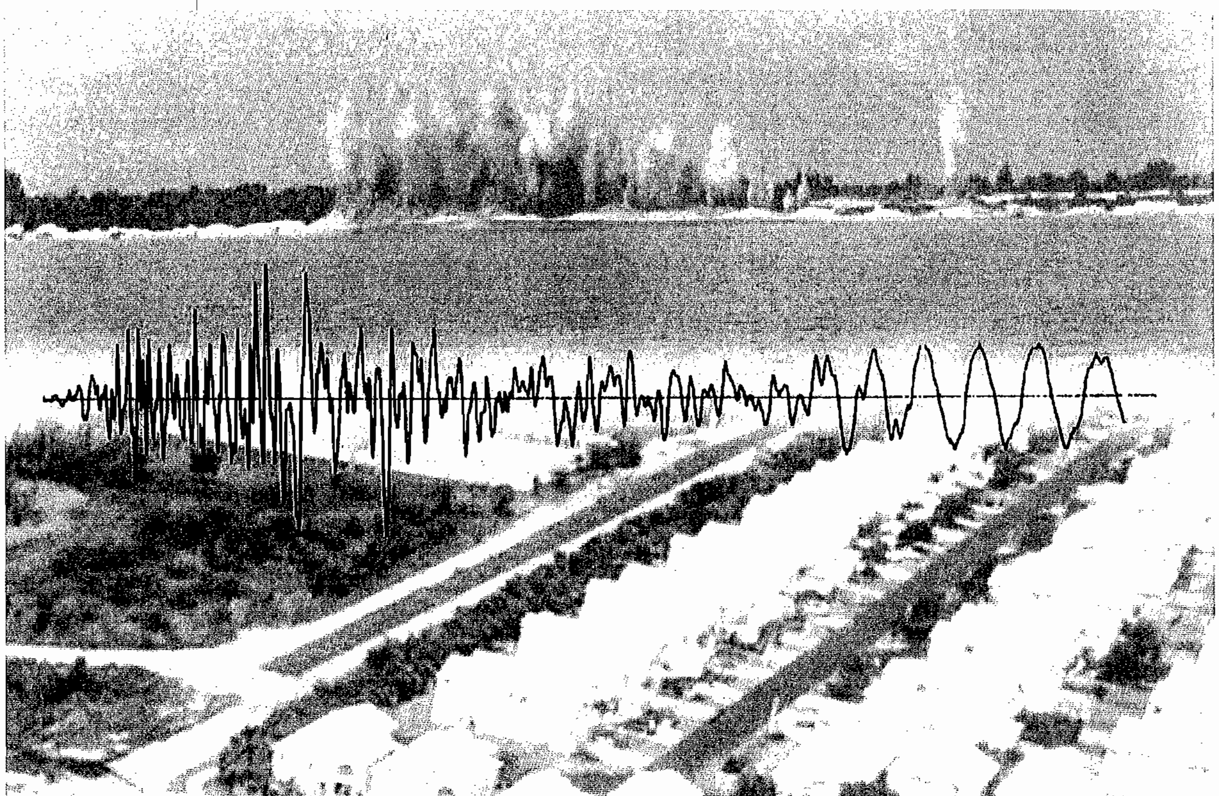
BLAST VIBRATION DAMAGE ASSESSMENT STUDY AND REPORT



PREPARED FOR:

THE MIAMI-DADE COUNTY BLASTING TASK FORCE

FINAL REPORT

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ASSESSMENT OF BLAST VIBRATION IMPACTS FROM QUARRY BLASTING IN DADE COUNTY

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May 10, 2000

EXECUTIVE SUMMARY

DESA examined Dade County blasting for the County through a contract with C3TS. Vibrations and structure responses were measured at 11 locations in the County between February and April, 2000. Also,10 homes were inspected to analyze the characteristics of their cracking and other damages. These results were combined with information collected by the County and other studies done in south Florida for a blasting impact assessment.

As a general conclusion, blasting in local quarries does not appear responsible for cracks and other damages existing in the Dade County residences examined. This is based on vibration amplitudes and frequencies, structure responses, theoretical analyses of material strength and strains, and the nature and degrees of the existing damages in the homes inspected. The existing Dade County blast vibration regulatory limit of 0.75in/s PPV, however, does need to be revisited.

Vibration Amplitude Analysis: The highest predicted vibrations for Dade County blasts at resident's homes are 0.18 in/s for the NW area and 0.35 in/s for the west Miami area based on the "Dade County Data Envelope" and the largest charge weights being used in each area. All amplitudes measured were well below these levels, particularly in the west area. The envelope itself was derived from the highest individual measurements. Vibration amplitudes are relatively high for these distances and charge sizes. Attenuation with distance is less in Dade County than found elsewhere with quarries having to use scaled distances several times higher than similar sites in the north. The vibrations are perceptible at very large distances from even relatively low charge weights per delay.

Vibration Character: Vibrations are of long durations at the homes (some over 17 seconds) and are a mixture of frequencies including "low" frequencies of about 8 Hz, which are close to house resonant frequencies, and very low frequencies of 2 to 4 Hz. The house responses to these low frequencies are particularly noticeable to persons and are understandably alarming.

Structure responses: The response nature of south Florida structures is sufficiently different from frame structures studied elsewhere to justify some concern. Walls of concrete blocks with concrete caps and extensive openings, and sometimes higher than standard 8-ft ceilings, respond as if they have low effective damping. The highest dynamic superstructure amplification exceeded 6x and there were several blasts and structures above 3.6x. More structure response measurements are needed to establish exactly how serious and widespread are these high responses. However, a reduction of the County's limit of 0.75 in/s should be considered and a suggested interim value would be 0.50 in/s.

<u>Wall strain calculations</u>: Worst case vibration amplitude of 0.18 in/s and response of 6.1x in the NW area corresponds to a global or overall in-plane wall strain of about 42 $\mu\varepsilon$. This is sufficiently below the initial cracking levels of 100 $\mu\varepsilon$ for CMU masonry walls that blasting should not have produced cracks in such walls. However, a vibration of 0.75 in/s with the same response factor would produce a global wall strain of over 150 $\mu\varepsilon$. This could cause cracking and justifies a reduction of the allowable limit by about 30 to 50 pct.

<u>Assessments of house damages:</u> Of the 10 houses inspected for the characteristics of damage, five have some wall cracks, mostly exterior, which *could be* from dynamic sources. These are: # 4, 11 (garage), 45, 34, and 42. "Dynamic" here is used for short-period or transient forces which cause superstructure racking and shear forces in the planes of the walls. Examples are blasting and winds. Long-term dynamic sources such as temperature, humidity and soil moisture cycles and unidirectional forces such as soil compaction, differential settlement, and material drying and curing all produce cracks with differing characteristics. The nature of responses from blasting and gusty winds are similar and the worst-case vibration-induced responses of 1.10 in/s (considering dynamic amplification) are equivalent to the effects of winds of about 57 mph. Considering recent Florida storms such as Irene and Andrew, this makes wind responses more likely than blasting to be responsible for the cracks.

<u>Damages other than wall cracks</u>: All other damages are not from blasting or wind-induced responses including any kinds of floor cracks and the very similar and characteristic below-window damages found in many of the homes. These are all construction related, environmental (e.g., water intrusion), or natural responses material responses such as shrinkage and compaction. There is a possible role in construction practices here also such as the question of sufficient foundation soil preparation, and proper stucco mixtures.

Floor damages of any and all sort are not characteristic of vibration responses. Racking of buildings from blast vibrations consists almost entirely of horizontal motions. Upper story floors simply go for a ride as load-bearing walls experience shear deformation and, if sufficiently racked, crack damage at stress concentrations (openings). Floors at ground level and anything below ground, e.g., pools, experience none of their racking and strain. These are only subjected to low-level compression, tension and flexing (bending) as described in Appendix B.

A general conclusion is that in most homes and in most places in the homes, there is a lack of the types of cracks in load-bearing superstructure walls that would be expected from vibration caused racking or any other conceivable vibration response. The few possible exceptions are individually discussed.

DESA STUDY OF DADE COUNTY QUARRY BLASTING

This report is an assessment of blast vibrations generated by quarry blasting in Dade County and of cracking and other damage alleged to have resulted from the blasting. The following questions were addressed:

PURPOSE

1) How typical are these blast vibrations, structures, and site conditions to those studied by the U. S. Bureau of Mines (USBM) and others in establishing the widely-adopted safe level blast vibration criteria?

2) What are the relative responses of selected structures to blast vibrations and non-blasting causes of structural stresses including natural forces.

3) Are the degree and nature of cracking and other damages existing in these structures of the type expected to result from blasting?

4) If judged not typical of blasting, what are the likely causes based on site, structure, construction features, and temporal factors?

5) Does blasting activity accelerate natural soil consolidation thereby causing or contributing to settlement of structures?

6) Are the existing Dade County codes and procedures protective of property from blasting vibrations, and if not, how should they be amended?

SCOPE OF THE PROJECT

This assessment is based on the following:

House inspections made in February and April, 2000

Ground vibrations a measured at eleven sites over a two month period starting February 24, 2000 and involving 42 quarry blasts,

Crack-width measurements at 21 locations plus dynamic monitoring at one site,

About 83 NW Miami vibration records supplied by the County from their 1999 blast monitoring,

Approximately 673 other vibration measurements from quarry and construction blasts in Dade and Broward Counties,

Theoretical analyses of cracking of house materials,

Structure response measurements of representative structures,

Comparisons with studies of blast vibration generation and impacts done by the USBM and others which are described in the Appendices and references.

As this authors of this report, we have high confidence in identifying the effects of blast vibrations and comparing the nature and degree of described damage to the vast body of historical blasting studies. We can with certainty exclude blasting as a cause of most cracks and other damage in these homes. However, we would need to have additional tests done to determine the exact causes for every crack, and fault. Examples of such tests are removal of wall panels, long-term response measurements, soil tests, and excavations down to footings. Therefore, the conclusions on non-blast influences and the specific reasons for damage are on less firm grounds and dependent on further study or other expertise.

Treatment of the technical issues for this assessment was kept brief to make the report more generally useful and readable. However, three comprehensive appendices are provided (B, C and D). These describe the studies used to develop the safe blasting criteria, the nature of blast and non-blast damages, measurements of blasting and non-blasting forces affecting homes, and causes of damage in homes.

STUDY PROCEDURES

The authors Installed seismographs for ground vibration (GV) and structural response (SR) monitoring at the time of their structural inspections. Phase I was the installation of 10 seismographs, February 24 to 27, 2000, in the NW Miami area: Miami Lakes and Palm Springs North (Table 1). In Phase II, five of the 10 seismographs were relocated to areas in west and SW Miami: Doral Landings, Shoma/Superior Homes, and Pelican Cove on April 9 and 10. The remaining five were left in place in the NW area. All instrumentation were removed the weekend of April 29.

Figure 1 shows the general distribution of monitoring sites and Figures 2 to 4 show the relationships of the monitored homes to specific quarries. Note that Riviera Isles (not shown) is just north of the Broward Co. line above Section 5.

SELECTION OF HOMES FOR MONITORING AND INSPECTION

Phase I examined the NW metro area. Dade County officials supplied a list of 19 candidate homeowners in Miami Lakes and Palm Springs North, presumably from a list of those who had complained about the blasting. All had previously been contacted by the County and had expressed at least a tentative willingness to cooperate by allowing inspections of their homes and installation of seismographs. Selection was done by DESA researchers (the authors) based on the best combination of the following:

1) A geographical diversity (sites spread around the area and not concentrated),
2) Closest to the blasting (the most westerly sites),
3) Both single and two story homes,
4) The nature of damage claims,
5) Accessibility of the home via a final okay by the homeowner.

The last item was critical. The home could not be part of the study if access was denied or the homeowner couldn't be reached. In this first phase, 10 seismographs were installed in six homes, three of which included structure response monitoring. In addition, long-term crack-width monitoring equipment was installed in one of the homes (#4). Figure 2 shows these home locations plus the sites for the County's own 1999 measurement program.

Phase II involved areas farther south in west and SW Miami. Again, a list of candidate homes was supplied by the County, 29 in total. However, tentative approvals were not obtained in advance and the approach to them by DESA had mixed results. The selection criteria were the same as Phase I and there was good success in locating the best homes in Doral Landings and at Shoma/Superior Homes (Table 1). The Pelican Cove (Lake, Bay?) area, by contrast, was a shut-out. Of the 10 homes, five declined on advice of their lawyers, one had a scheduling demand that couldn't be met, three did not return calls, and one required someone who spoke Spanish. A public building was found in this area to provide a secure place to locate the last remaining seismograph (Structure #49). Locations of homes for this phase are shown in Figures 3 and 4.

Table 1.- DESA monitoring locations for quarry blasts in Dade Co., Year 2000, in the order instrumented.

House	Location(s) in house	Dates	SN	Trigger
House #6 Palm Springs North, Lakes on the Green	Outside, west wall (GV).	2-24 to 4-29	979	0.02 in/s
	2nd floor ceiling truss in closet of MBR (SR).	2-24 to 4-8	402	0.02
		4-8 to 4-29	402	0.05
House #13 Palm Springs North	Foundation slab SW corner (GV).	2-24 to 4-29	407	0.02
	Roof rafter @ house's SW corner (SR).	2-24 to 4-8	1133	0.02
		4-8 to 4-29	1133	0.05
House #15 Palm Springs North	Slab, NW corner of patio (GV).	2-25 to 4-8	642	0.02
House #4 Miami Lakes (west)	Garage slab at N. wall (GV).	2-25 to 4-30	690	0.02
	Two crack monitors: inside garage on N-wall horiz. crack (SR).	2-27 to 4-30	- -	- -
House #12 Miami Lakes (west)	Garage slab, ctr. of south wall (GV).	2-26 to 4-8	163	0.02
	In ground at SW corner of garage slab (GV).	2-26 to 4-8	187	0.02
	First floor ceiling truss above garage. Trusses run N-S (SR).	2-26 to 4-8	772	0.02
House#11 Miami Lakes (east)	SW corner floor on second story bathroom floor (SR).	2-26 to 4-8	776	0.05
House #45 Doral Landings (NW Miami, close to #42)	Second floor ceiling truss in attic, floor centered (SR).	4-9 to 4-30	642	0.05

Table 1.- DESA monitoring locations for quarry blasts in Dade Co., cont.

House	Location(s) in house	Dates	SN	Trigger
House #34 Shoma Homes/ Superior Homes (west Miami)	N. side of home on slab (GV).	4-9 to 4-30	772	0.025
House #33 Shoma Homes/ Superior Homes (west Miami)	Back Yard, buried (GV).	4-9 to 4-30	187	0.02
House #42 Doral Park (NW Miami)	Back yard, buried (GV).	4-9 to 4-30	776	0.02
Structure #49 SW of West-wind Lakes (SW Miami)	Concrete slab in storage room (GV).	4-10 to 5-1	163	0.04

Notes:
GV = ground vibration measurement
SR = structure response measurement

Houses #6, 11, 42, and 45 are two stories. All others are single story.

