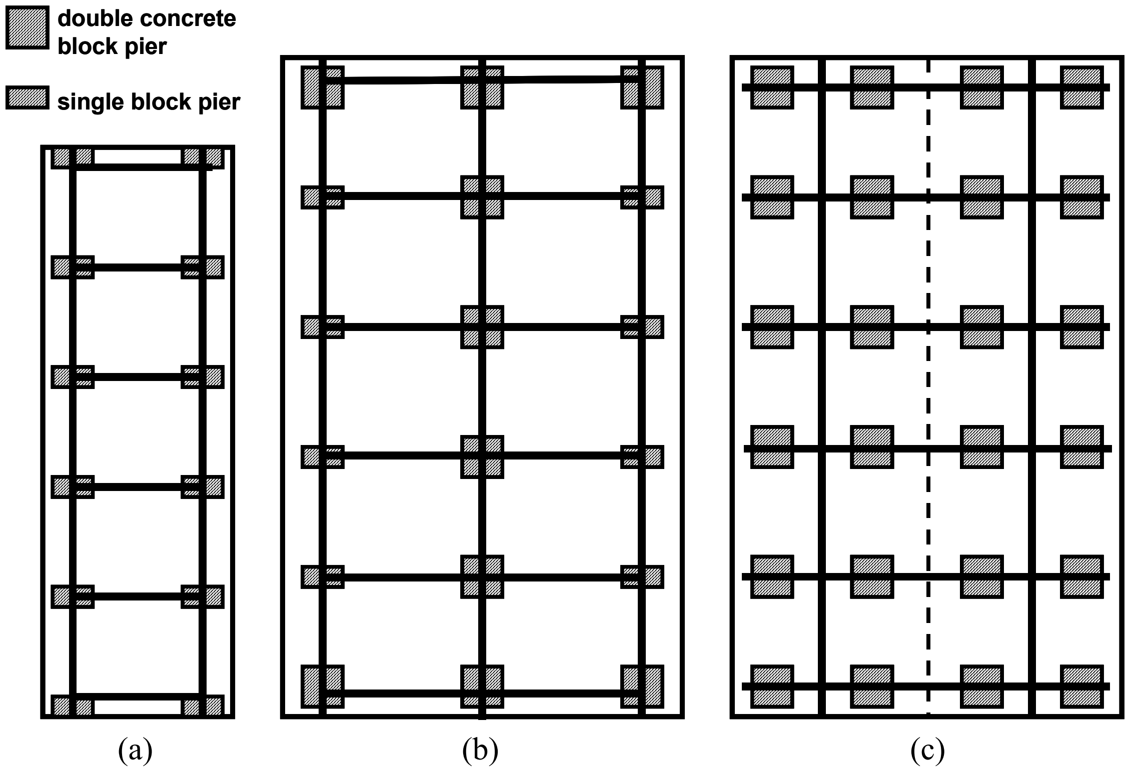


Figure 1 Three generalized trailer pier support system layouts (a) for single wide trailers using single stacked CMUs, and double wide trailer supports (b) using single and double CMUs beneath three axis beams (c) four rows of double CMUs

Figure 2 Hurricane straps required by building code in states in which trailer were selected for the study in Ohio, Tennessee, Alabama, and Indiana

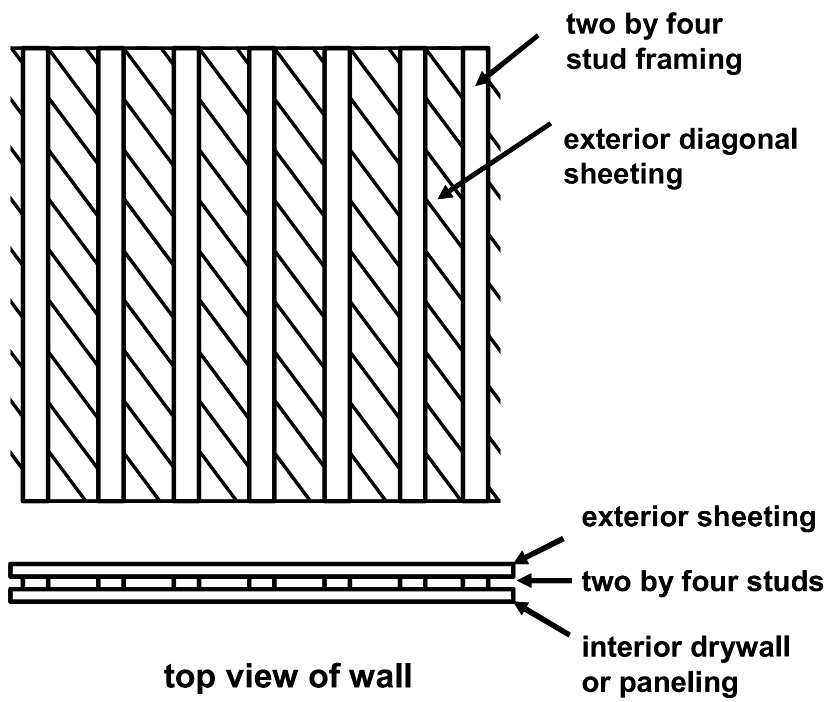
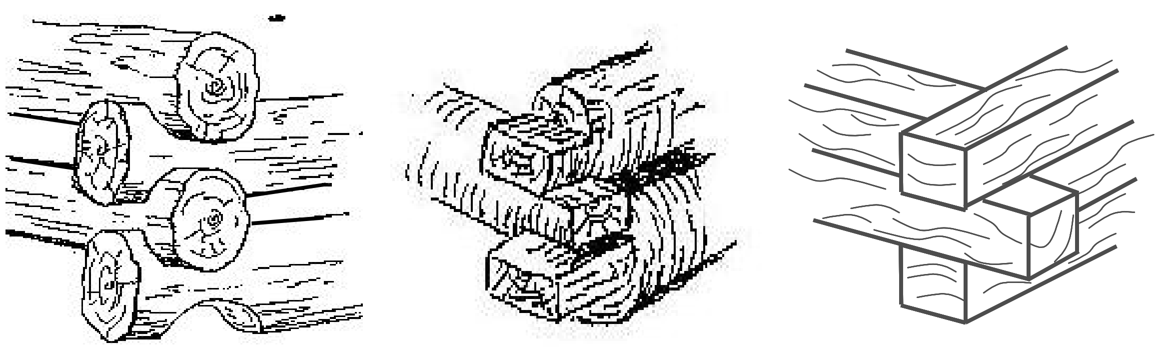
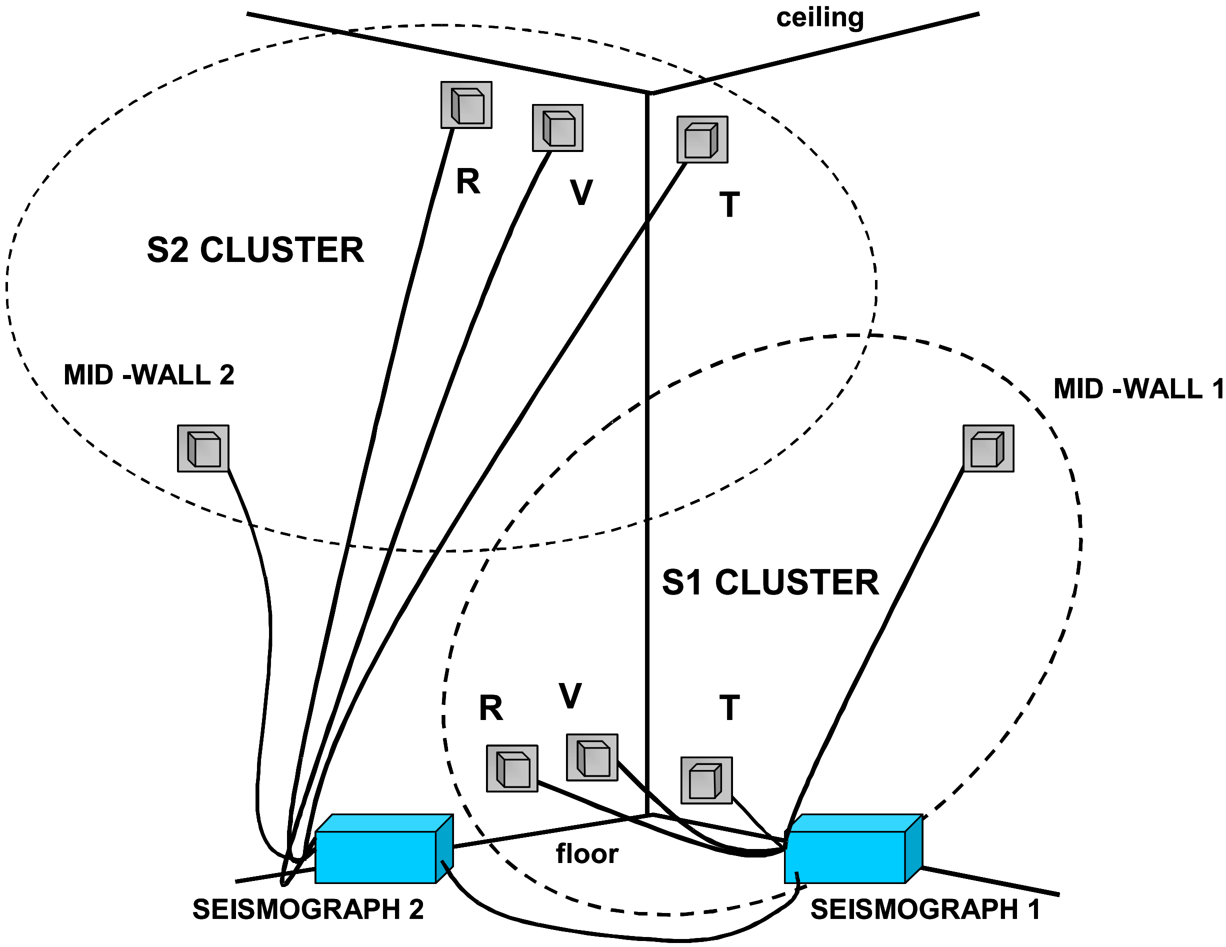


Figure 3 Details of mining camp wall structure

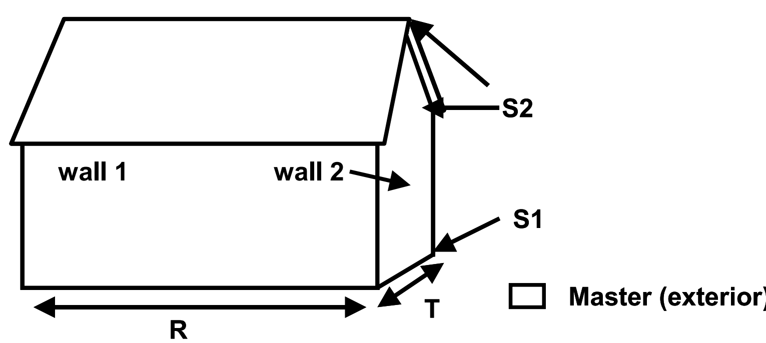


(a) (b) (c)

Figure 4 Three types of log fitting (a) saddle lock-notched with spacing between the logs for chinking, (b) notched and scribed, and (c) butt-jointed (After Martell, 2002)