House 42 is part of a multi-unit town house oriented N-S. All others except structure #49 are single-family residences. Structure #49 is a public building.

Notes: airblasts were measured at locations # 6, 13, 15, 4, 12, 34, 33, and 42 with triggers set at 120 dB.

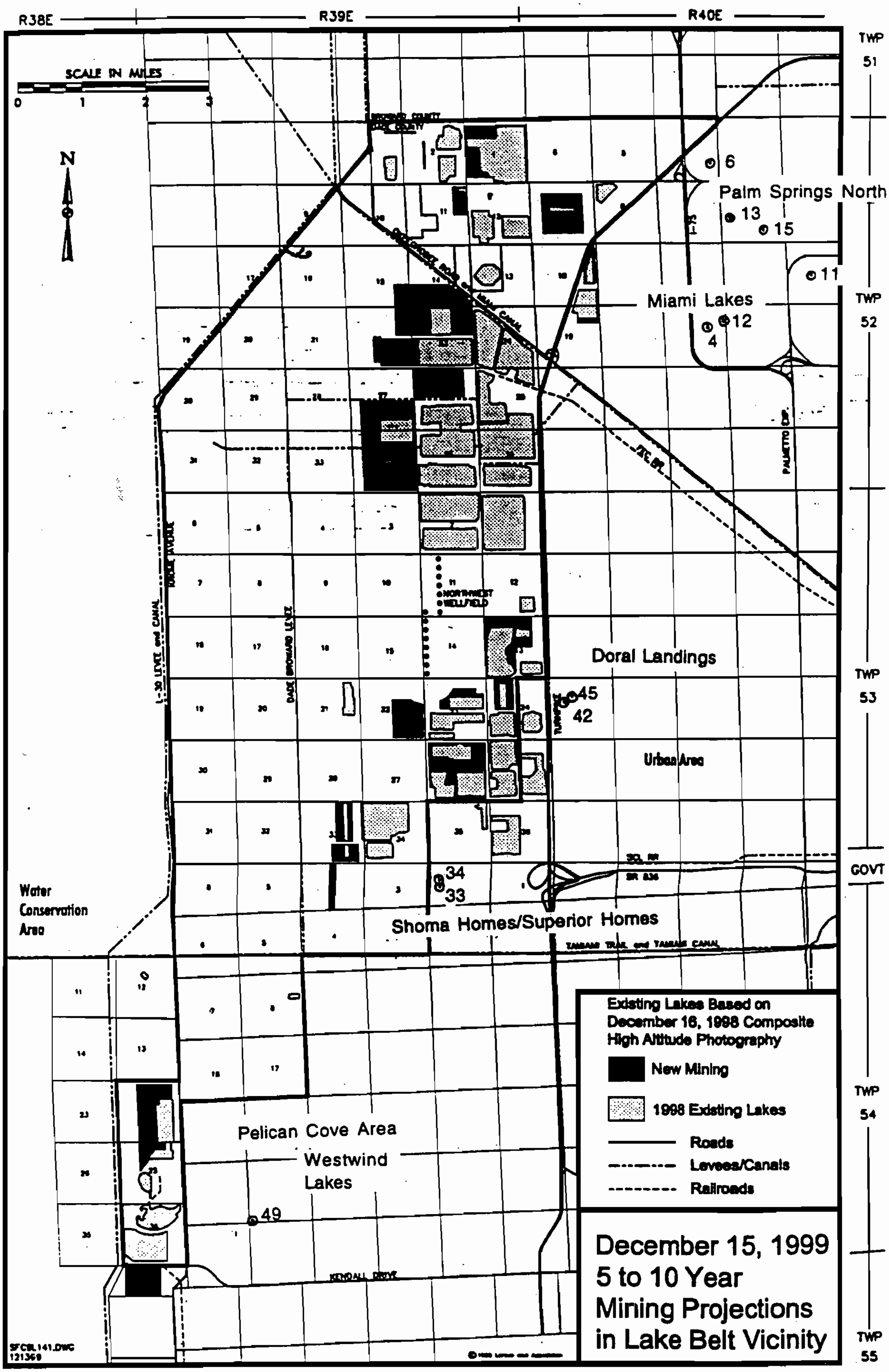


Figure 1.- Overall area of DESA monitoring of Dade County quarry blasts.

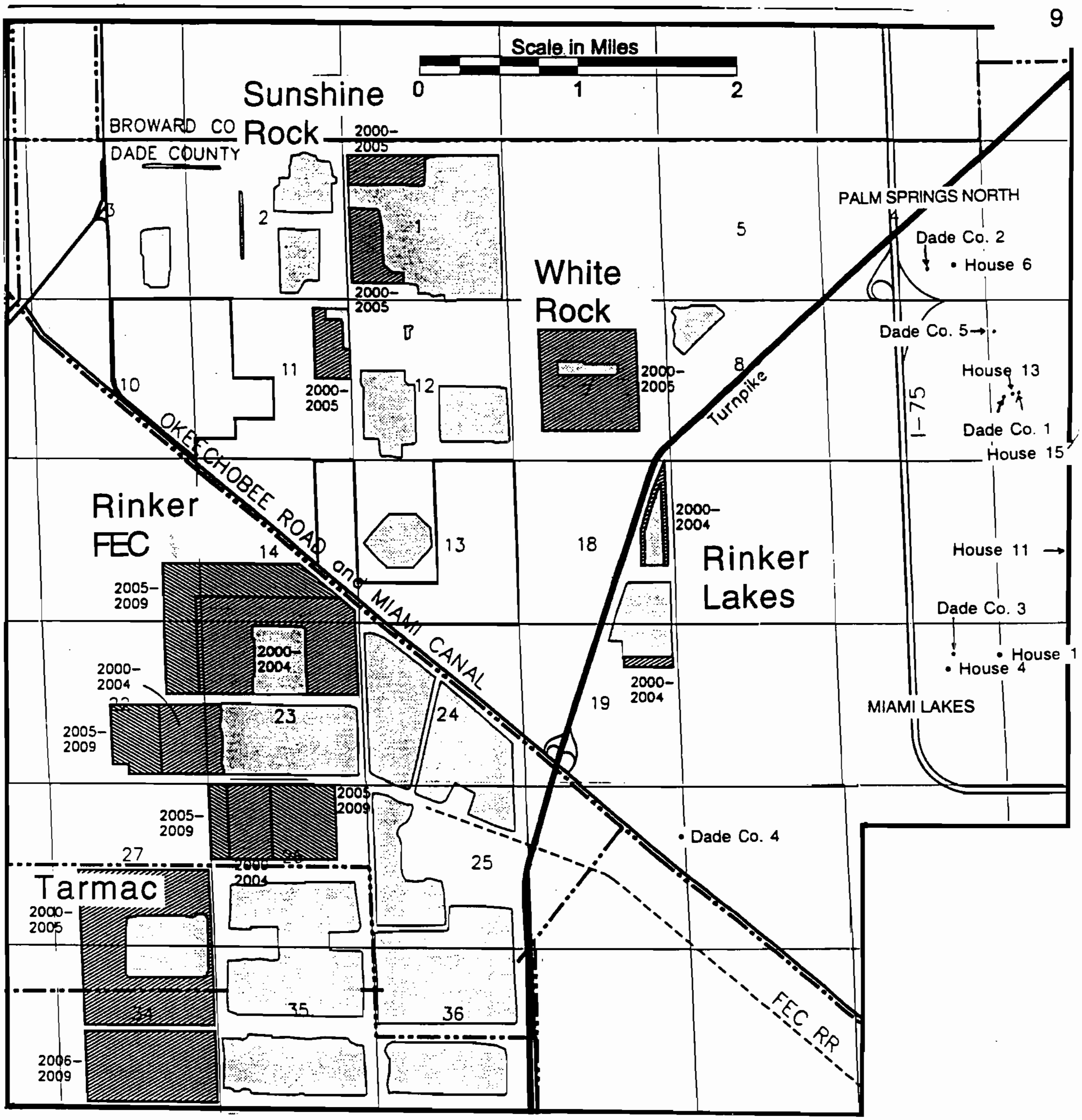


Figure 2.- DESA monitoring in NW Miami area, Dade County.

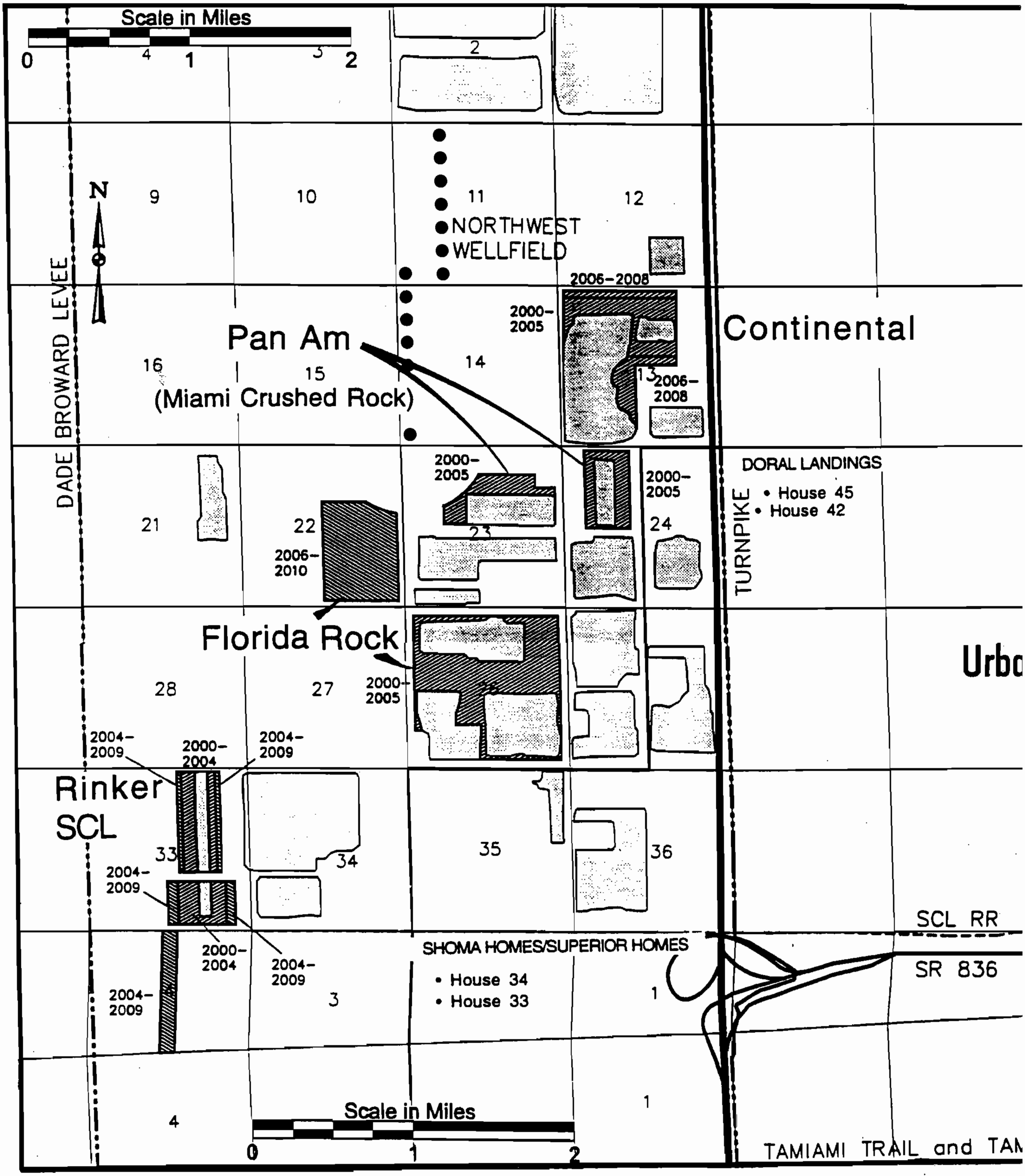


Figure 3.- DESA monitoring in west Miami area, Dade County.

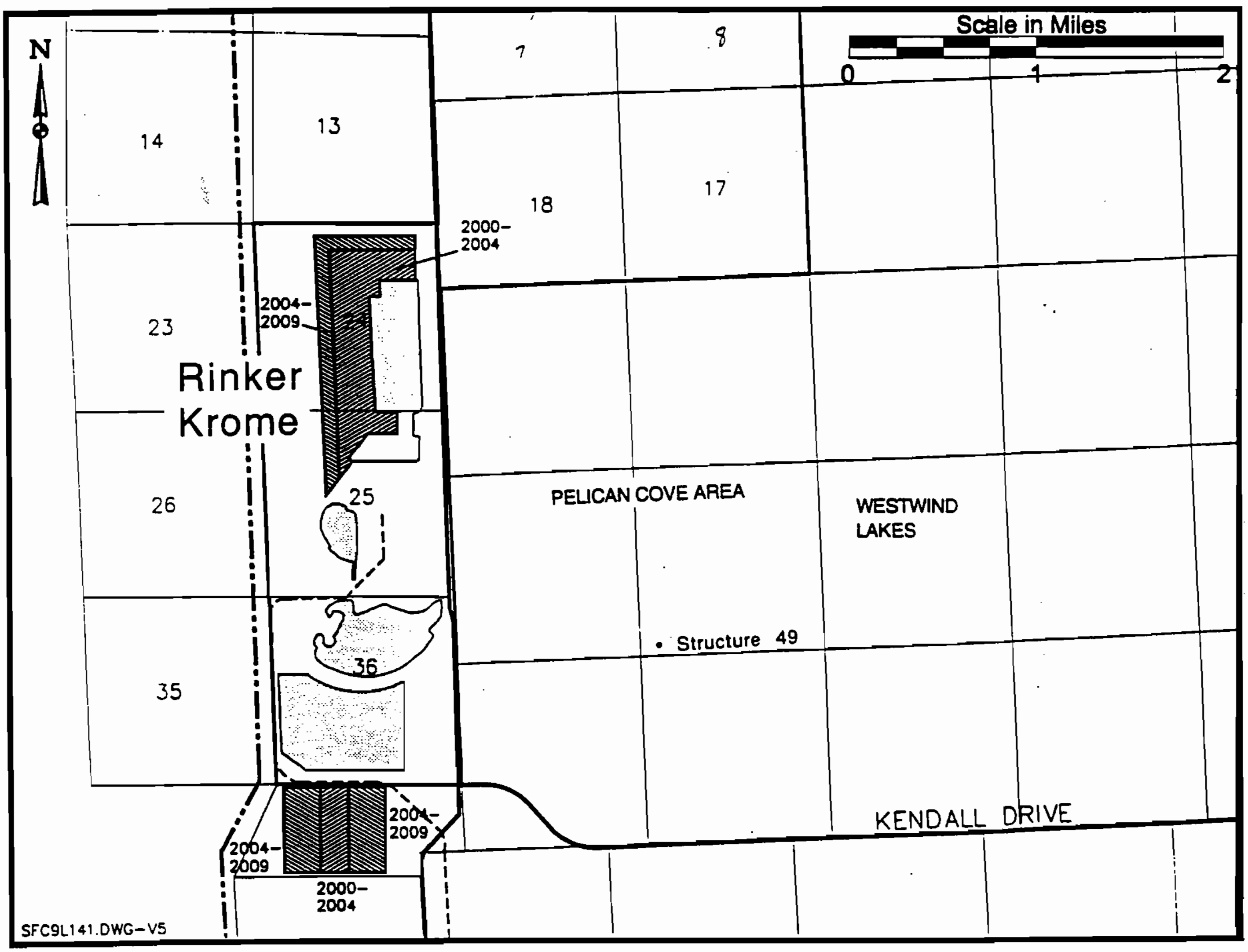


Figure 4.- DESA monitoring in SW Miami area, Dade County.