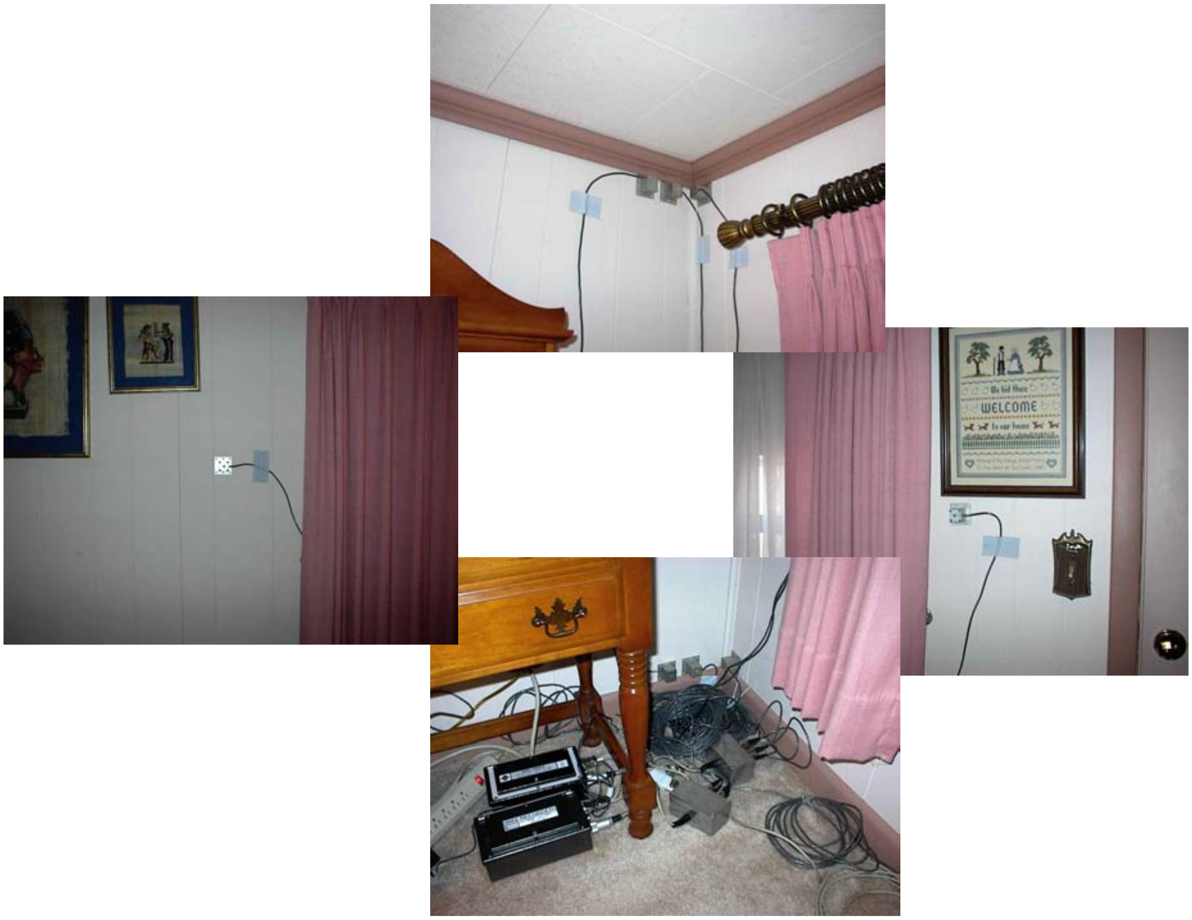


(a)

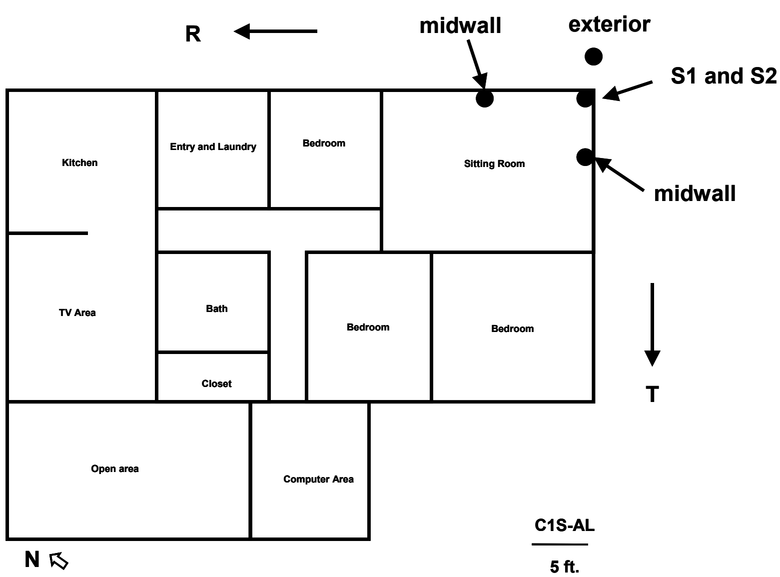


(b)

Figure 5 Typical instrument layout showing (a) S1 and S2 interior velocity sensors used to measure whole structure and mid-wall vibrations (b) location of exterior master seismograph showing orientations of the radial (R) and transverse (T) components



(a)



(b)

Figure 6 Instrumentation layout for mining camp structure C1S-AL

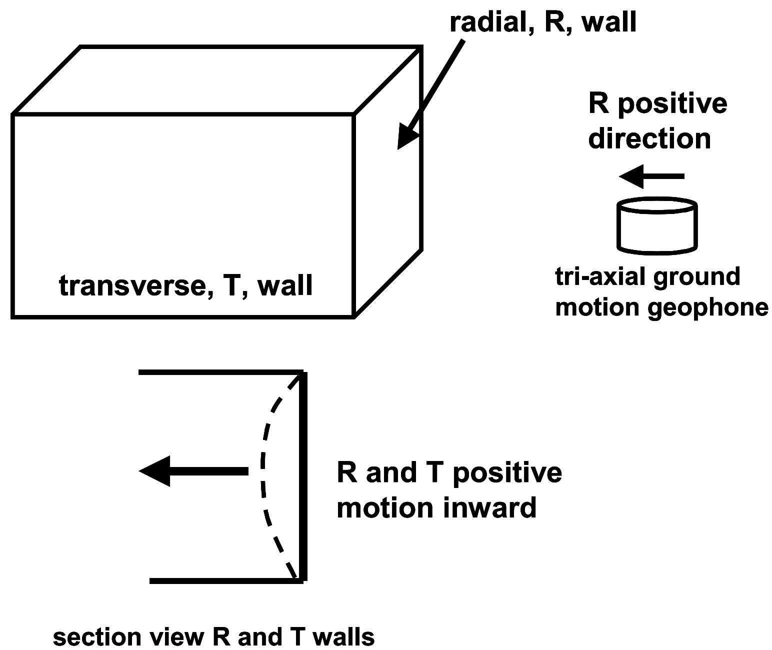


Figure 7 Convention used for radial, R, and transverse, T, geophone orientations

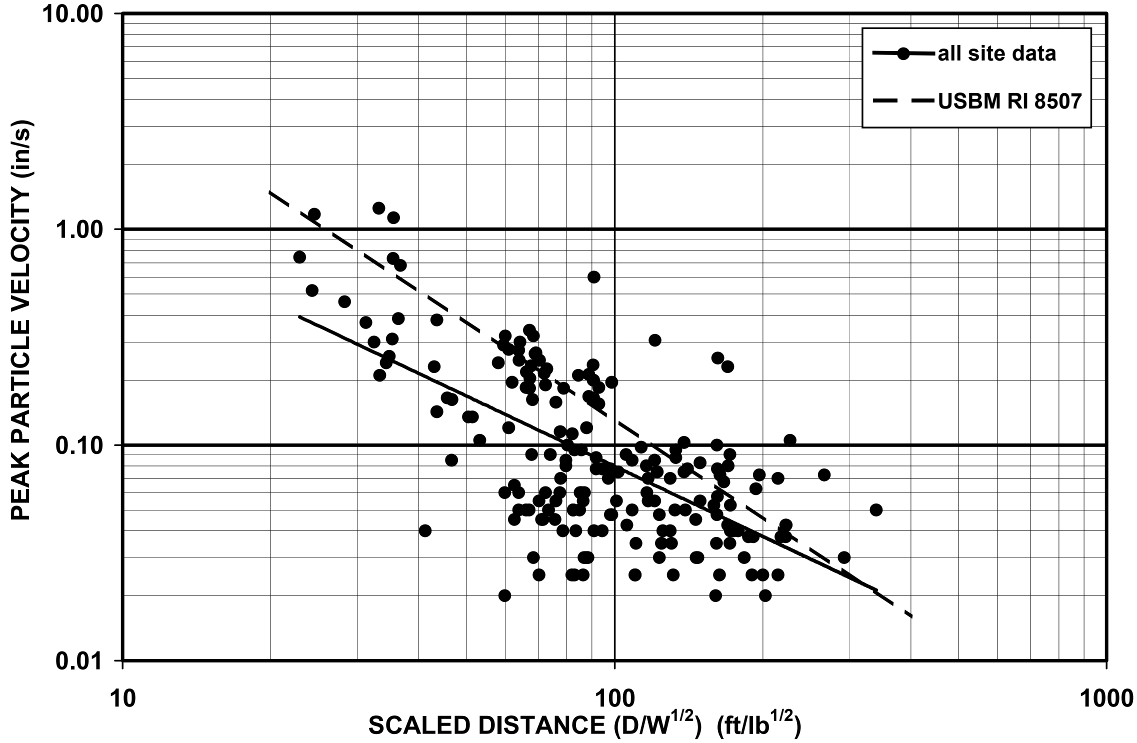


Figure 8 Attenuation plot of maximum ground vibrations for all data

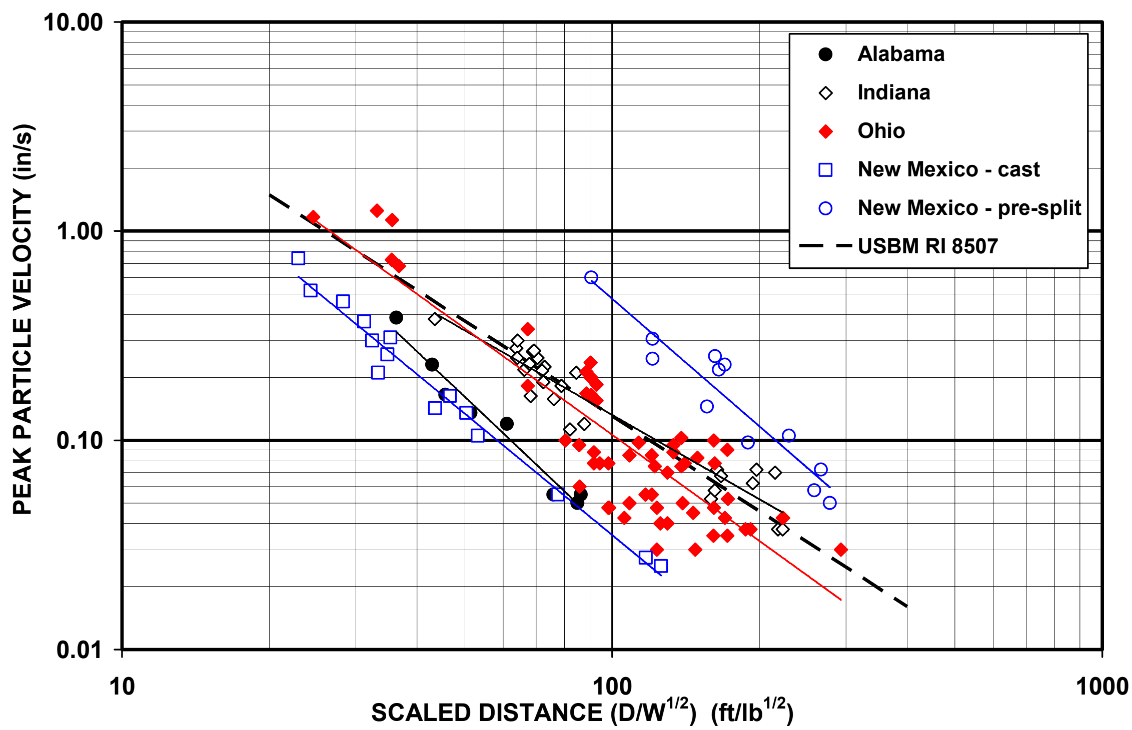


Figure 9 Attenuation plots of maximum ground vibrations separated by site (regression equations shown in Table 3)

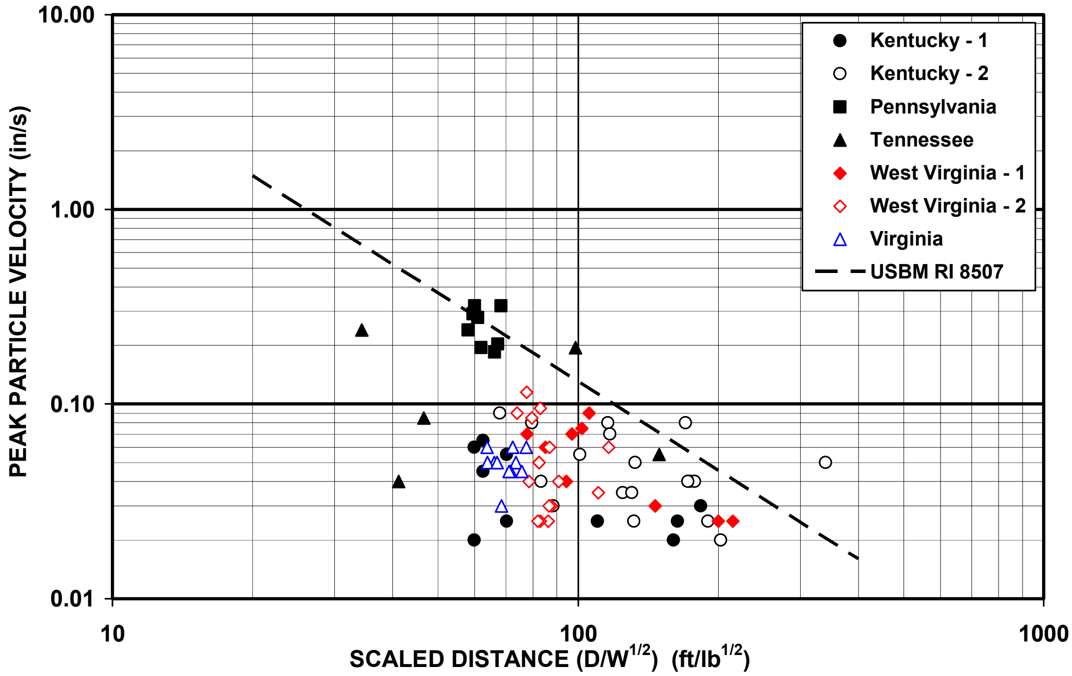


Figure 10 Maximum ground vibrations for clustered and uncorrelated data

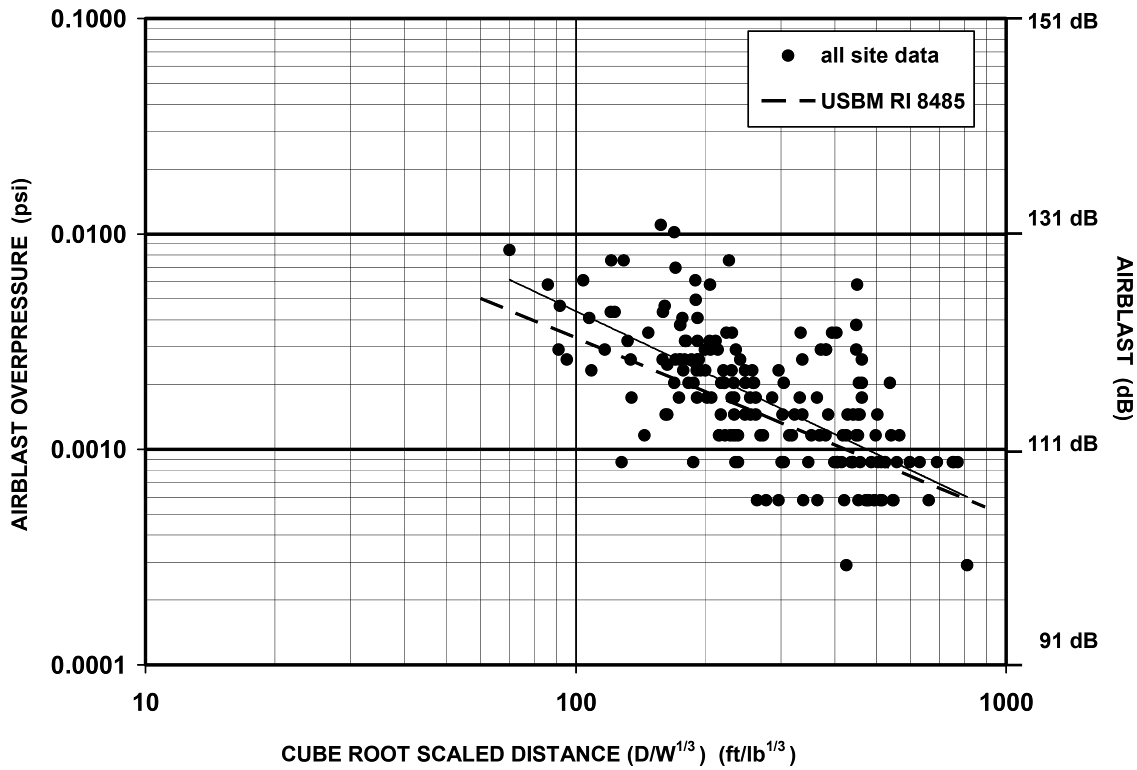


Figure 11 Airblast overpressure attenuation for all data (airblast in dB = 20 log [overpressure in psi] + 170.8)

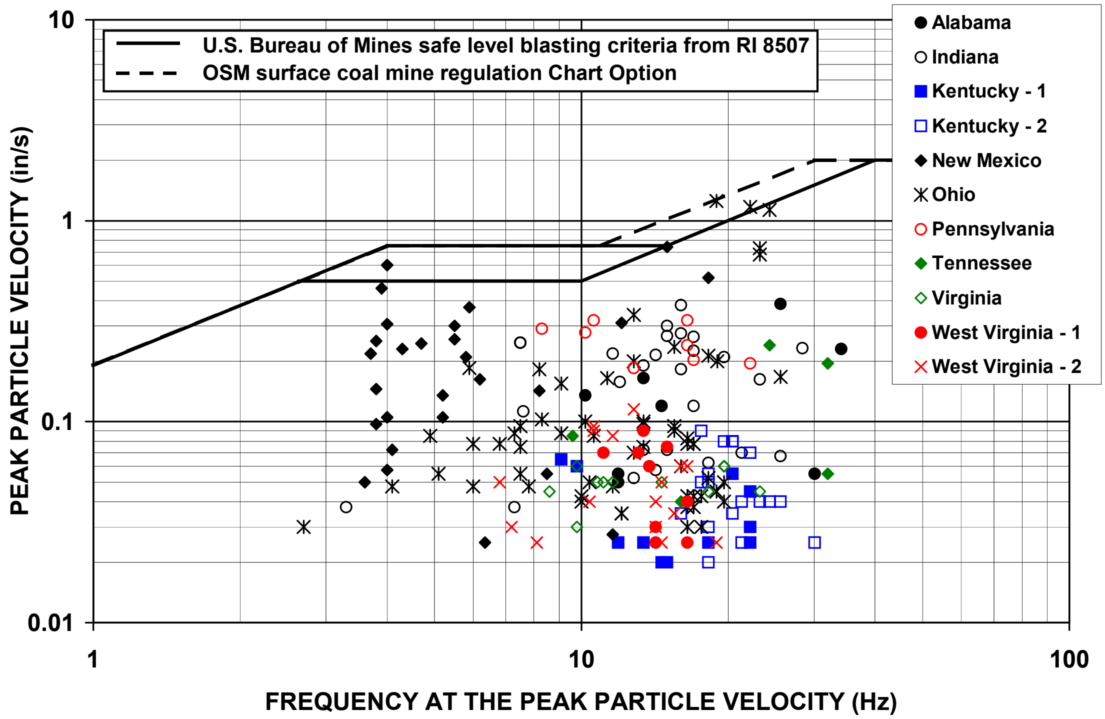


Figure 12 Peak particle velocity (PPV) versus frequency at the PPV

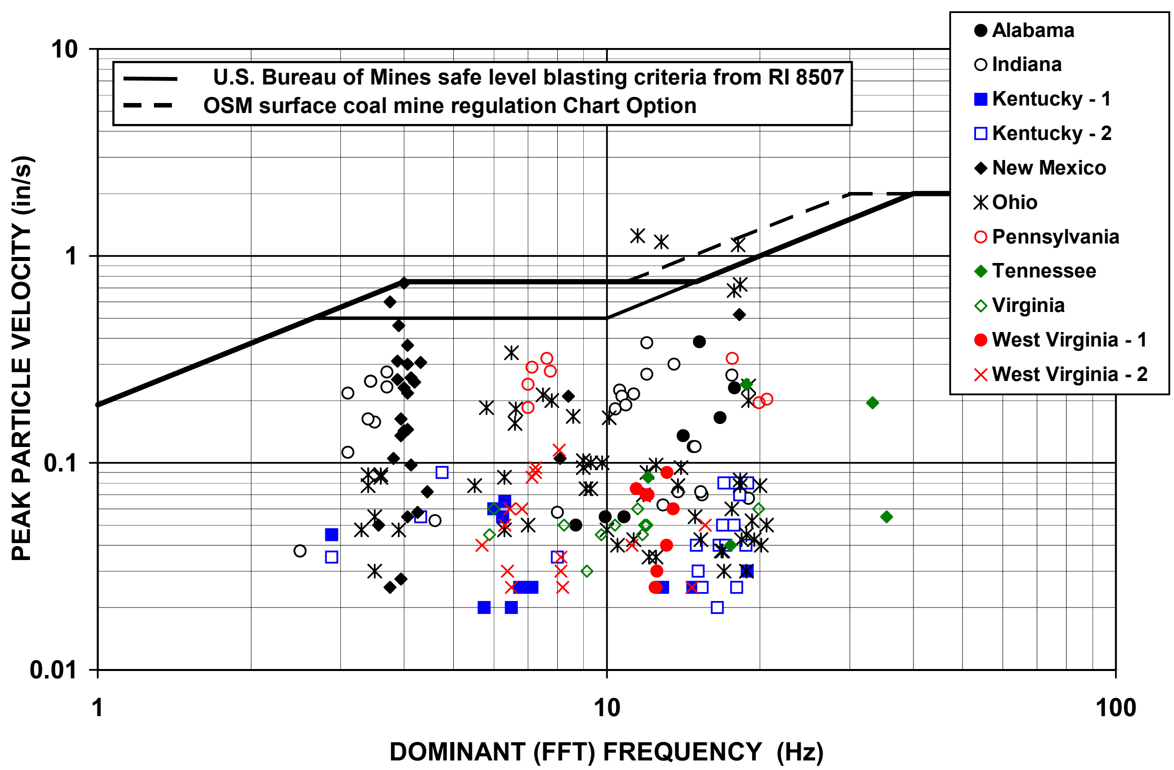


Figure 13 Peak particle velocity (PPV) versus predominant frequency using FFT methods