VIBRATIONS GENERATED BY BLASTING IN DADE COUNTY QUARRIES

QUARRY PROCEDURES RELATED TO BLAST VIBRATION

Blast designs and procedures used by Dade County quarries were beyond the scope of this study and not evaluated. However, DESA wanted to compare vibration amplitudes for this study period with previous times, such as the 1999 monitoring by the County. This required the charge weights per delay for all the blasts after February 25, 2000. Distances were determined from a master map, similar to Figures 2 to 4. Exact locations for blasts in the designated Year 2000 quarry production areas were not known relative to the city street map used to locate the homes. Therefore, blast-to-structure distances were determined from the center of the area designated for year 2000 production and provided the bases for the calculation of scaled distances (A few exceptions to this were blasts at Florida Rock and Miami Crushed Rock as described in the section on vibration amplitudes). This makes distances and scaled distances in doubt by 5 to 10 pct. However, this amount of tolerance is not very significant or even noticeable on the log-log plots which were prepared.

South Florida has become one of the most extensively studied area for blast vibration generation. Figures 5 to 8 are plots of vibration versus scaled distance for all the data collected in south Florida available to the authors. These kinds of plots of vibration amplitude versus distance are standard engineering practices for vibration assessment. The use of scaled rather than simple distances allows a single plot to represent blasts of all sizes. If all blasts were the same size, in pounds per delay, simple distance could then be used.

Peak particle velocities were used in this study and not resultants (vector sums). This is particularly important for structure response assessments where directions (motion components) of vibration and structure response are to be compared. For comparison purposes, resultants are about 10 pct higher that the maximum of the three single components of motion. Figure 5 is resultant data. In the other three plots, ground vibration is the maximum peak particle velocity of the largest component of motion (PPV). The general purpose of such plots are to allow vibration amplitude predictions and also comparisons between different sites and times of monitoring.

VIBRATION AMPLITUDES AT SOUTH FLORIDA HOMES, HISTORICAL DATA

Four sets of historical south Florida data are known to the authors, including the 1999 Dade County monitoring results supplied for this study. Because these were collected from a variety of sites and represent two distinct ways to express vibration amplitude, there was no attempt to produce one grand statistical plot. However, one set is outstanding in the number of measurements and the wide range of scaled distances available for the plot (Johnson, et al., 2000).

Figure 5 shows the Johnson's summary plot of vibrations from 609 Broward County blasts. These are resultant values (vector sums) and not single-component amplitudes (PPV's), plotted by Johnson in accordance with Broward County regulations. There is great variability in this data, partly because measurements from four different sites are combined. However, even single sites were found to have much variability. For example, at a scaled distance of 300 $ft/lb^{1/2}$, the mean vibration amplitude was 0.07 in/s with a measurement range of about .035 to 0.17 in/s. This variability is from geologic differences at the measuring sites and in the vibration transmission paths and also possibly from differing blasting practices. Many quarries studied by the U.S. Bureau of Mines and others have had far less scatter (Siskind, 1997 and 2000).

There are two ways to produce worst-case vibration estimating lines from such data: using some number of standard deviations and using a line which envelopes the data. In this case, the authors chose the more conservative route, an envelope line based on the highest of Johnson's 609 amplitudes (dotted line). This line will also provides a basis of comparisons for the other vibration data sets.

The equation for this line is: $RPPV_{in/s} = 163(ft/lb^{1/2})^{-1.20}$

The "$ft/lb^{1/2}$" term is the square-root scaled distance. With resultants about 10 pct higher than the largest single component of motion, a maximum peak particle velocity line would be:

$$PPV_{in/s} \approx 146(ft/lb^{1/2})^{-1.20}$$

This is the "Johnson data envelope" which is shown on the subsequent plots.

Figure 6 is a summary of quarry blast vibrations collected by Dade County in the year 1999. This represent all the 1999 blasts in the NW Miami area where the seismograph triggers settings of 0.02 in/s were exceeded. Even with no values recorded for blasts below 0.02 in/s, there is still a large range of amplitudes for any given scaled distance. An envelope line was also derived from this data and is shown on the plots as the "Dade County Envelope." This line is close to, but slightly higher than, the Johnson Envelope.

$$PPV_{in/s} = 222(ft/lb^{1/2})^{-1.22}$$

As this is the highest prediction line, it was used to calculate worst-case vibrations for the Dade County blasting. All actual measurements were at or below this line.

Figure 7 shows the Weston data (Siskind, et al., 1996) and the 1979 Rinker Lake measurements (Andrews, 1979). The Weston data have extreme scatter, in part, because some monitoring was done on unconsolidated granular soil. The two high points, for example, would be absent if data measured on the foundation slabs were used. All the Weston and the Rinker Lake measurements fall below the Dade County Envelope and, except for the two high points, also below the envelope from Johnson's data set.

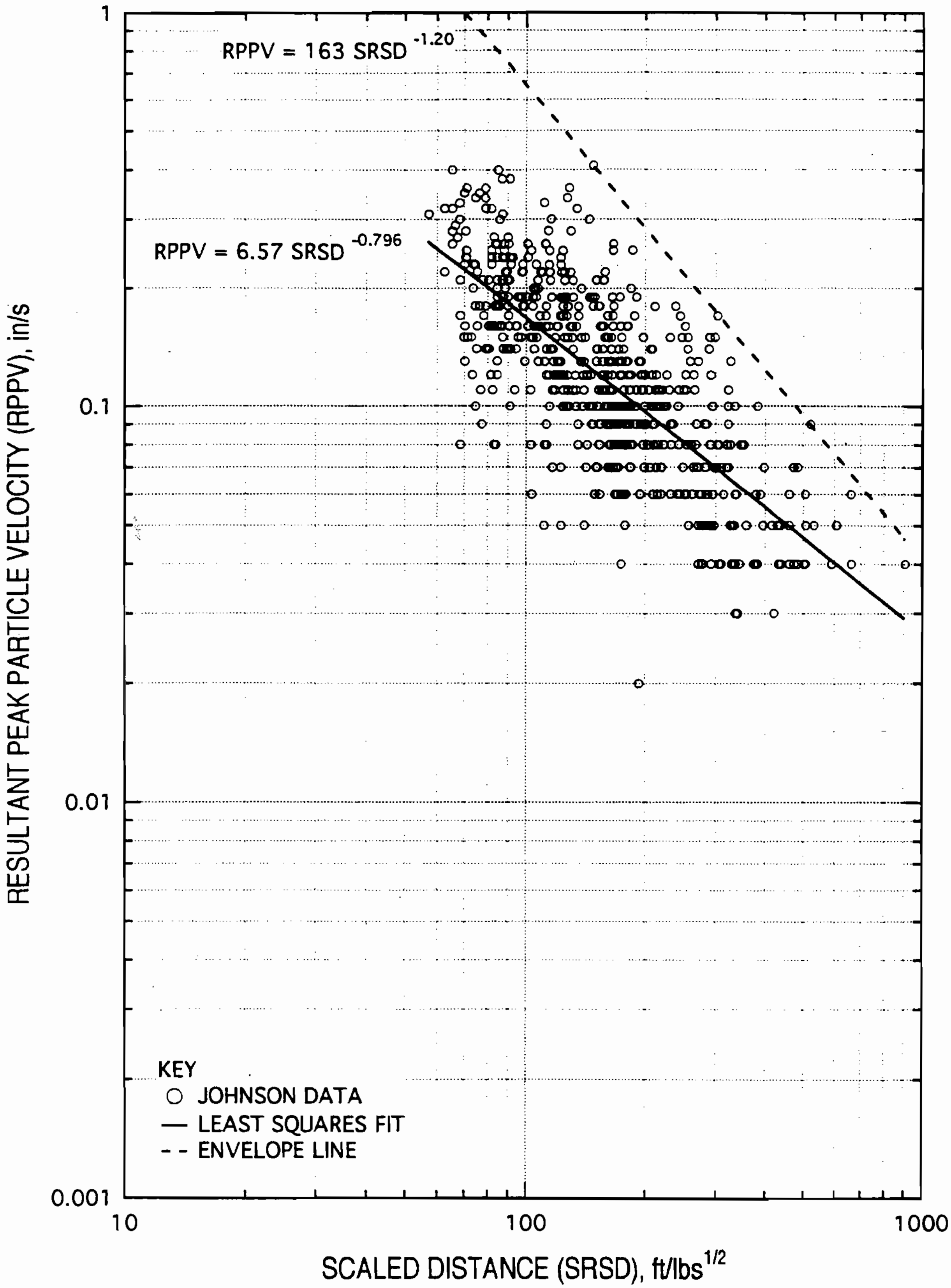
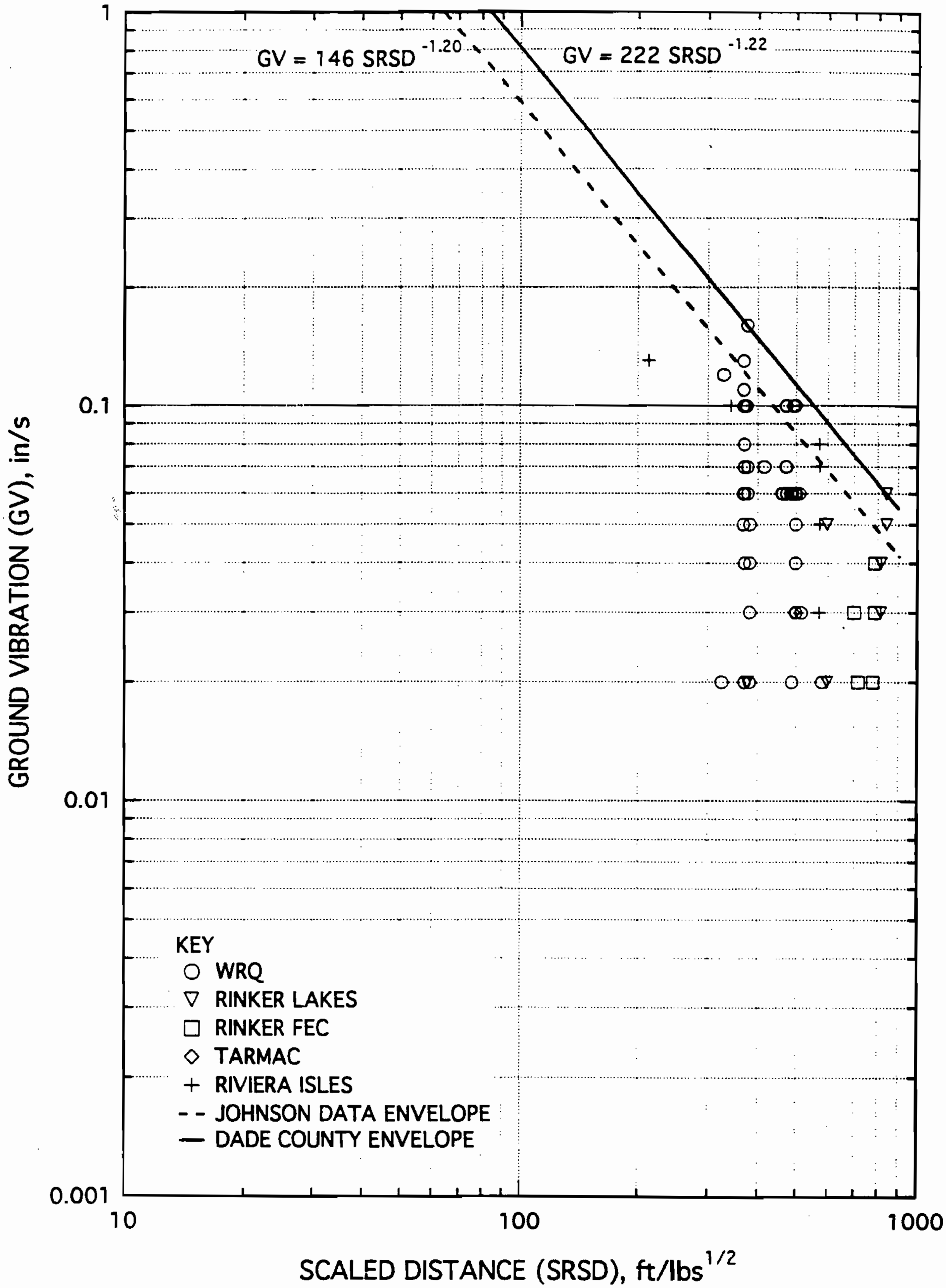


Figure 5.- Propagation plot, vibration amplitude versus distance from 609 blasts in Broward County, from Johnson, et al., 2000. Values plotted are resultants (vector sums).

DESA



DESA

Figure 6.- Propagation plot, vibration amplitude versus distance from 1999 Dade County monitoring of quarry blasts in NW Miami areas of Miami Lakes and Palm Springs North.