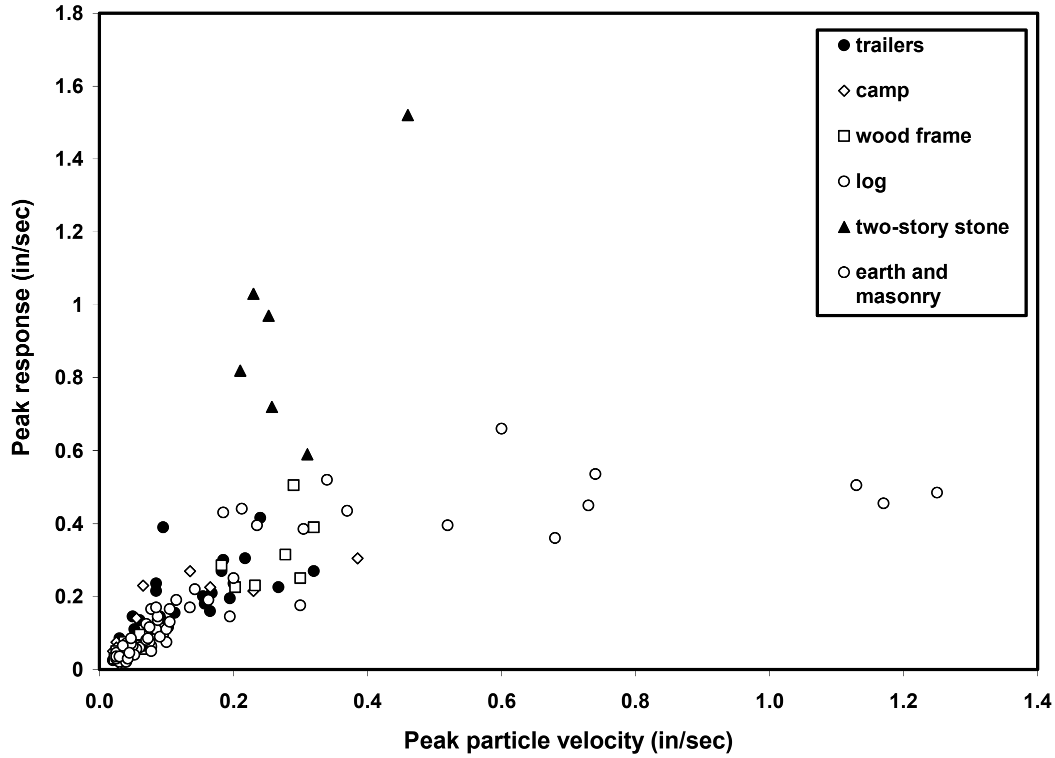


Figure 14 Ground motion-induced whole structure response

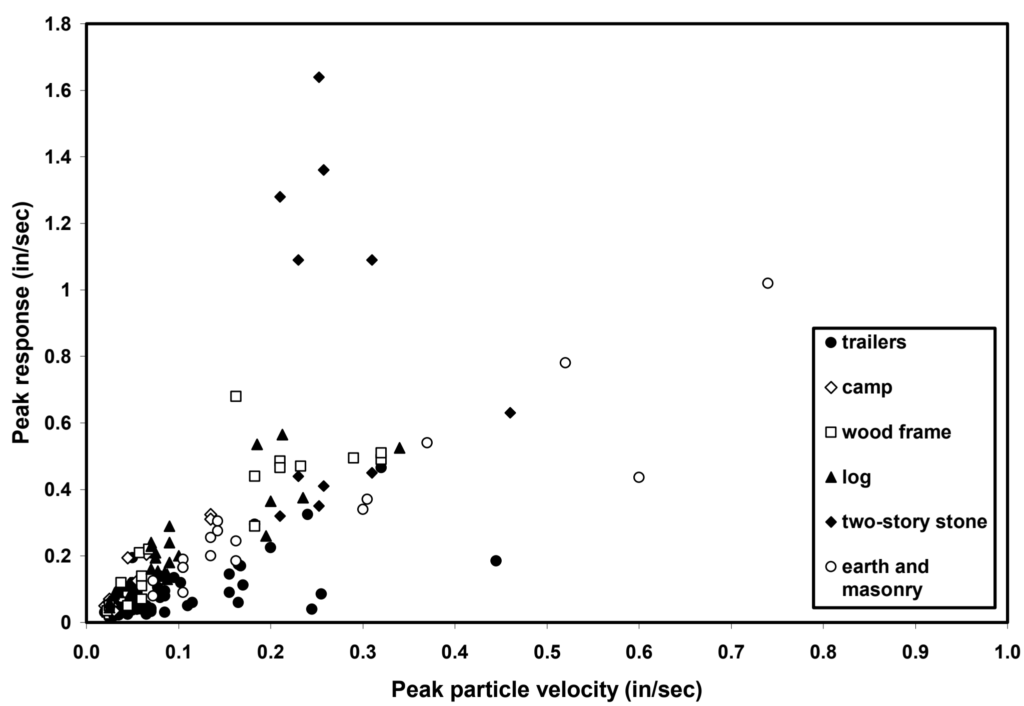


Figure 15 Ground motion-induced mid-wall response

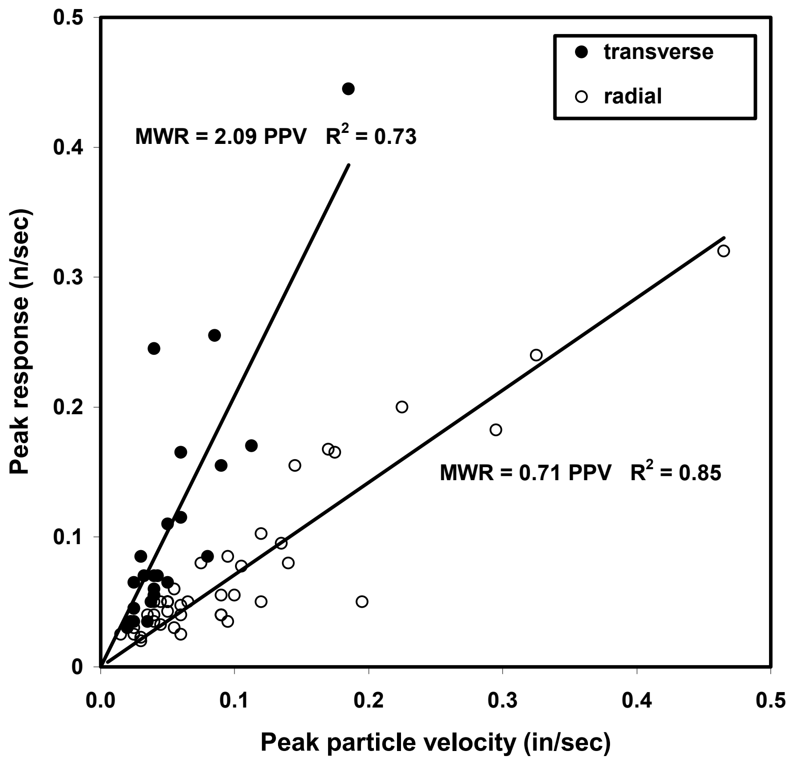


Figure 16 Ground motion-induced mid-wall responses for trailers

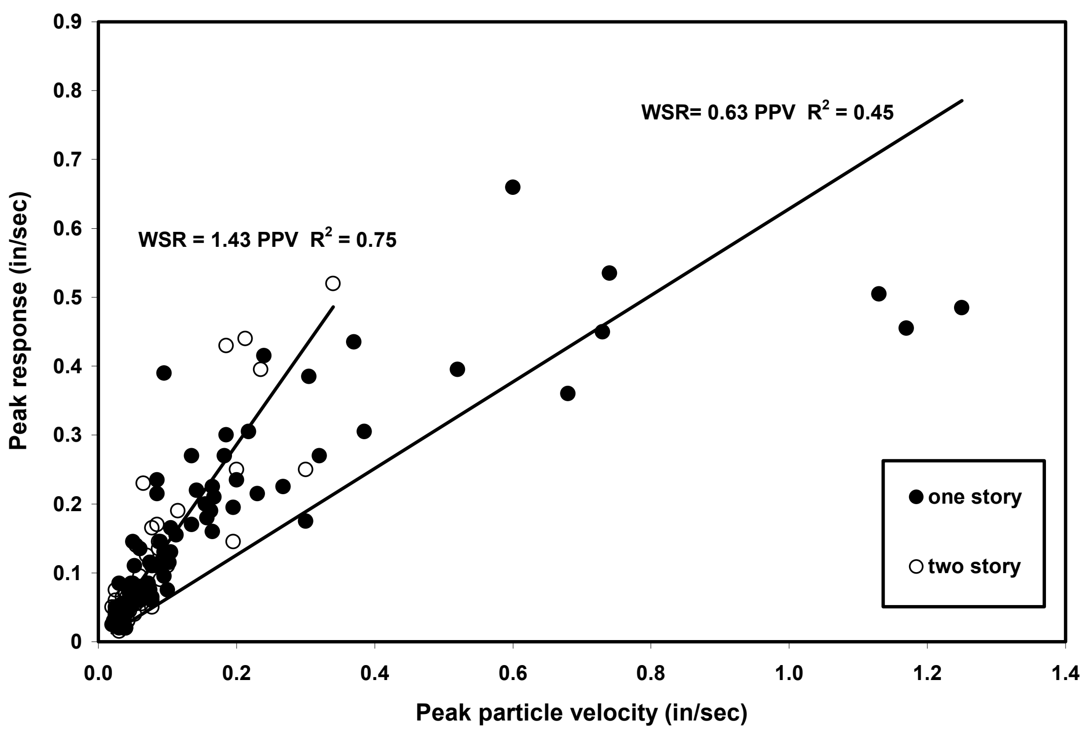


Figure 17 Ground motion-induced whole structure response for one and two story structures