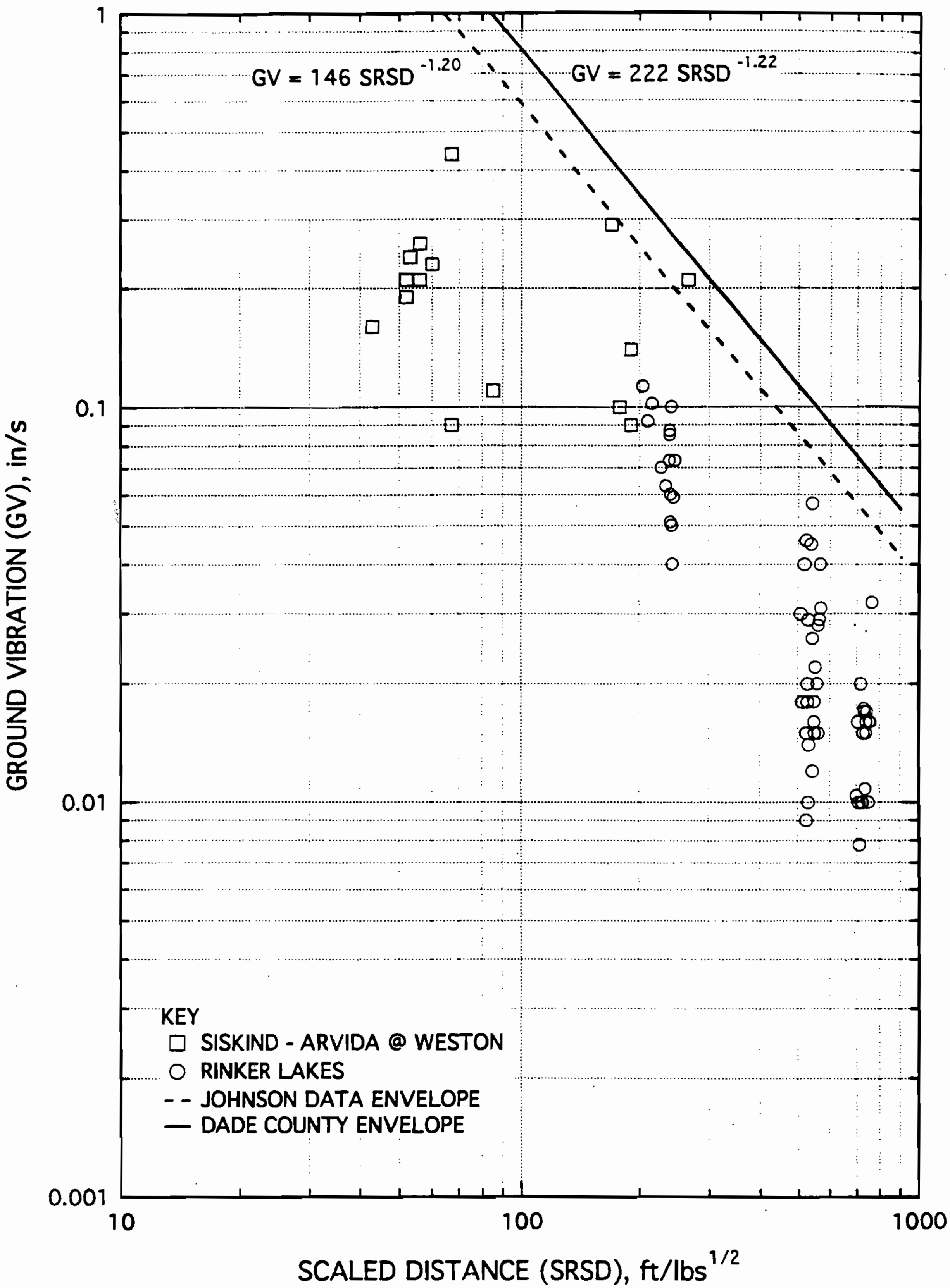


Figure 7.- Propagation plot, vibration amplitude versus distance from USBM's Weston Arvida site study (Siskind, et al., 1996) and the Andrews Rinker Lake study of 1979.

VIBRATION MEASUREMENTS AT AREA HOMES FROM FEB. TO APRIL, 2000

Figure 8 summarizes data collected by DESA for this study with the measurements from the 41 blasts listed in Appendix A. The scatter here is far less than the County's 1999 data, although it is only two months of monitoring compared to one year for the County. These amplitudes are, on the average, similar to those obtained by the County in 1999 and all are below the worst-case Dade County data envelope.

Some individual vibration amplitudes appear high. This and the high scatter or variability suggest the question is: did the blast detonated properly or was the effective charge weight per delay somehow not as designed or reported?
The causes of the relatively high vibration are beyond the scope of this study, however, some ideas come to mind. The water filled pits likely provide additional confinement during the critical and short explosive detonation process when the vibrations are generated. This would lead to higher vibrations at the source. The geology and structure greatly influence the vibration decay with distance. The low attenuation is almost certainly from the highly permeable layer over more competent rock. This favors the generation of surface waves, particular vibration frequencies, and especially low frequencies (discussed in the next section).

The U.S. Bureau of Mines had found generally high vibration amplitudes at other low-frequency sites and correlated these to the use of two-short delays (Siskind et al., 1989). The usual practice of using 8-ms intervals to define charge weight per delay may not work effectively at sites where the wave periods are 100 ms and longer (vibrations of less than 10 Hz) and longer time intervals may be needed there to provide the destructive wave interference for multi-delayed blast rounds. Experimenting with delays is a possible tool for the quarries to reduce vibration amplitudes and possible impacts to neighbors.

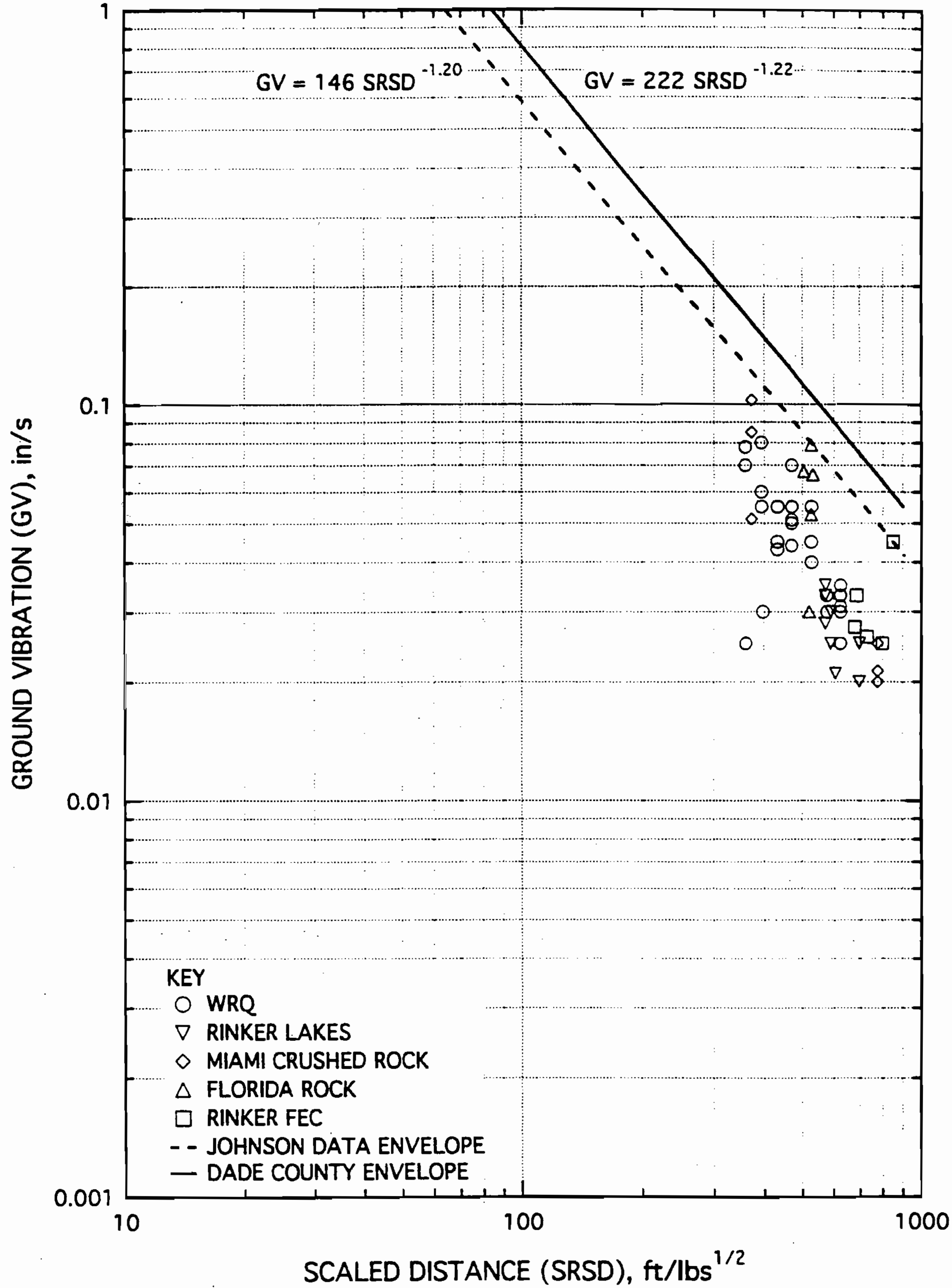


Figure 8.- Propagation plot, vibration amplitude versus distance from DESA monitoring of Dade County quarry blasts, February to April 2000.

VIBRATION AMPLITUDE PREDICTIONS FOR DADE COUNTY HOMES

The purpose of the above plots and analyses are to answer the questions: Are the vibrations generated by Dade County blasts typical of other areas and were the vibrations measured by DESA during the February to April 2000 study period typical of other periods of blasting in the County? The answers are "no" and "yes," respectively.

Dade county blasting generates relatively high vibrations and great scatter (variation). Use of prediction formulas to control vibrations in place of monitoring would not be a good idea here. For example, a summary of eleven northern USA limestone quarries found a mean and maximum vibration of about 0.10 and 0.20 in/s, respectively, at a scaled distance of 100 $ft/lb^{1/2}$. The Dade County data suggests about 0.15 and 0.45 for this same scaled distance, even correcting for the differences between resultant and PPV. This difference becomes greater at larger distances. Some Dade County blasts had amplitudes of 0.06 in/s at scaled distances above 800. The maximum envelope (highest vibration amplitude) at 11 limestone quarries outside of Florida was 1/30 of this at the same at this scaled distance. Because 0.06 in/s creates perceptible house responses, this explains why people at great distances complain about blasting and are concerned about possible damages.

Figure 9 shows the Dade County measurements superimposed on the eleven-limestone quarry summary and their relatively high vibration amplitudes at large scaled distances.

Table 2 gives predicted worst-case amplitudes for the closest homes to the Dade County quarries based on the Dade County envelope of highest measured values. Some quarries cover an extensive area and distances to neighboring homes vary enormously depending where in the permit area they are blasting. This is particularly so with Miami Crushed Rock and Florida Rock which have homes closer than most of the NW area quarries. Because of their large operating areas relative to the blast-to-home distances, scaled distances for these two quarries were calculated from their blast coordinates and not average values. These two quarries would likely have to reduce their shot sizes when operating near their eastern borders. Vibration amplitudes would then be lower than predicted in Table 2. Based on the few of blasts monitored by DESA in the west and SW Miami area, the highest vibration there would likely be under 0.12 in/s.

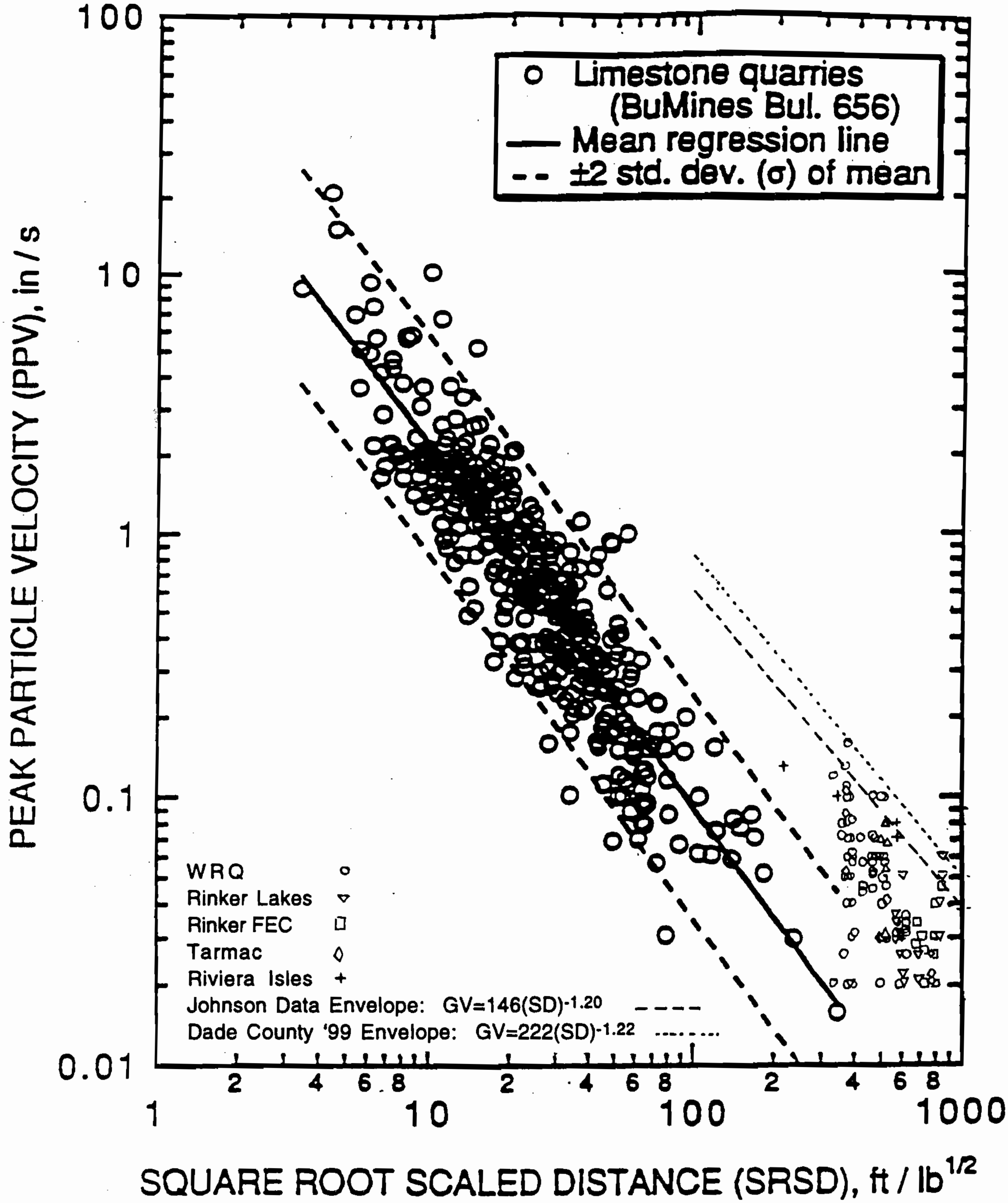


Figure 9.- Summary of 11 northern limestone quarries plus Dade County quarry vibration values. From, Crum, et al., 1995.

Table 2.- Vibration predictions for homes based on the Dade County data envelope.