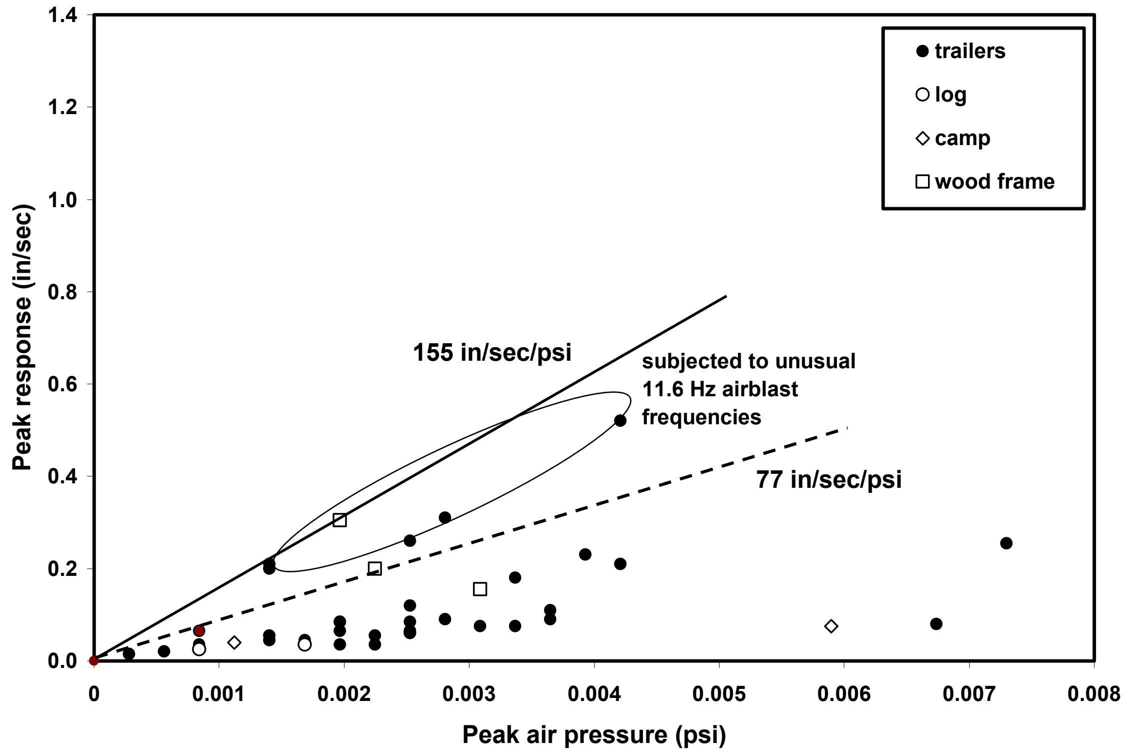


Figure 18 Airblast-induced whole structure response

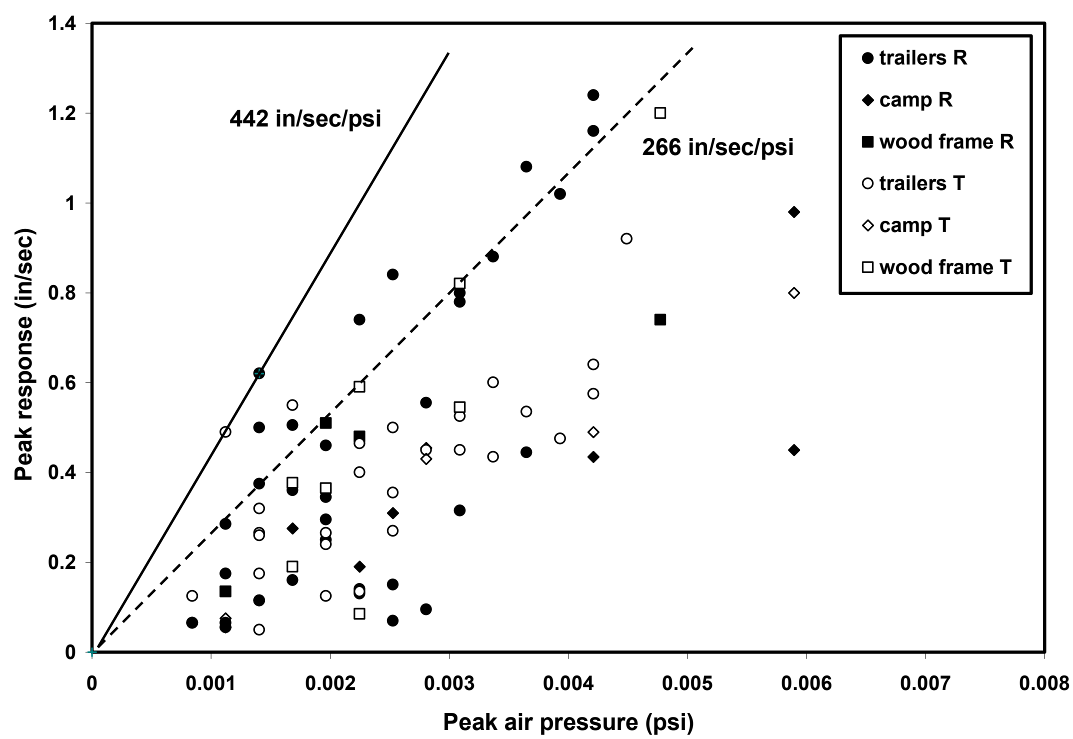


Figure 19 Airblast-induced mid-wall response

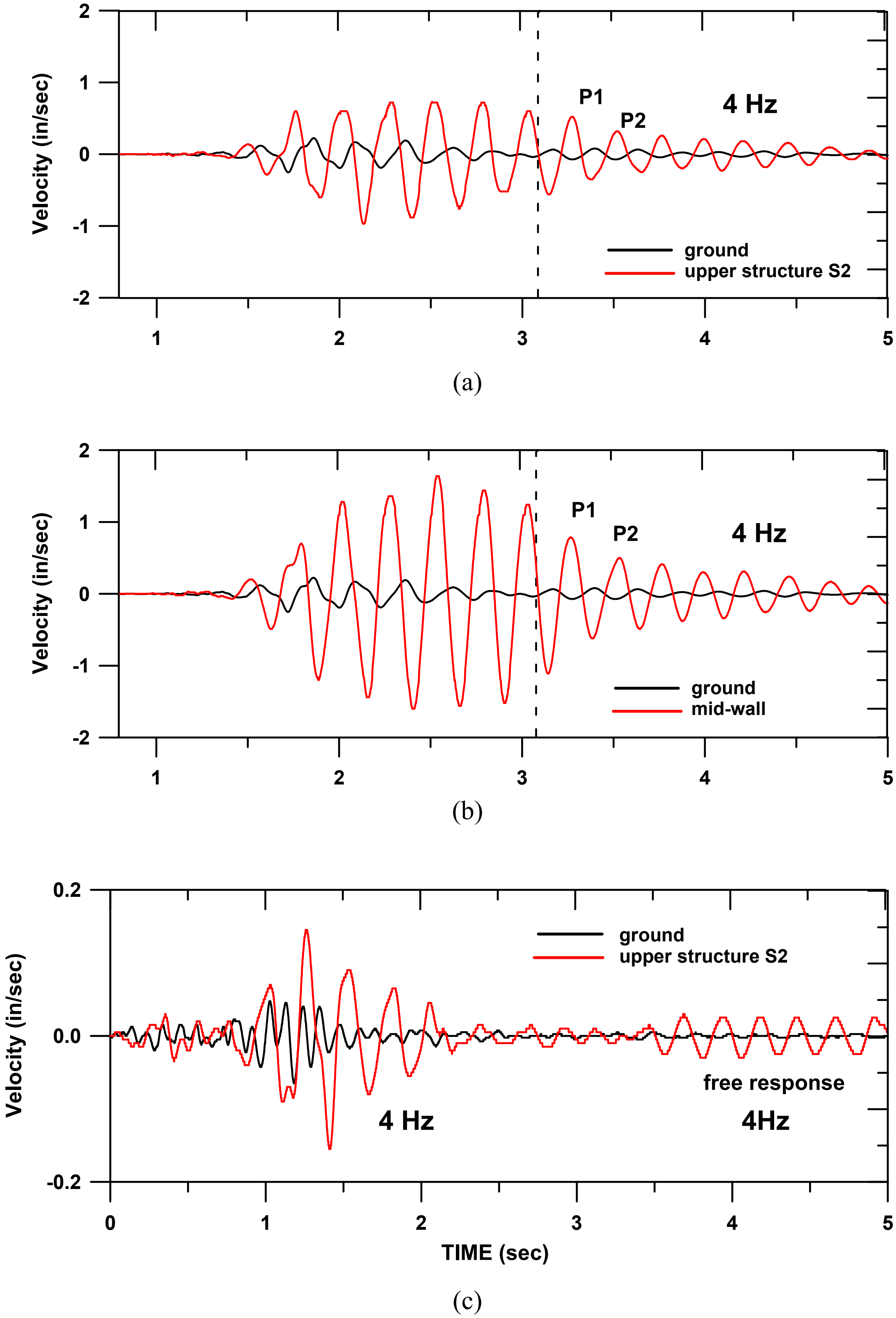


Figure 20 Natural frequency response for stone structure E2S-NM (a) whole structure and (b) mid-wall horizontal structure response compared with ground motions; (c) whole structure free response in trailer structure TS-OH prior to airblast arrival at 4.7 seconds.

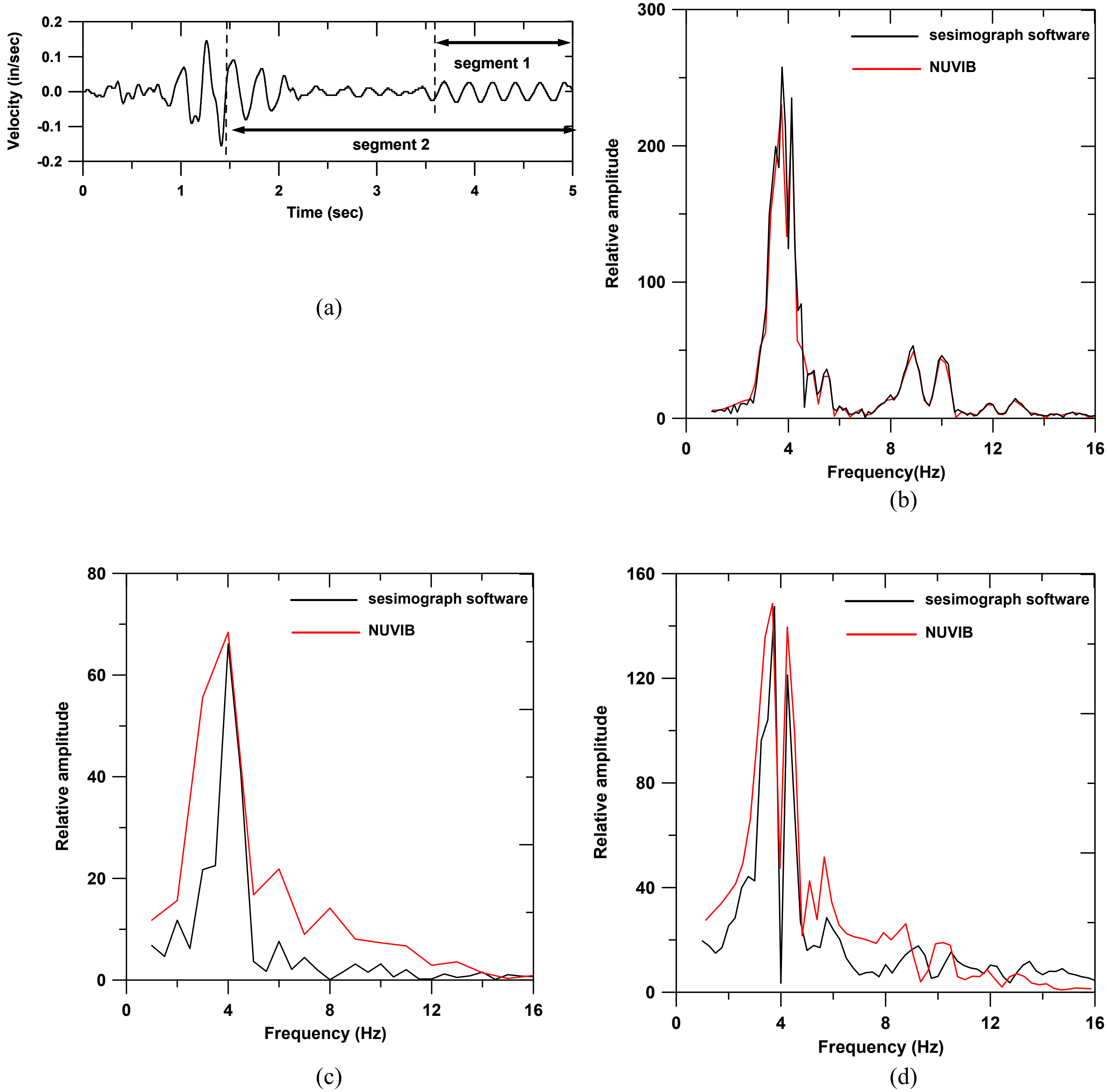


Figure 21 Upper corner transverse response FFT plots for trailer TS-OH response shown in (a), comparing the FFT power spectrum using two different software for (b) the entire time history, (c) segment 1 free response only, and (d) segment 2

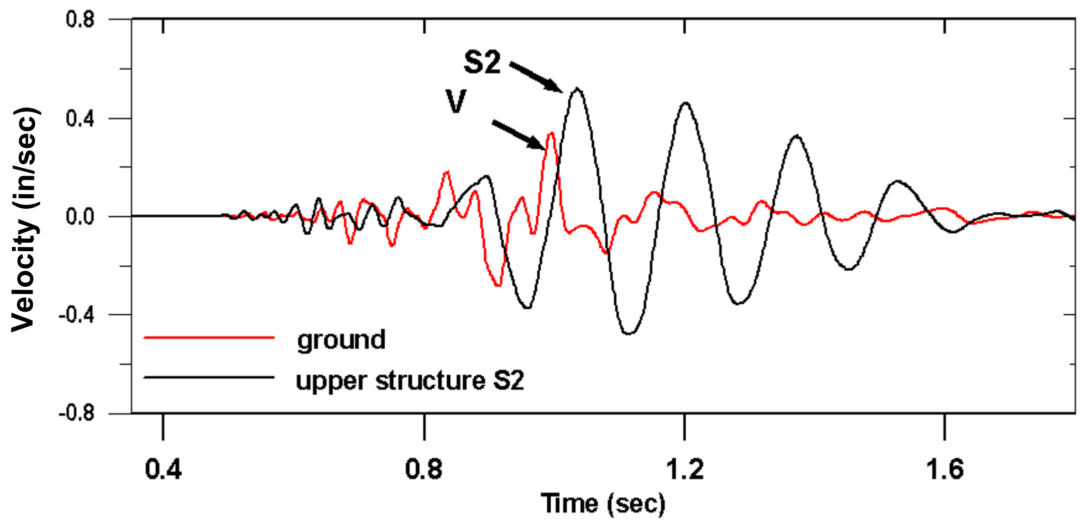


Figure 22 Selection of peaks S2 and V for calculating amplification factors AF

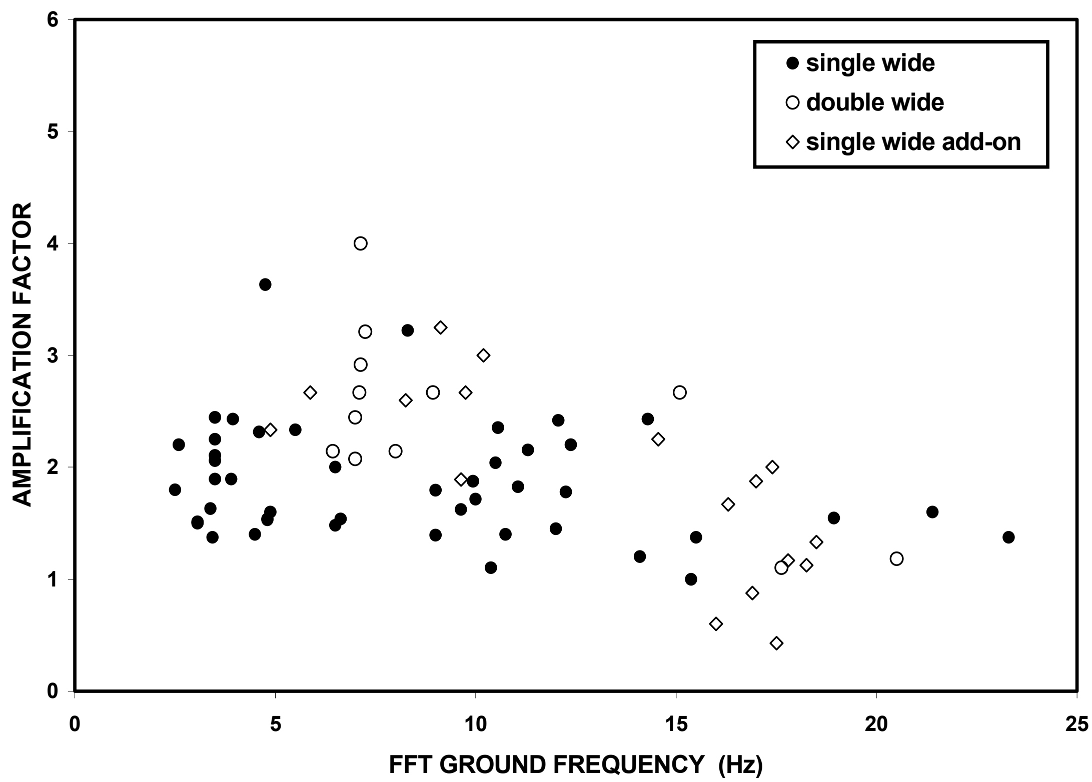


Figure 23 Amplification factor versus FFT ground frequency for all trailers

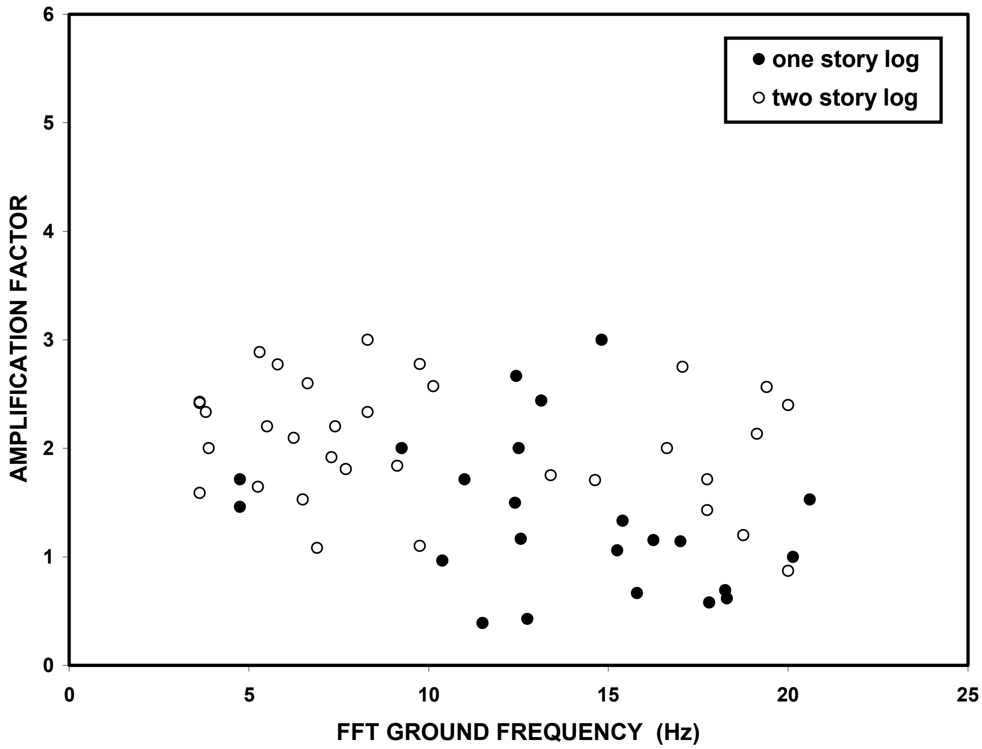


Figure 24 Amplification factor versus FFT ground frequency for all log structures

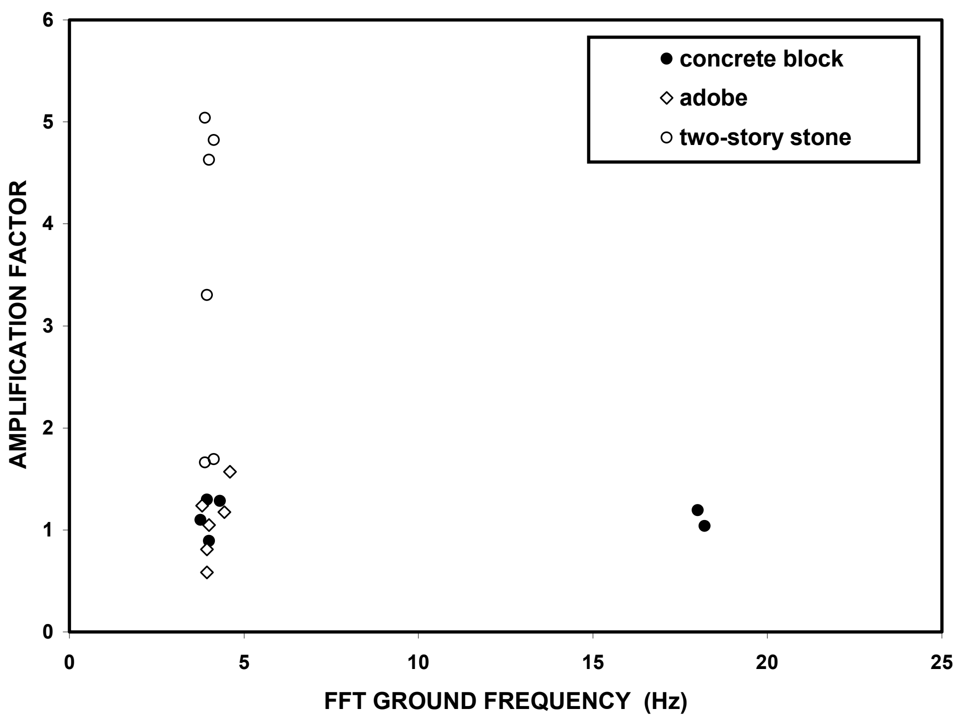


Figure 25 Amplification factor versus FFT ground frequency for all earth and masonry structures

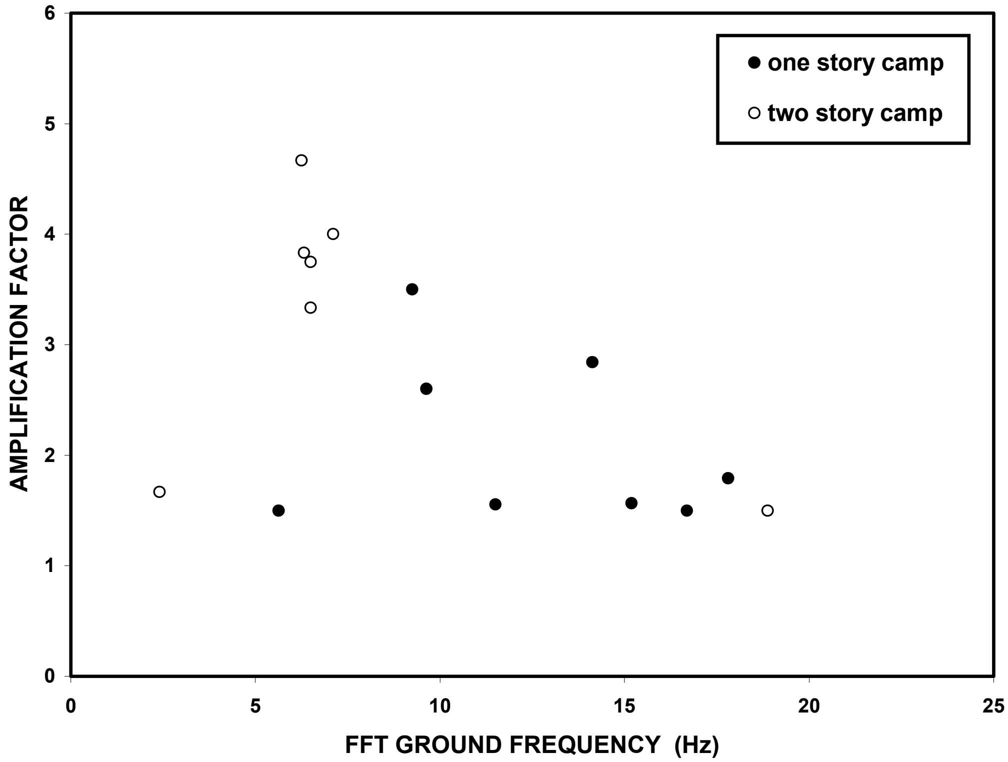


Figure 26 Amplification factor versus FFT ground frequency for all camp structures