Max or worst-case $PPV_{in/s} = 222(ft/lb^{1/2})^{-1.22}$
$ft/lb^{1/2}$ is scaled distance

House number	Minimum dist., ft	Close Quarry	Max weight, lbs/delay	Minimum scaled dist	Maximum PPV, in/s
6	11,800	WRQ#7	1,242	335	0.18
13	13,000	WRQ#7	1,242	369	0.16
13	11,400	Rinker Lakes	413	561	0.10
15	15,600	WRQ#7	1,242	443	0.13
15	13,900	Rinker Lakes	413	684	0.08
4	14,600	WRQ#7	1,242	414	0.14
4	9,200	Rinker Lakes	413	453	0.13
4	25,000	Tarmac	1,347	689	0.08
12	15,500	WRQ#7	1,242	440	0.13
12	10,800	Rinker Lakes	413	531	0.11
11	20,900	WRQ#7	1,242	593	0.09
11	18,400	Rinker Lakes	413	905	0.06
45	5,700	Continental	NA	- -	- -
45	4,600	Miami Cr Rk	473	211	0.32*
45	8,200	Fl Rock	421	400	0.15
34	7,100	Rinker SCL	NA	- -	- -
34	7,600	Fl Rock	421	370	0.16*
33	7,300	Rinker SCL	NA	- -	- -
33	7,900	Fl Rock	421	385	0.156
42	5,700	Continental	NA	- -	- -
42	4,300	Miami Cr Rk	473	198	0.35*
42	7,600	Florida Rock	421	370	0.16*
49	9,400	Rinker Krome	NA		

NA = charge weights not available and calculations not made.
* Likely vibrations would be < 0.12 in/s (see text).

SPECIFIC BLASTS IDENTIFIED DURING STUDY PERIOD

3-29-00 @ 10:30: This blast was of particular concern to neighbors but was measured as only 0.035 in/s. This is about half the amplitude of the blast of 3-27-00 which had similar frequency and duration characteristics. Unfortunately, there were no structure responses for these blasts.

VIBRATION CHARACTER: FREQUENCIES AND DURATIONS

South Florida sites: Some of these are known to generate long-duration low-frequency vibrations of around 4 Hz. These can be particularly noticeable and alarming even at relatively low amplitudes. Low frequencies from blasting are not particularly unusual, resulting wherever there is a near-surface low-velocity layer over a more competent strata. Examples have been found in areas of thick glacial drift and old lake bed deposits near the surface. The USBM studied and reported on such sites in Kentucky, Pennsylvania, and Indiana . Specific to south Florida are the Weston tests and the 1979 study of Rinker Lake quarry in Dade County.

Procedures: All DESA seismograph measurements in Dade Co. had the R (radial) component oriented E-W and the T (transverse) oriented N-S, making the radial approximate the direction to the quarries. Initially, recording durations were set to 8 seconds with the expectation that continuing high vibration or a high airblast would retrigger the seismograph. Durations were increased to 16 seconds for the second phase. Some specific peaks have amplitudes and frequencies indicated on them as an aid in analysis.

Waveform examples: Figures 10 through 13 are waveform for vibrations measured at four of the homes. Additional results are given in the response section. The frequency and duration characteristics were generally similar at homes throughout the area. Two features stand out:1) most waveform records exhibit two distinct frequencies, a high beginning of 8 to about 30 Hz and a later arriving surface wave of 2 to 4 Hz, and 2) they have long durations of up to and sometimes exceeding 16 seconds.

Figures 10 shows the long duration of recordings made at large distances. The amplitude here is low in terms of possible structure cracking but still within the range of producing noticeable structure rattling. The complexity of these waveforms indicates the significant and unpredictable influence of the layered geology and a possible but lesser role for the source function of design and geometry. The frequency complexity is evident by casual inspection. This waveforms start out at relatively high frequencies of 17 to 30 Hz. An 8-Hz character begins to become visible at about 3 seconds with the higher frequency still present and riding the 8-Hz wave. This is joined by a 2-Hz starting after about 4.5 seconds which becomes the dominant wave after about 8 seconds and is still going at the record's end at 17 seconds. This tail-end ground-roll has the characteristics of a Rayleigh surface wave, strongest on the vertical, also present on the radial, but absent on the transverse. Rayleigh waves are generated by low velocity surface layers overlying stronger rock.

Figure 11 shows a somewhat different character with a low frequency of about 6 Hz right at the beginning. Figure 12 is from the southwest area (Shoma/Superior Homes) and has similar character to Figure 10 from Palm Springs North. Figure 13 from Dural Park (actually Dural Landings) has a resemblance to Figures 10 and 12 but a shorter duration from the closer blast and less geology (shorter travel path and time) to spread out the vibration wave.

D. E. SISKIND & ASSOCIATES (DESA)
FOR C3TS / DADE COUNTY
STRUCTURE: 6
LOCATION: PALM SPRINGS NORTH

Event Number: 036 Date: 4/24/00 Time: 9:45 + 2H
Acoustic Trigger: 120 dB Seismic Trigger: 0.02 in/s Serial Number: 979

Amplitudes and Frequencies	**Graph Information**
Acoustic: 106 dB @ 19.6 Hz.	*Duration:* 0.000 sec To: 17.000 sec
Radial: 0.025 in/s @ 19.6 Hz.	*Acoustic:* 0.20 Mb (0.05 Mb/div)
Vertical: 0.0225 in/s @ 42.6 Hz.	*Seismic:* 0.02 in/s (0.005 in/s/div) .036 in/s in of graph
Transverse: 0.0225 in/s @ 17.0 Hz.	*Time Lines at:* 1.00 sec intervals
Vector Sum: 0.025 in/s	

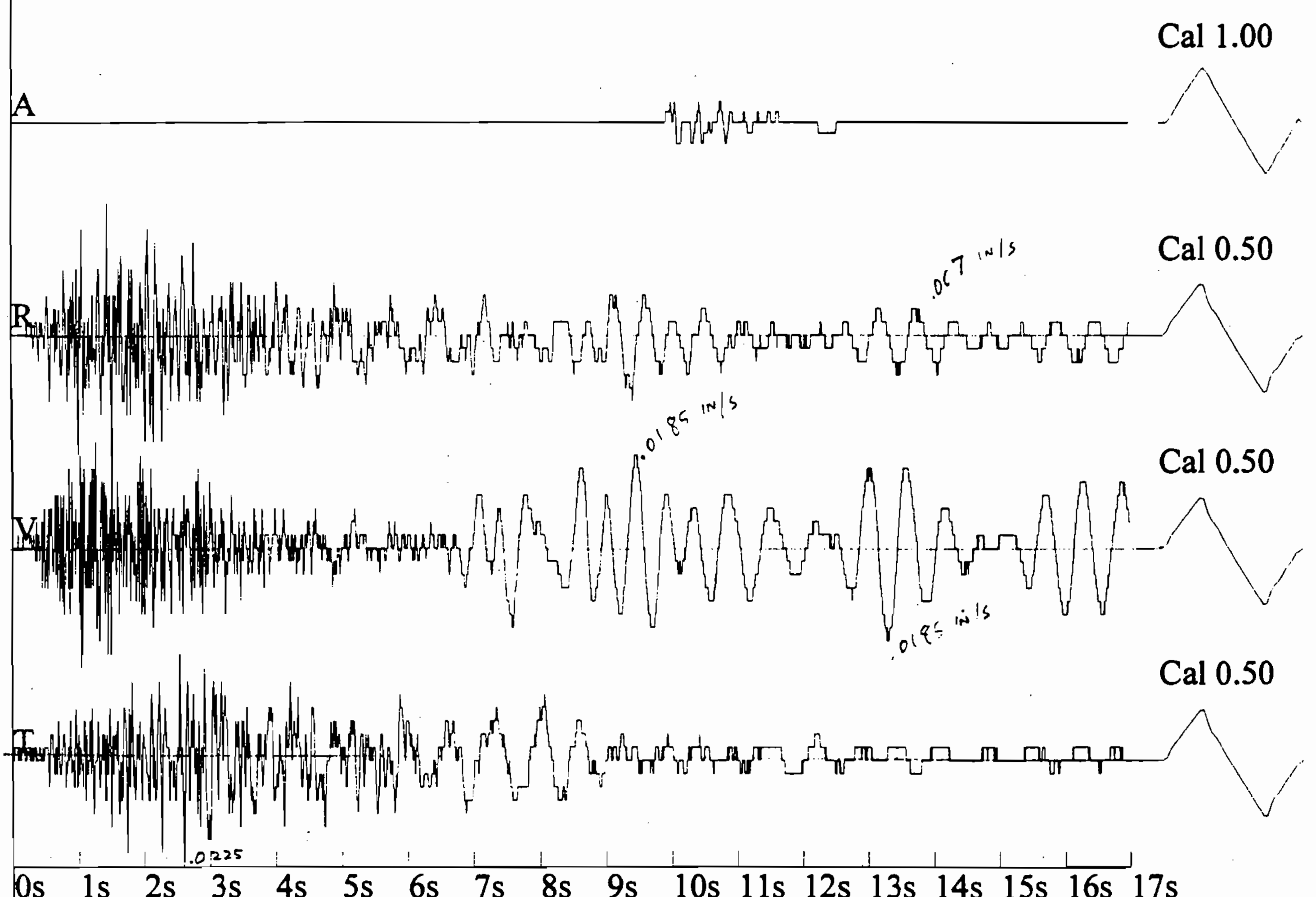


Figure 10.- Long duration vibration waveform record with both high and low frequencies. WRQ Section 7 blast at about 12,700 ft. Palm Springs North.

D. E. SISKIND & ASSOCIATES (DESA)
FOR C3TS / DADE COUNTY
STUCTURE: 15
LOCATION: PALM SPRINGS NORTH

Event Number: 019 Date: 3/27/00 Time: 14:34
Acoustic Trigger: 120 dB Seismic Trigger: 0.02 in/s Serial Number: 642

Amplitudes and Frequencies	Graph Information
Radial: 0.07 in/s @ 5.3 Hz.	*Duration:* 0.000 sec To: 9.000 sec
Vertical: 0.06 in/s @ 2.9 Hz.	*Seismic:* 0.07 in/s (0.0175 in/s/div)
Transverse: 0.05 in/s @ 2.8 Hz.	*Time Lines at:* 1.00 sec intervals
Vector Sum: 0.07 in/s	

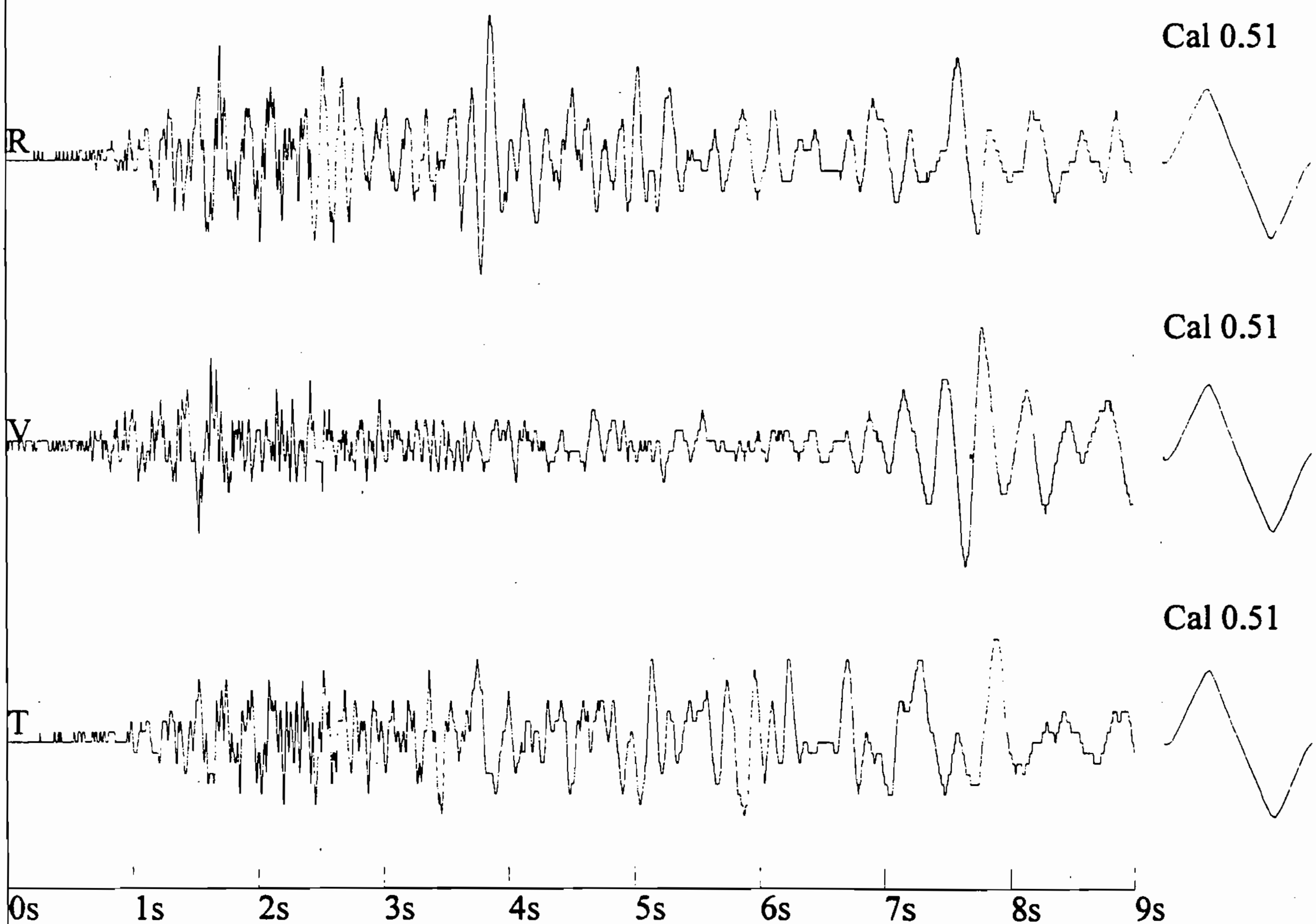


Figure 11.- Ground vibration record from WRQ Section 7 blast 15,500 ft from House 15.

D. E. SISKIND & ASSOCIATES (DESA)
FOR C3TS / DADE COUNTY
STRUCTURE: 33
LOCATION: SHOMA HOMES

Event Number: 029 Date: 4/26/00 Time: 12:03 + 1HR
Acoustic Trigger: 120 dB Seismic Trigger: 0.02 in/s Serial Number: 187

Amplitudes and Frequencies	**Graph Information**
Radial: 0.025 in/s @ 19.6 Hz.	*Duration:* 0.000 sec To: 17.000 sec
Vertical: 0.04 in/s @ 32.0 Hz.	*Seismic:* 0.08 in/s (0.02 in/s/div)
Transverse: 0.0787 in/s @ 28.4 Hz.	*Time Lines at:* 1.00 sec intervals
Vector Sum: 0.0787 in/s	

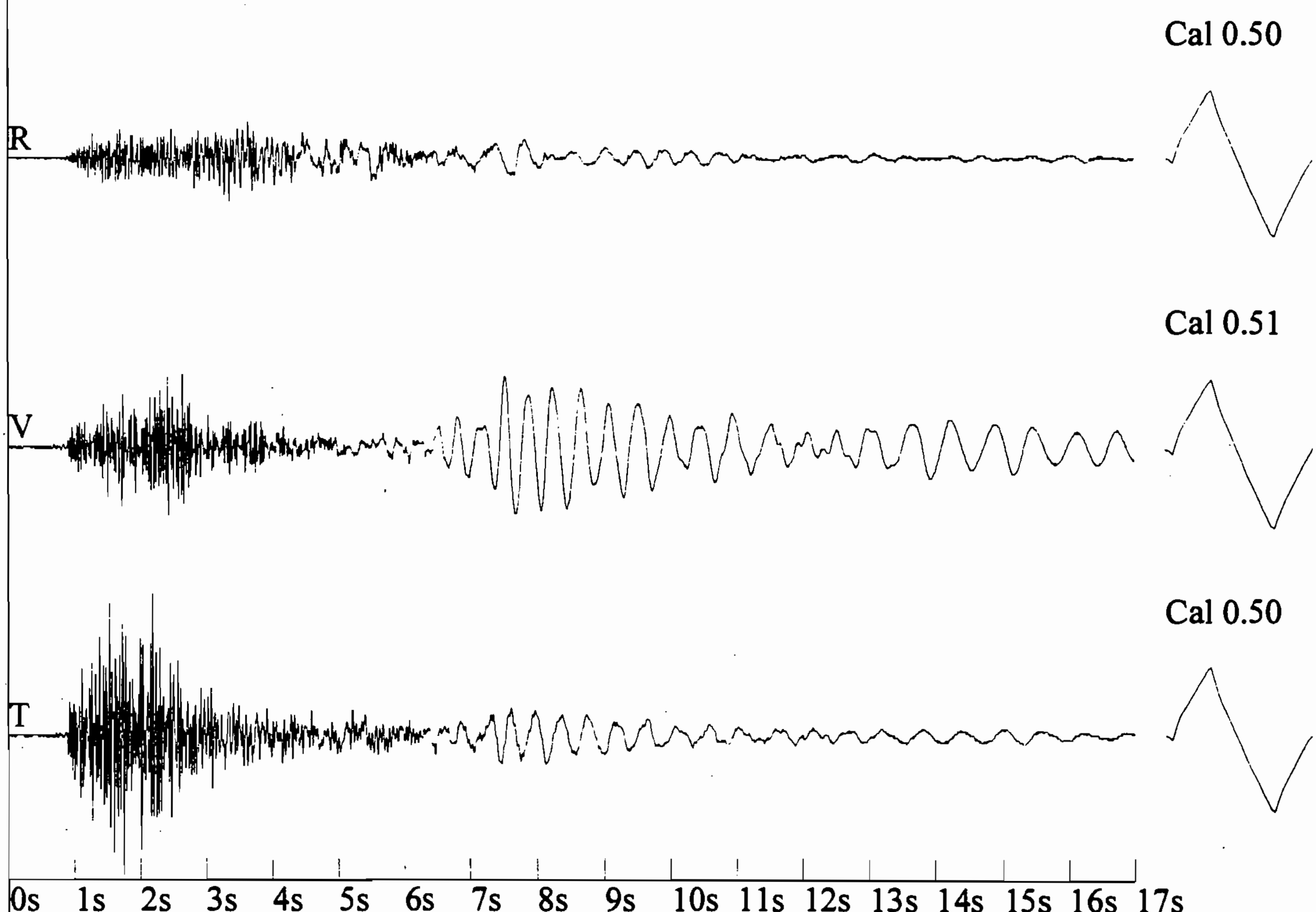


Figure 12.- Long-duration vibration waveform record with both high and low frequencies. Florida rock blast at about 10,900 ft. Shoma Homes area.

D. E. SISKIND & ASSOCIATES (DESA)
FOR C3TS / DADE COUNTY
STRUCTURE: 42
LOCATION: DORAL PARK

Event Number: 003 Date: 4/10/00 Time: 10:31 +1HR
Acoustic Trigger: 120 dB Seismic Trigger: 0.02 in/s Serial Number: 776

Amplitudes and Frequencies	**Graph Information**
Acoustic: 100 dB @ 0.0 Hz.	*Duration:* 0.000 sec To: 17.000 sec
Radial: 0.1025 in/s @ 51.2 Hz.	*Acoustic:* 0.20 Mb (0.05 Mb/div)
Vertical: 0.0725 in/s @ 51.2 Hz.	*Seismic:* 0.10 in/s (0.025 in/s/div)
Transverse: 0.0413 in/s @ 32.0 Hz.	*Time Lines at:* 1.00 sec intervals .165 in/s / in of graph
Vector Sum: 0.1138 in/s	

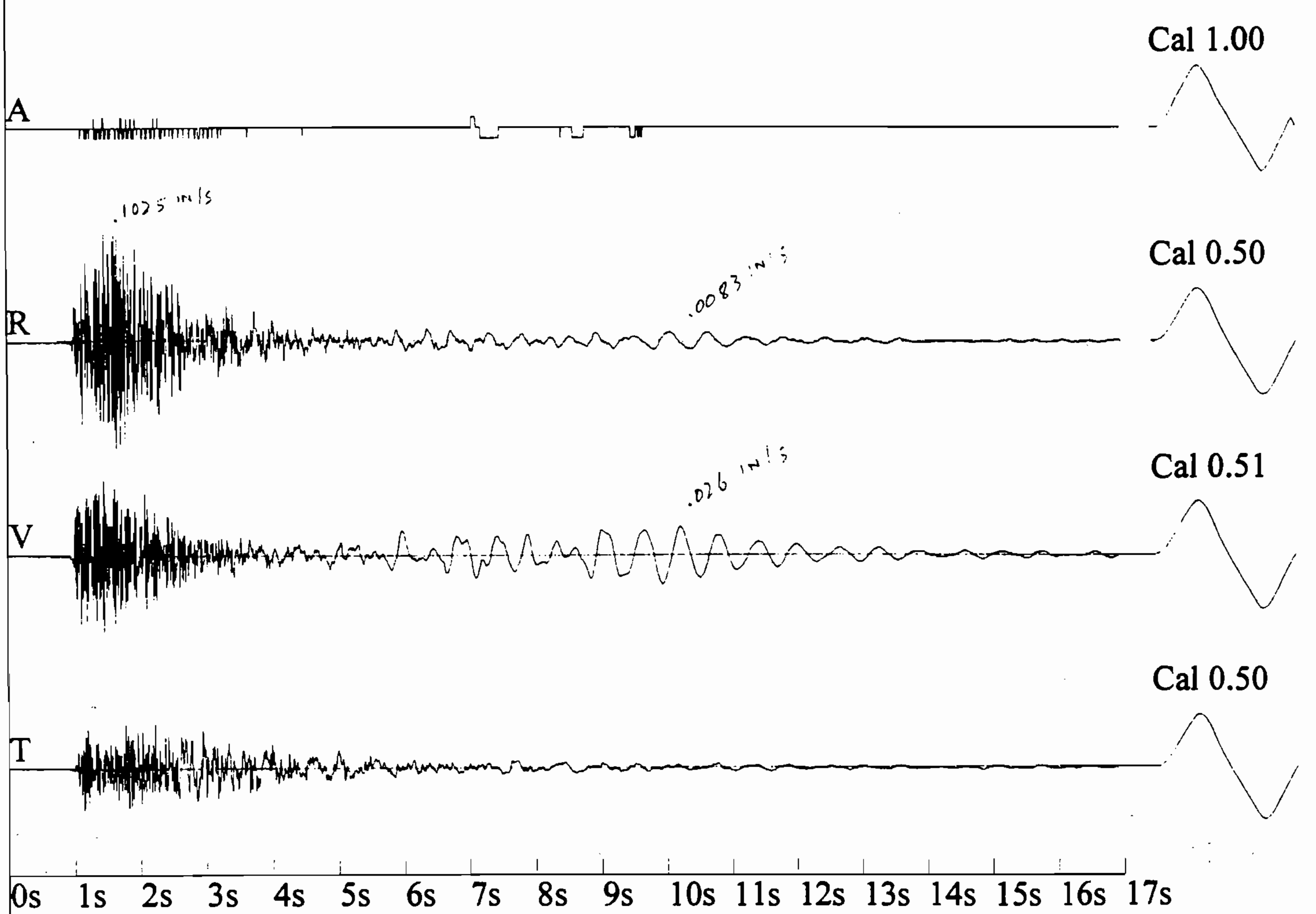


Figure 13.- Highest vibration record from monitoring at House 42. This is a Miami crushed Rock blast at 8,100 ft.

RESPONSES OF SOUTH FLORIDA HOMES TO BLAST VIBRATION

HISTORICAL DATA

Two previous studies examines structure responses from south Florida blasts. The first was the previously mentioned study of Rinker Lake quarry blasting and structure responses in the late 1970's (Andrews, 1979). Five structures total and four per blast were monitored for vibration and response at distances of 3/4 to 2-3/4 miles. The 18 production and six single-hole blasts were 300 and 400 lbs per delay. Researchers found frequencies as low as 3.3 Hz and high relative responses (up to 3.7x racking response amplification). Note, amplification factors are responses compared to ground vibrations, time correlated. With the highest PPV being 0.135 in/s, there were no new cracks or crack extensions although some homeowners found the responses alarming.

In 1995, U.S. Bureau of Mines studied the blasting at the Weston's Arvida Development in Broward County. Vibrations were again found to be low frequency. Most significantly, some of the structural responses, at 4.7x, were slightly higher than previous tests elsewhere on wood frame houses, which maxed at 4.3x (Appendix C). Analysis suggested that the reason was the large extent of glass represented by the full length windows and doors in a key high-ceiling structural corner and relatively high wall mass. This corner had less interior stiffening than would have existed with a stud/wallboard structure and therefore had a relatively low vibration damping. Response frequencies were still within the typical range of homes studied elsewhere, but the low damping apparently resulted in relatively high responses at resonance frequency. The relationship between frequency, damping, and response is discussed in Appendix C.

DESA RESPONSE DATA FOR DADE COUNTY HOMES, FEBRUARY TO APRIL 2000

<u>Blasting:</u> Figures 14 and 15 are waveforms records for ground vibrations and structure responses, respectively, for House #6. Figures 16 and 17 are similar records for House 13. Because of the complexity of reading these records with their different amplitude scales, amplitudes and frequencies of significant parts of the waveforms have been measured and labeled on the figures. Additionally, dynamic amplification factors are given on the response plots (Figures 15 and 17) at the approximate times they apply. Note that separate response assessments were made for the high and low frequencies.

Generally, the most useful data for response and cracking potential are the horizontal responses. Vertical structure motions are not amplified. In addition in House 6 (Figure 15), the structural response transducer was on a second floor

D. E. SISKIND & ASSOCIATES (DESA)
FOR C3TS / DADE COUNTY
STUCTURE: 6
LOCATION: PALM SPRINGS NORTH

Event Number: 027 Date: 2/28/00 Time: 14:12 + 1 HR
Acoustic Trigger: 120 dB Seismic Trigger: 0.02 in/s Serial Number: 979

Amplitudes and Frequencies	**Graph Information**
Radial: 0.07 in/s @ 7.0 Hz.	*Duration:* 0.000 sec To: 8.500 sec
Vertical: 0.0675 in/s @ 2.0 Hz.	*Seismic:* 0.07 in/s (0.0175 in/s/div)
Transverse: 0.0475 in/s @ 5.8 Hz.	*Time Lines at:* 1.00 sec intervals
Vector Sum: 0.075 in/s	0.085 IN/S / IN OF GRAPH SCALE

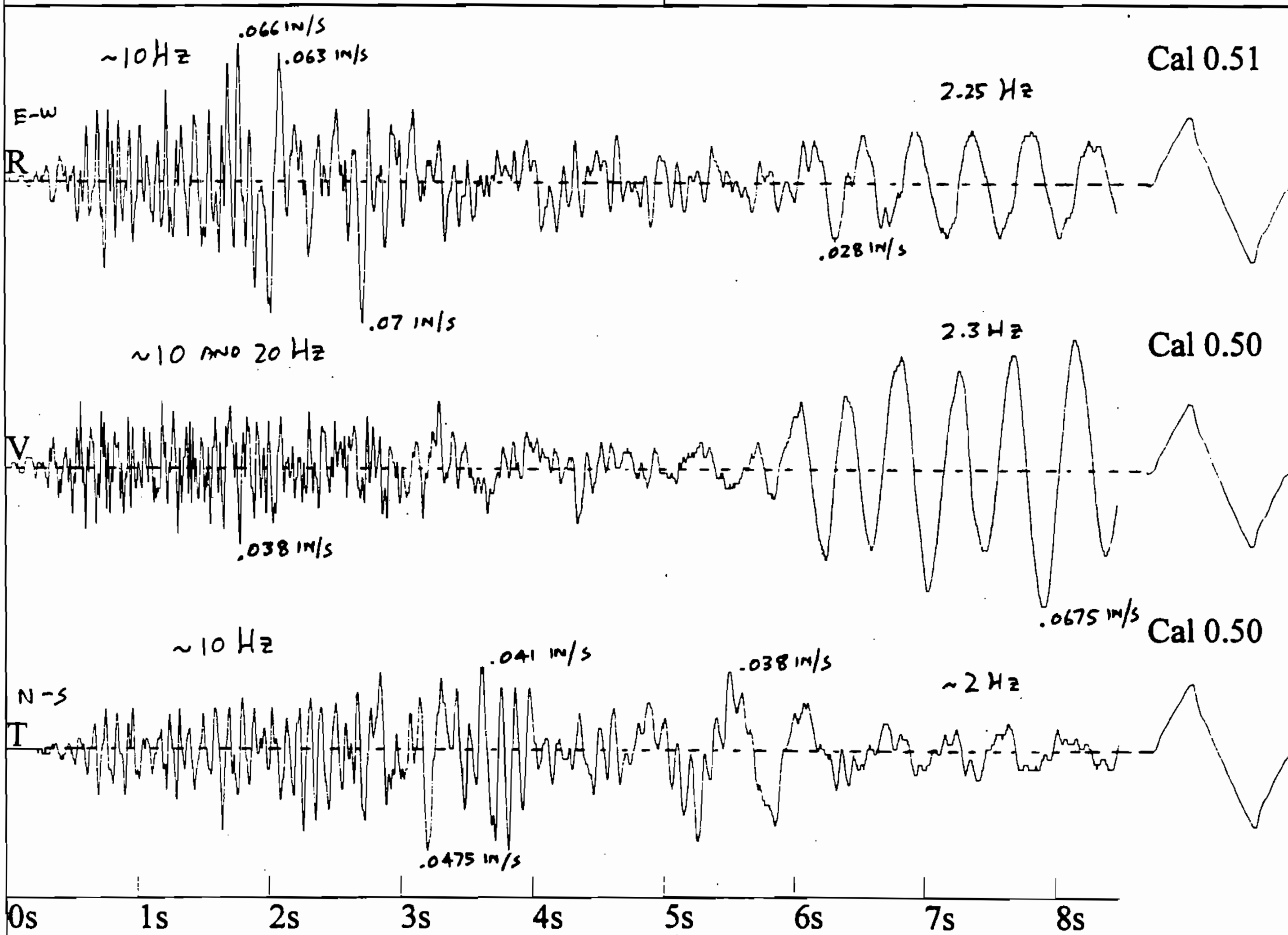


Figure 14.- Highest vibration record from monitoring at House 6. WRQ Section 7 blast at about 12,600 ft.