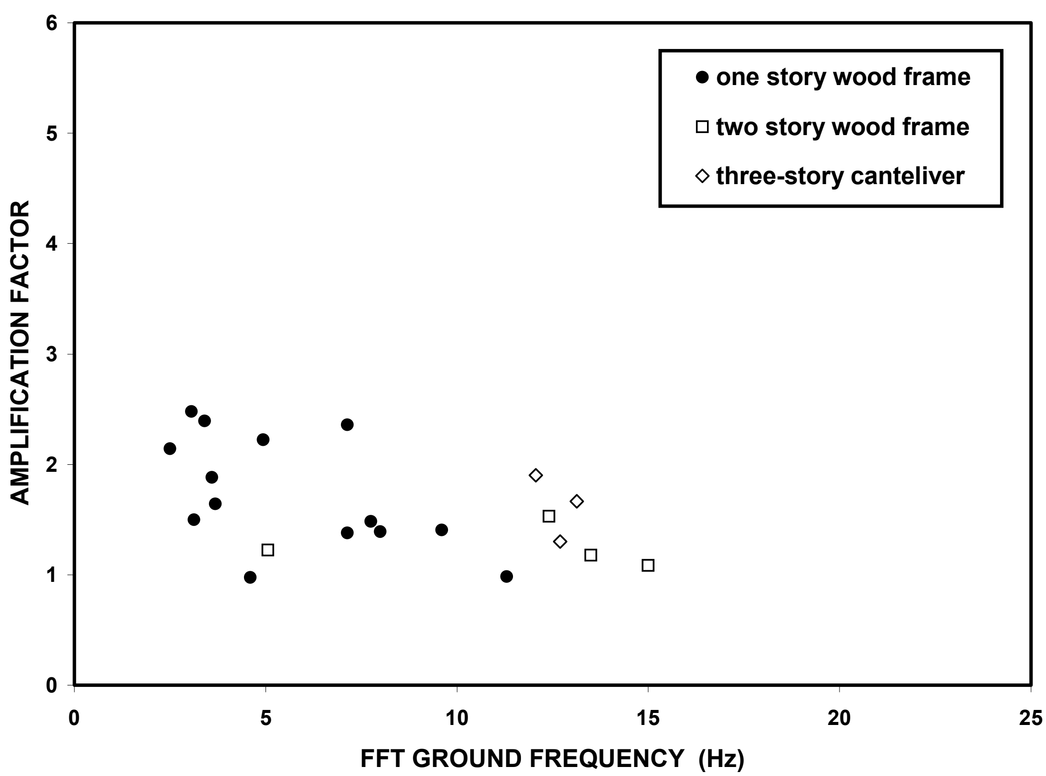


Figure 27 Amplification factor versus FFT ground frequency for all wood-frame structures

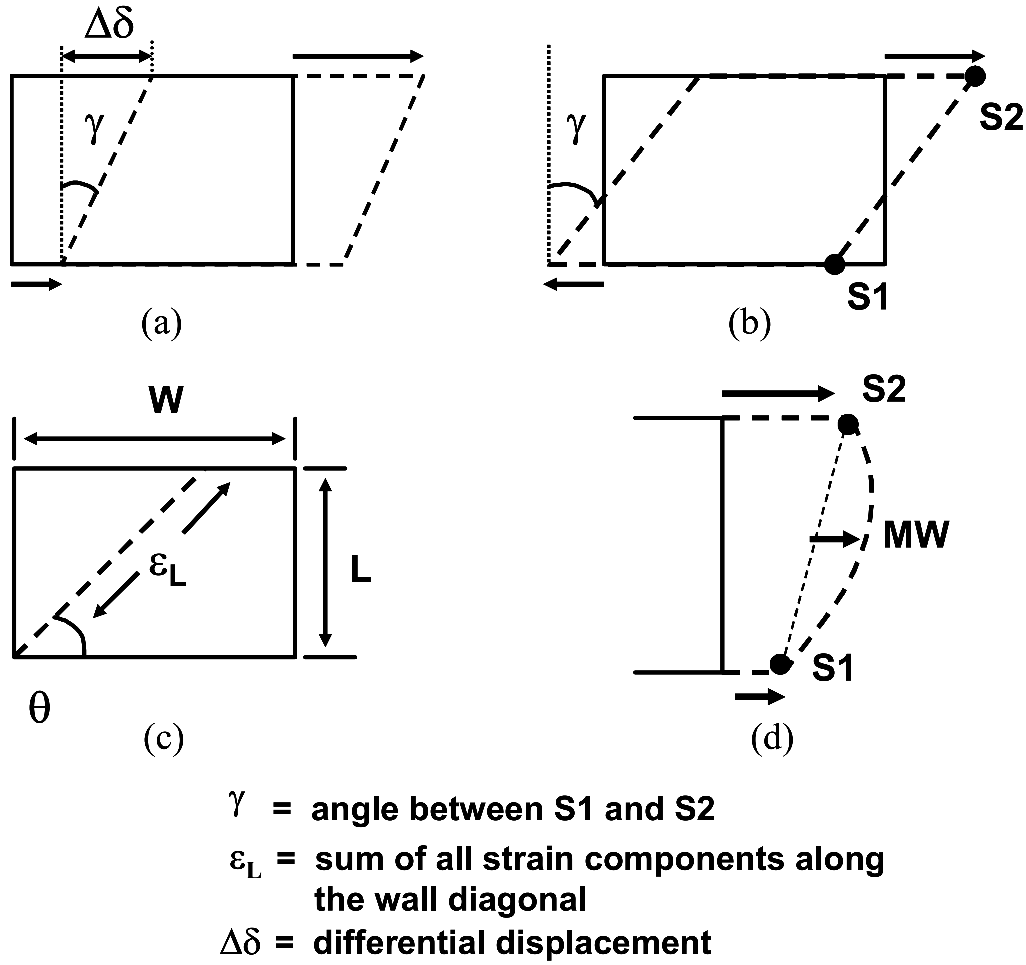
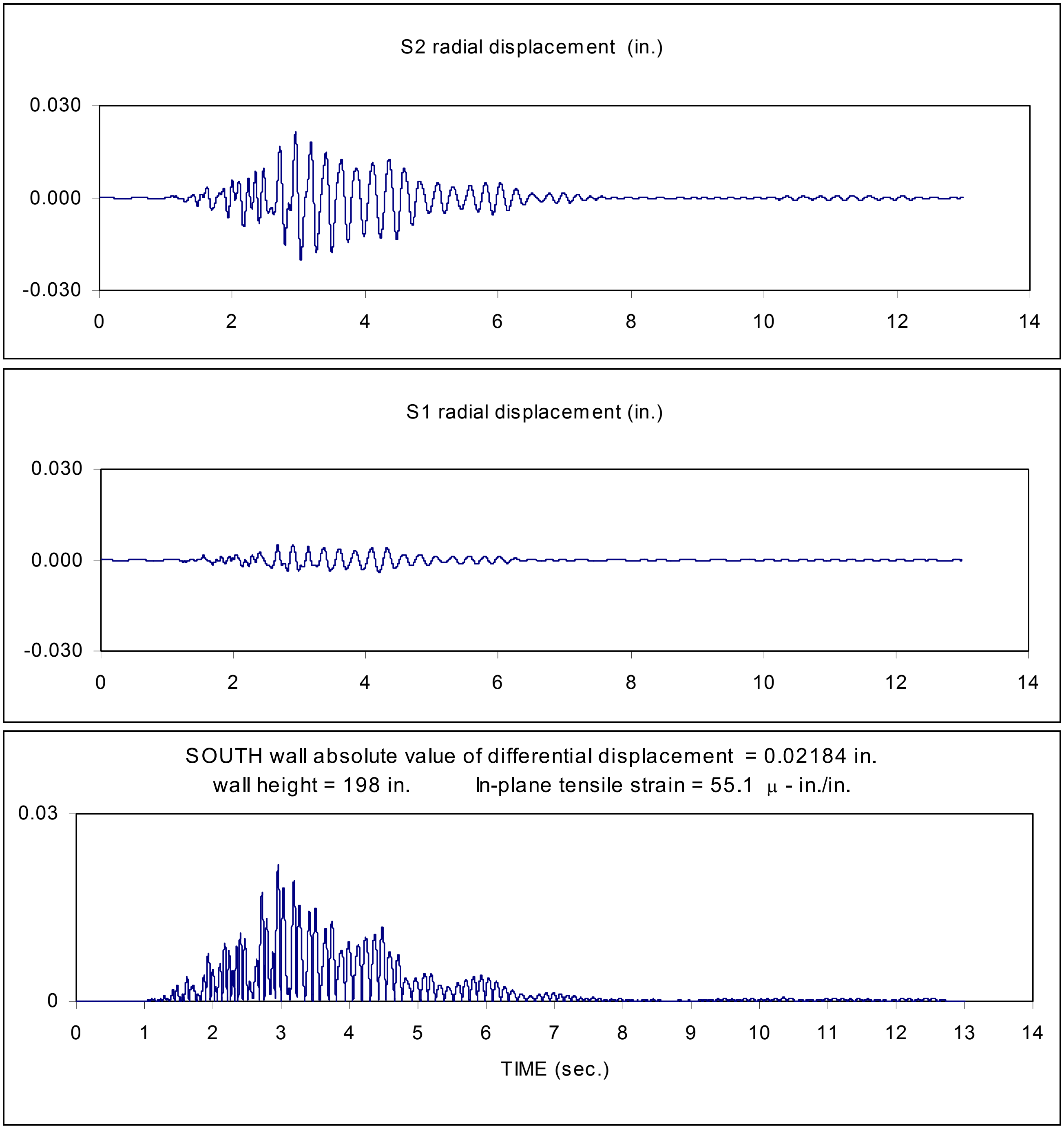
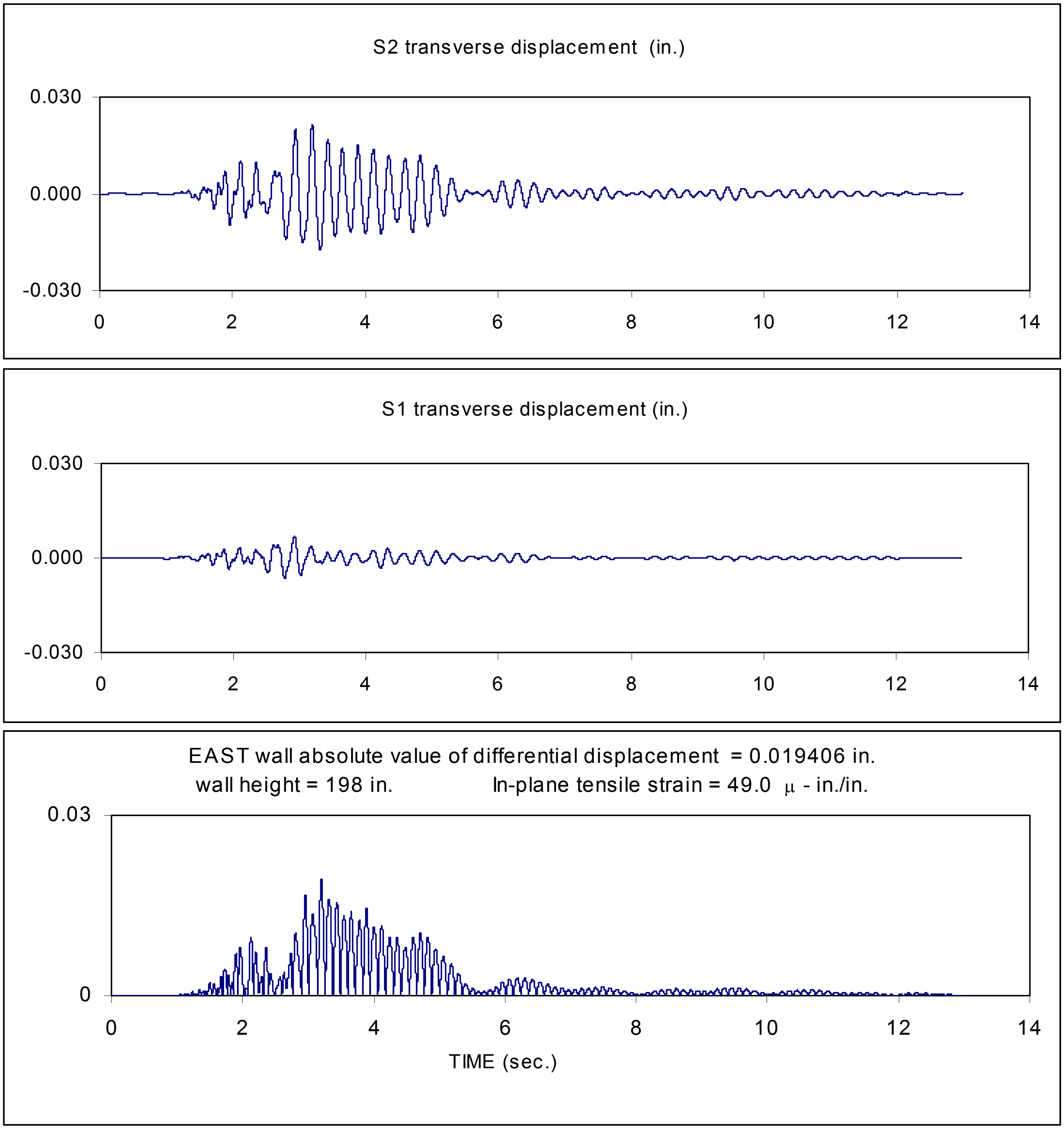