D. E. SISKIND & ASSOCIATES (DESA)
FOR C3TS / DADE COUNTY
STUCTURE: 6
LOCATION: PALM SPRINGS NORTH
2ND STORY CEILING

Event Number: 132 Date: 2/28/00 Time: 15:16
Acoustic Trigger: 128 dB Seismic Trigger: 0.02 in/s Serial Number: 402

Amplitudes and Frequencies	Graph Information
Radial: 0.245 in/s @ 9.4 Hz.	*Duration:* 0.000 sec To: 8.500 sec
Vertical: 0.295 in/s @ 11.9 Hz.	*Seismic:* 0.30 in/s (0.075 in/s/div)
Transverse: 0.25 in/s @ 10.0 Hz.	*Time Lines at:* 1.00 sec intervals
Vector Sum: 0.36 in/s	0.36 in/s / in of graph

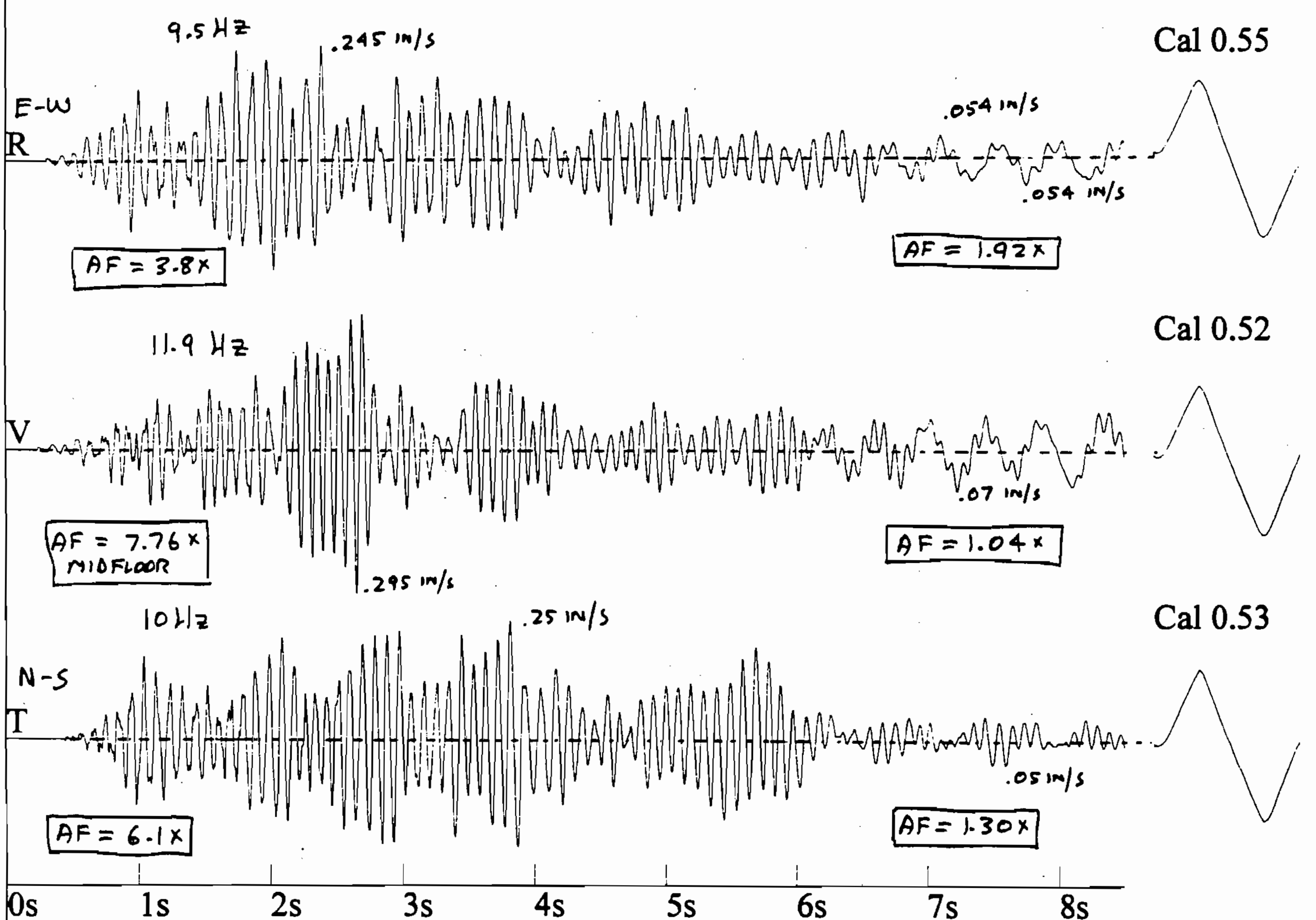


Figure 15.- Structure response record for House 6 from the same blast shown in Figure 14.

D. E. SISKIND & ASSOCIATES
FOR C3TS / DADE COUNTY
STRUCTURE: 13
LOCATION: PALM SPRINGS NORTH

Event Number: 001 Date: 2/25/00 Time: 14:44
Acoustic Trigger: 130 dB Seismic Trigger: 0.02 in/s Serial Number: 407

Amplitudes and Frequencies	**Graph Information**
Radial: 0.045 in/s @ 6.7 Hz.	*Duration:* 0.000 sec To: 9.000 sec
Vertical: 0.045 in/s @ 2.1 Hz.	*Seismic:* 0.06 in/s (0.015 in/s/div)
Transverse: 0.055 in/s @ 1.3 Hz.	*Time Lines at:* 1.00 sec intervals
Vector Sum: 0.055 in/s	.072 IN/S/IN OF GRAPH

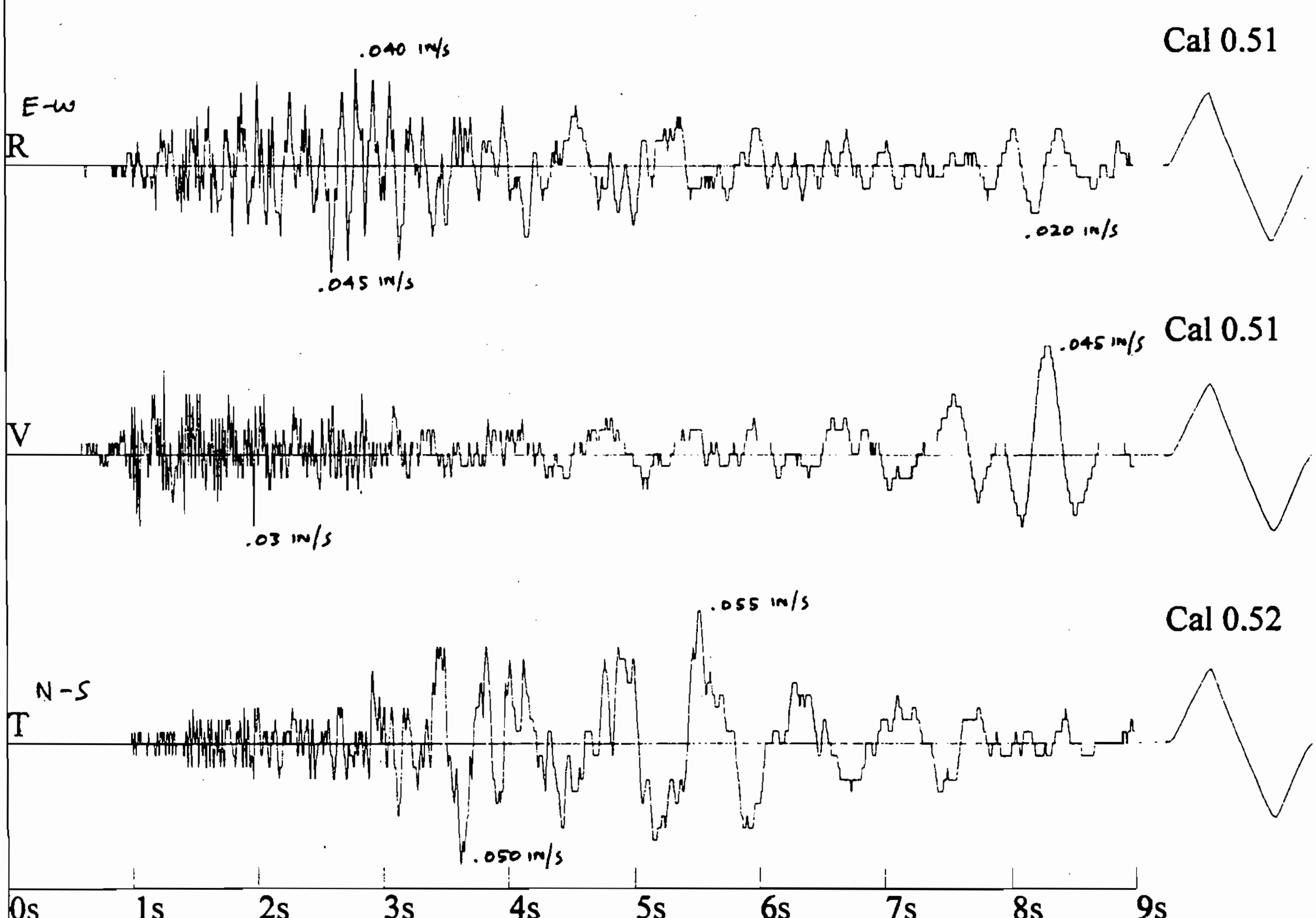


Figure 16.- Vibration record from monitoring at House 13 when structure response was also recorded (Figure 17). WRQ Section 7 blast at about 13,900 ft.

D. E. SISKIND & ASSOCIATES (DESA)
FOR C3TS / DADE COUNTY
STUCTURE: 13
LOCATION: PALM SPRINGS NORTH
1ST STORY CEILING

Event Number: 007 Date: 2/25/00 Time: 14:45
Acoustic Trigger: 120 dB Seismic Trigger: 0.02 in/s Serial Number: 1133

Amplitudes and Frequencies	Graph Information
Radial: 0.0725 in/s @ 13.8 Hz.	*Duration:* 0.000 sec To: 8.500 sec
Vertical: 0.0525 in/s @ 30.1 Hz.	*Seismic:* 0.07 in/s (0.0175 in/s/div)
Transverse: 0.065 in/s @ 15.0 Hz.	*Time Lines at:* 1.00 sec intervals
Vector Sum: 0.075 in/s	.085 in/s/in of graph

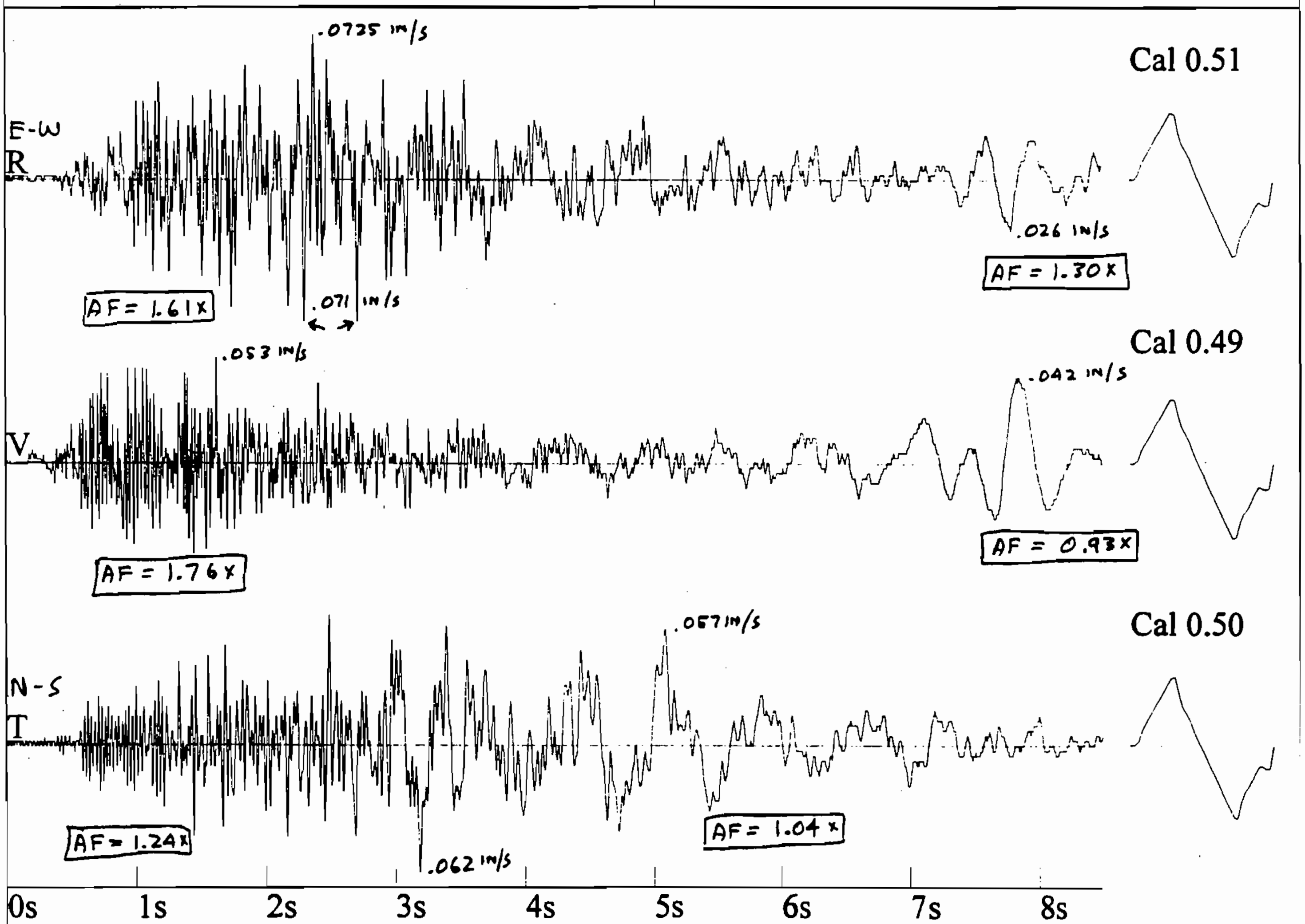


Figure 17.- Structure response record for House #13 from the same blast shown in Figure 16.

ceiling rafter and not a structural corner. Hence the vertical component does not measure whole structure response but rather mid-floor motion. House 13 by contrast measured corner responses with all three components of motion.

House 6: Most significant for two-story house were the large dynamic amplifications of horizontal vibrations 3.8x (E-W) and 6.1x (N-S) at the "higher" frequencies of 9 to 10 Hz. Previous non-Florida USBM data for amplifications found averages of about 2x and maximums of 4.3x. These responses are high, even without even knowing if the exact resonant frequencies were experienced and if these are the highest responses possible.