Figure 28 Global structure strains for (a) in-phase and (b) out-of-phase structure motions; in-plane tensile wall strains are defined in (c), and wall bending strains are shown in (d)



(a)

Figure 29 (a) Example calculations for whole structure differential displacement (absolute values) time history for the radial direction (transverse wall) of structure E2S-NM



(b)

Figure 29 (b) Example calculations for whole structure differential displacement (absolute values) time history for the transverse direction (radial wall) of structure E2S-NM

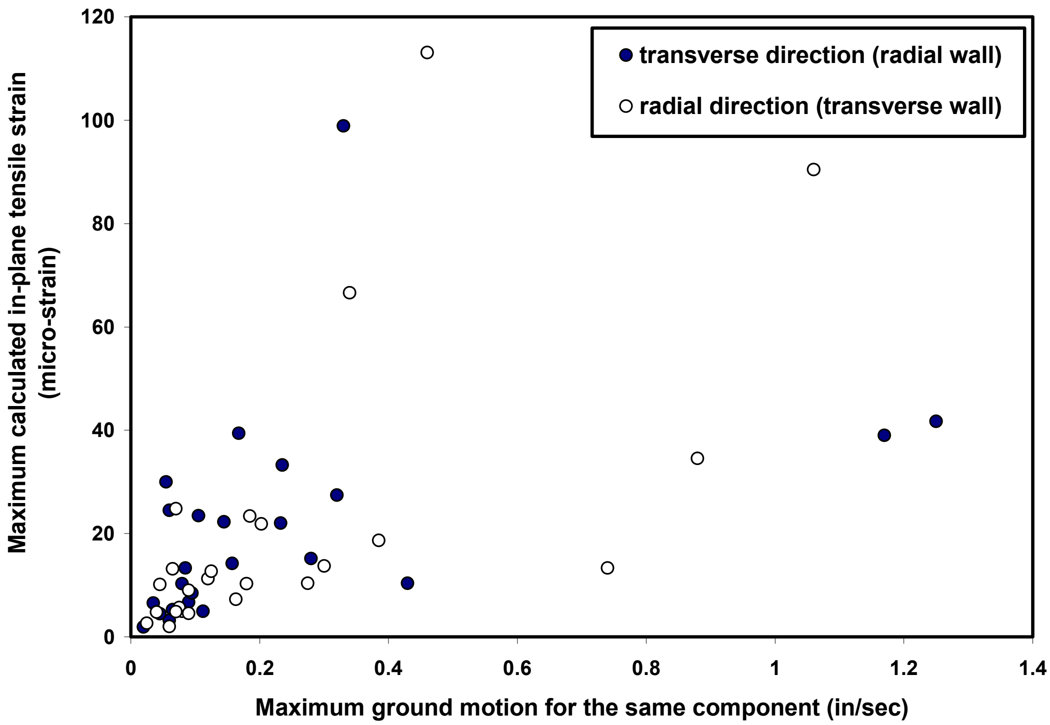


Figure 30 Calculated in-plane tensile strains versus peak particle velocity

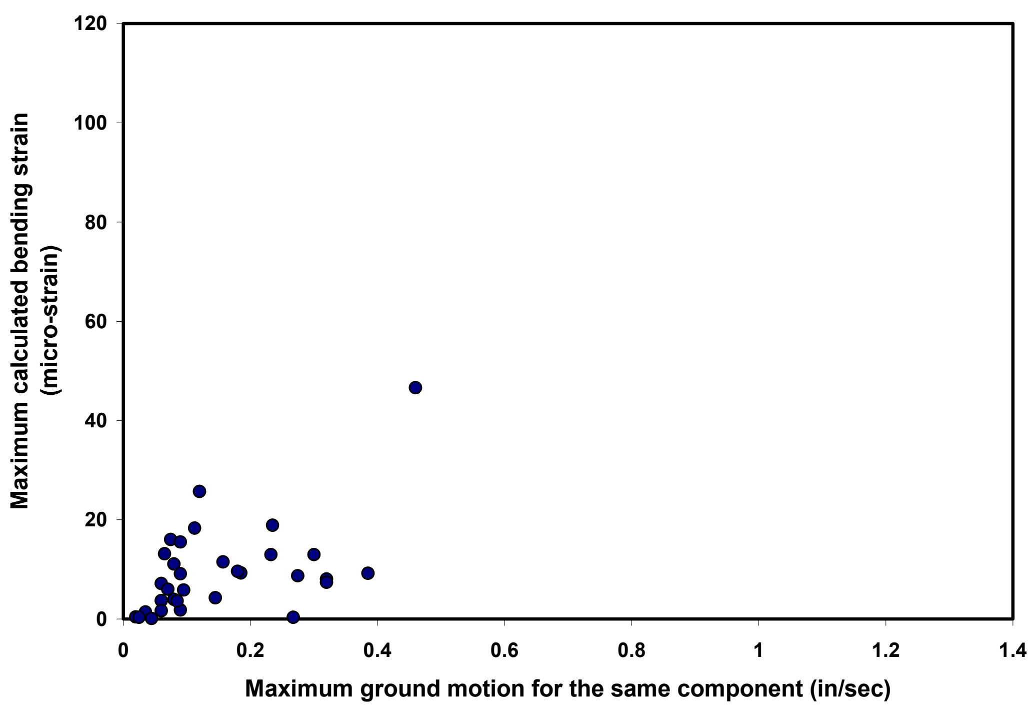
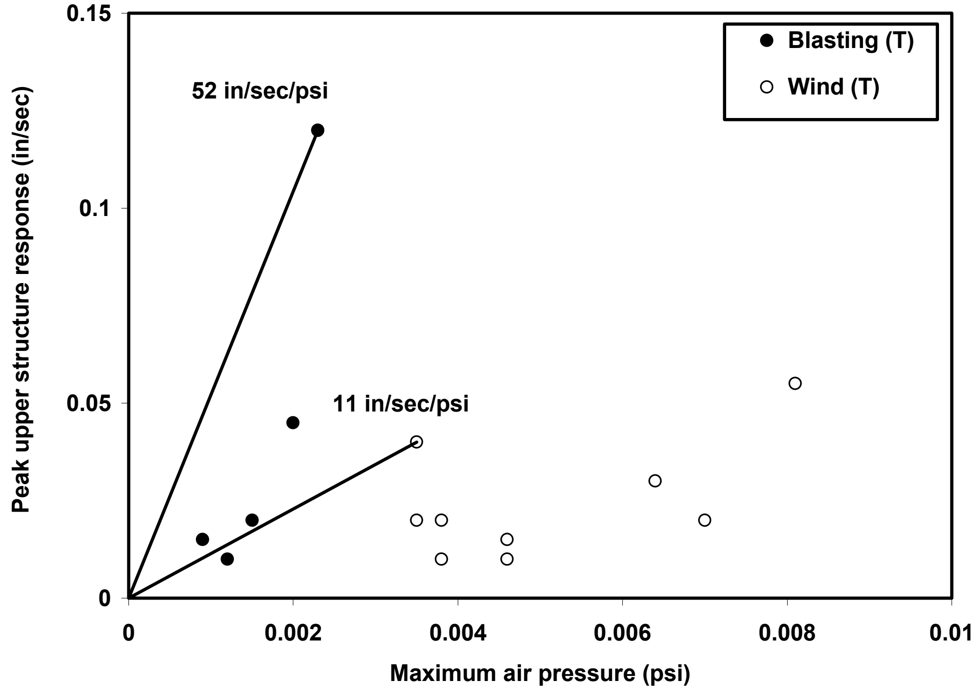
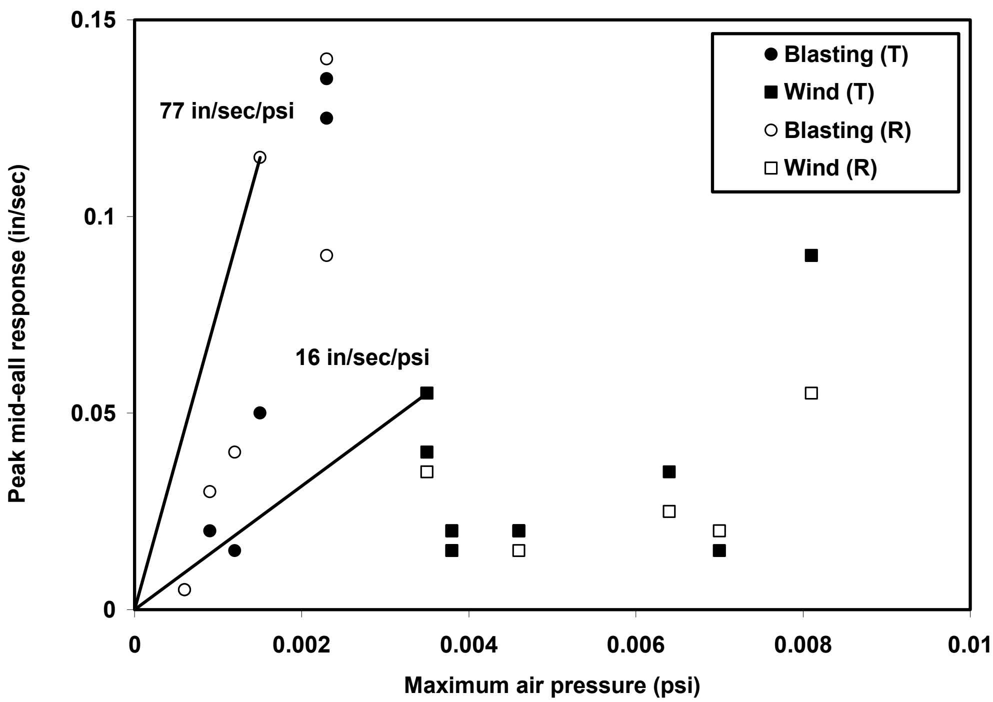


Figure 31 Calculated wall bending strains versus the corresponding peak particle velocity for all horizontal components



(a)



(b)

Figure 32 Structure response versus maximum air pressure measured during blasting and wind gusts for single wide trailer TS-KY2 (a) upper structure (S2) and (b) mid-wall responses