House 13: By contrast to House 6, the single story house's response was typical of homes studied previously and elsewhere with dynamic amplifications of around 1.2 to 1.76. Again unfortunately, there is no way with the small amount of response data to verify that this was the worst possible case. The initial part of the vertical response component is of such a high frequency, at 30 Hz, that it likely the vertical flexing of the mounting bracket or structural sub-component rather than representative of the structure as a whole. In any event, it is the horizontal responses which are relevant to high strains and cracking potential.

House 11: This house was far enough from the blasting that responses rather than ground vibrations were measured. There were only three triggers between 2-26 and 4-8 (23 blasts) and Figure 18 is the largest of these.

House 45: Like structure 6, this is a two-story house with structure response measured in the second floor attic. Ground vibration was not measured here but nearby at House 42 (Figure 13). With the close proximity of these two structures relative to the structure-to-blast distances, the ground vibration was assumed to apply to both homes. Fig 19 is the largest response measured at this house.

Summaries of measured structure responses and calculated amplification factors are given in Tables 3 and 4. Amplifaction factors are time-correlated.

Non-blast responses: Figures 20 and 21 are non-blast structure responses. The one for House 13, Figure 20, is likely the closing of the sliding door in the wall beneath the corner being monitored. This amplitude was as high as many of the blasts. The House 12 record, Figure 21, appears to be a real event (and not an electronic spike) and is of a significant amplitude of 0.64 in/s in the E-W direction and is the largest of 86 such events. As the trusses run N-S, there is likely little stiffness transverse to them and such response from a hard door closing is possible. The high frequency suggests a component response rather than whole-structure.

D. E. SISKIND & ASSOCIATES (DESA)
FOR C3TS / DADE COUNTY
STRUCTURE: 11
LOCATION: MIAMI LAKES
2ND STORY FLOOR

Event Number: 009 Date: 3/27/00 Time: 14:31
Acoustic Trigger: 142 dB Seismic Trigger: 0.05 in/s Serial Number: 776

Amplitudes and Frequencies	**Graph Information**
Radial: 0.0562 in/s @ 4.7 Hz.	*Duration:* 0.000 sec To: 8.500 sec
Vertical: 0.025 in/s @ 2.8 Hz.	*Seismic:* 0.06 in/s (0.015 in/s/div)
Transverse: 0.0637 in/s @ 4.2 Hz.	*Time Lines at:* 1.00 sec intervals
Vector Sum: 0.0725 in/s	

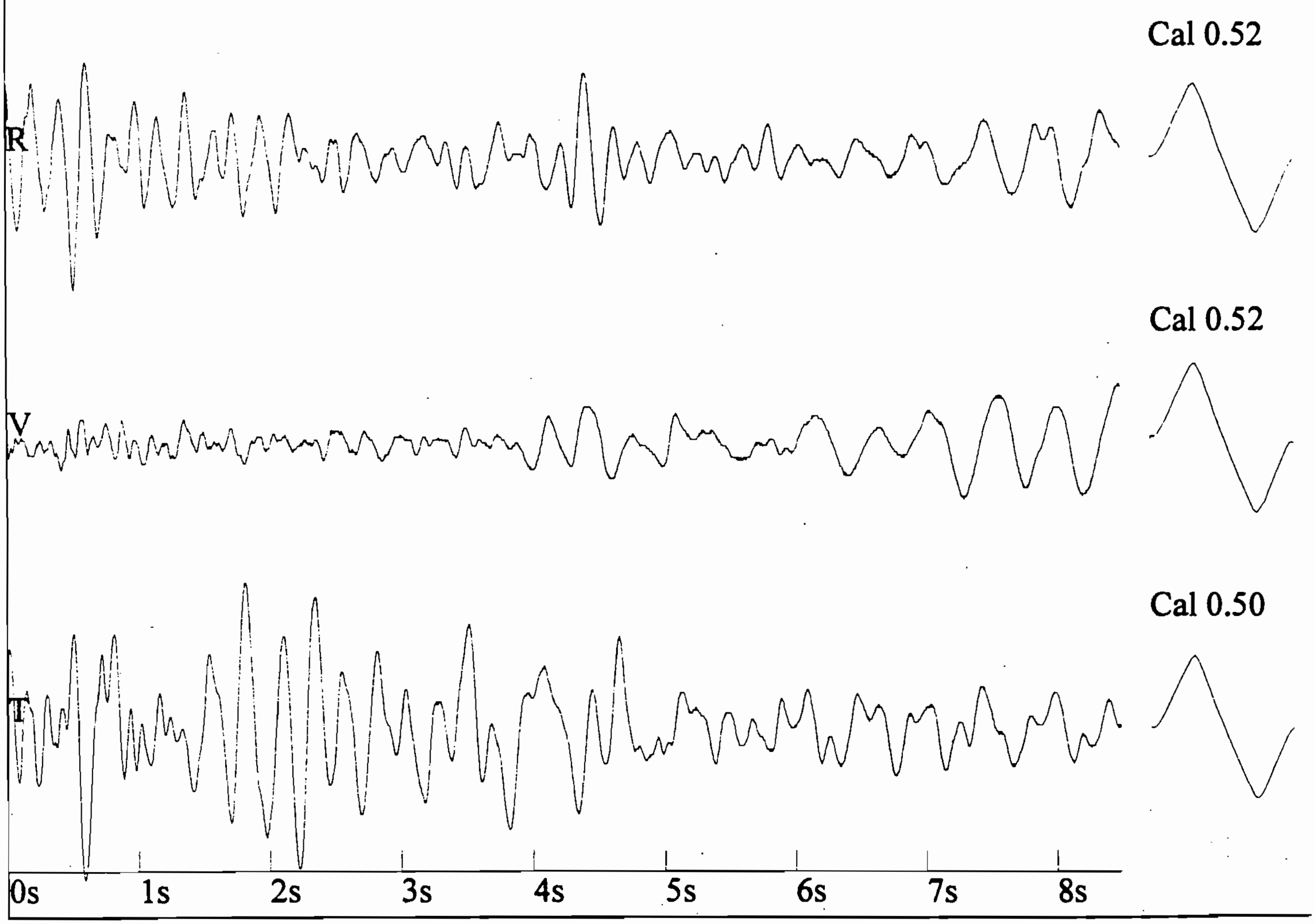


Figure 18.- Highest structure response record from House 11.

D. E. SISKIND & ASSOCIATES (DESA)
FOR C3TS / DADE COUNTY
STRUCTURE: 45
LOCATION: DORAL PARK
2ND STORY CEILING

Event Number: 003 Date: 4/10/00 Time: 10:34 + 1HR
Acoustic Trigger: 142 dB Seismic Trigger: 0.05 in/s Serial Number: 642

Amplitudes and Frequencies	**Graph Information**
Radial: 0.095 in/s @ 28.4 Hz.	*Duration:* 0.000 sec To: 17.000 sec
Vertical: 0.08 in/s @ 13.4 Hz.	*Seismic:* 0.10 in/s (0.025 in/s/div) .12 in/s / in of graph
Transverse: 0.105 in/s @ 9.1 Hz.	*Time Lines at:* 1.00 sec intervals
Vector Sum: 0.115 in/s	

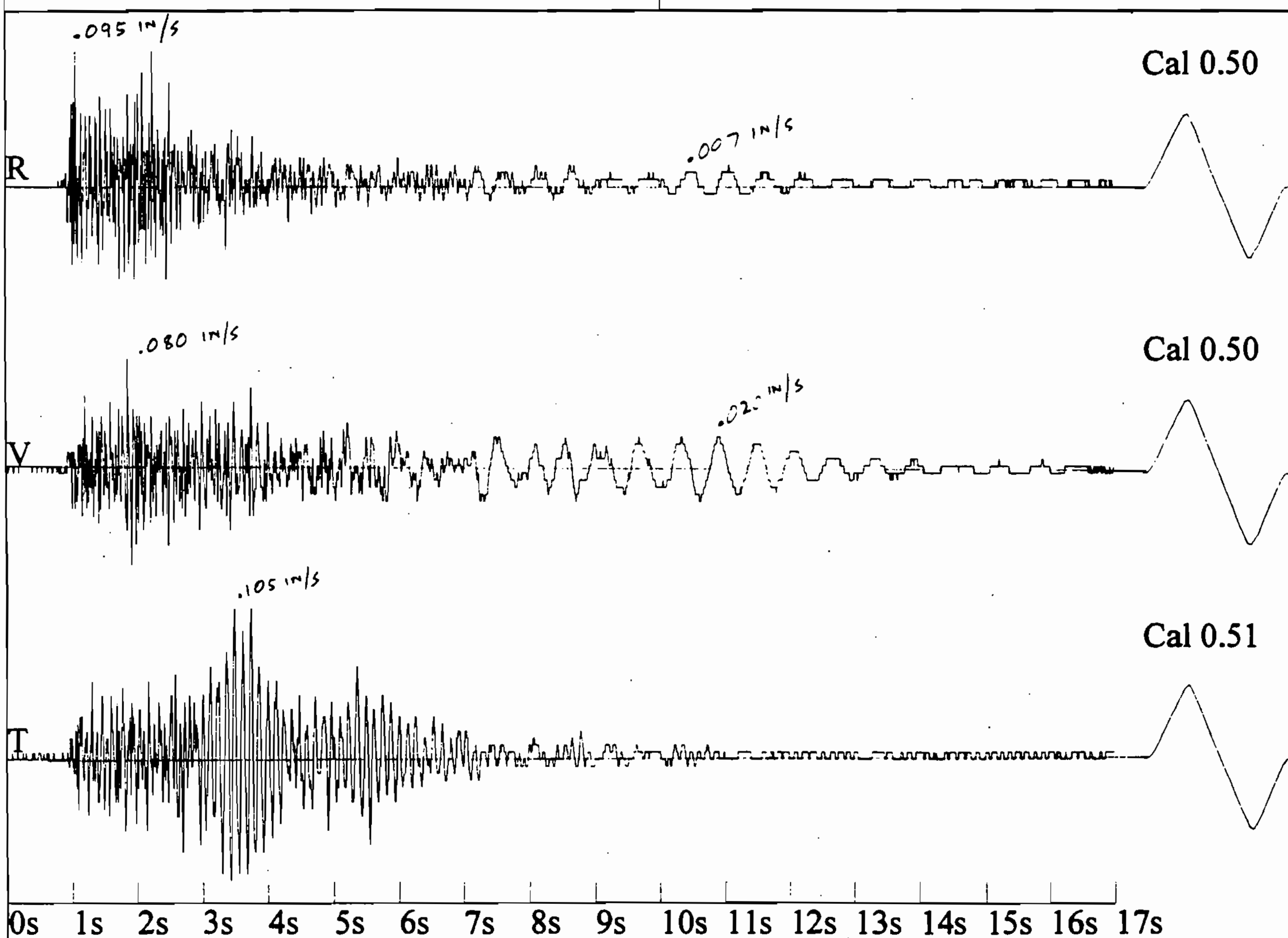


Figure 19.- Structure response waveforms corresponding to the ground vibration in Figure 13.

Table 3.- DESA structure response measurements in Dade Co, year 2000.

Date	Time	Quarry	House	Response, in/s R	V	T	Location in house
2-25	14:46	WRQ#7	6	.155	.170	.195	2nd floor ceiling
2-28	15:16	WRQ#7	6	.254	.295	.250	"
3-3	13:53	Tarmac	6	.030	.025	.030	"
4-11	14:32	RinkerFEC	6	.050	.040	.060	"
4-17	16:57	Sunshine	6	.060	.050	.055	"
4-18	11:37	????	6	.070	.090	.095	"
4-24	11:50	WRQ#7	6	.095	.070	.085	"
2-25	14:45	WRQ#7	13	.073	.053	.065	1st floor ceiling
2-28	15:14	WRQ#7	13	.070	.055	.070	"
4-18	11:36	????	13	.085	.050	.055	"
4-24	11:49	WRQ#7	13	.065	.045	.045	"
2-28	15:15	WRQ#7	11	.026	.019	.063	2nd floor floor
3-27	14:33	WRQ#7	11	.056	.025	.064	"
4-4	15:11	WRQ#7	11	.036	.015	.060	"
4-10	11:33	M Cr Rk	45	.095	.080	.105	2nd floor ceiling
4-12	13:10	M Cr Rk	45	.075	.050	.045	"
4-13	15:42	M Cr Rk	45	.045	.050	.085	"
4-17	13:57	Fl Rock	45	.055	.040	.060	"
4-17	13:58	Tarmac	45	.015	.025	.055	"
4-26	13:04	Fl Rock	45	.045	.045	.070	"

Table 4.- Dynamic amplification factors measured by DESA for Dade Co. homes.

Date	Time	House	R (E-W)		T(N-S)		V	
			hf	lf	hf	lf	hf	lf
2-25	14:46	6	3.8	1.9	6.1	1.3	7.8	1.0
2-28	15:16	6	3.2	1.7	2.7	1.9	4.8	1.0
4-18	11:33	6	2.5	1.3	3.4	none	2.8	1.0
4-24	11:45	6	4.2	1.4	3.8	none	5.0	1.0
2-25	14:45	13	1.6	1.3	1.2	1.0	1.8	0.93
2-28	15:14	13	1.2	1.4	2.2	1.1	1.7	1.2
4-18	11:33	13	2.1	1.5	2.2	1.0	1.7	1.0
4-24	11:46	13	2.2	none	1.8	0.9	1.8	1.3
4-10	11:34	42/45	0.92	0.84	2.44	none	1.10	0.77
4-12	13:08	42/45	0.88	1.5	1.6	none	0.87	0.95
4-13	15:40	42/45	0.86	1.3	3.6	none	1.4	1.2
4-17	13:53	42/45	1.3	none	1.6	none	0.76	1.32
4-26	13:02	42/45	1.5	none	3.6	none	1.71	0.91

hf = high frequency, the early part of the ground vibration waveform. Was found to be anywhere from 8 to 30 Hz.

lf = low frequency, the later (surface wave) part of the waveform, typically 2 to 4 Hz.

Note: vertical response for House 6 was mid-span.

D. E. SISKIND & ASSOCIATES (DESA)
FOR C3TS / DADE COUNTY
STUCTURE: 13
LOCATION: PALM SPRINGS NORTH
2ND STORY

Event Number: 020 Date: 2/29/00 Time: 17:22
Acoustic Trigger: 120 dB Seismic Trigger: 0.02 in/s Serial Number: 1133

Amplitudes and Frequencies	**Graph Information**
Radial: 0.01 in/s @ 36.5 Hz.	*Duration:* 0.250 sec To: 1.250 sec
Vertical: 0.0175 in/s @ 34.1 Hz.	*Seismic:* 0.03 in/s (0.0075 in/s/div)
Transverse: 0.025 in/s @ 46.5 Hz.	*Time Lines at:* 0.10 sec intervals
Vector Sum: 0.025 in/s	

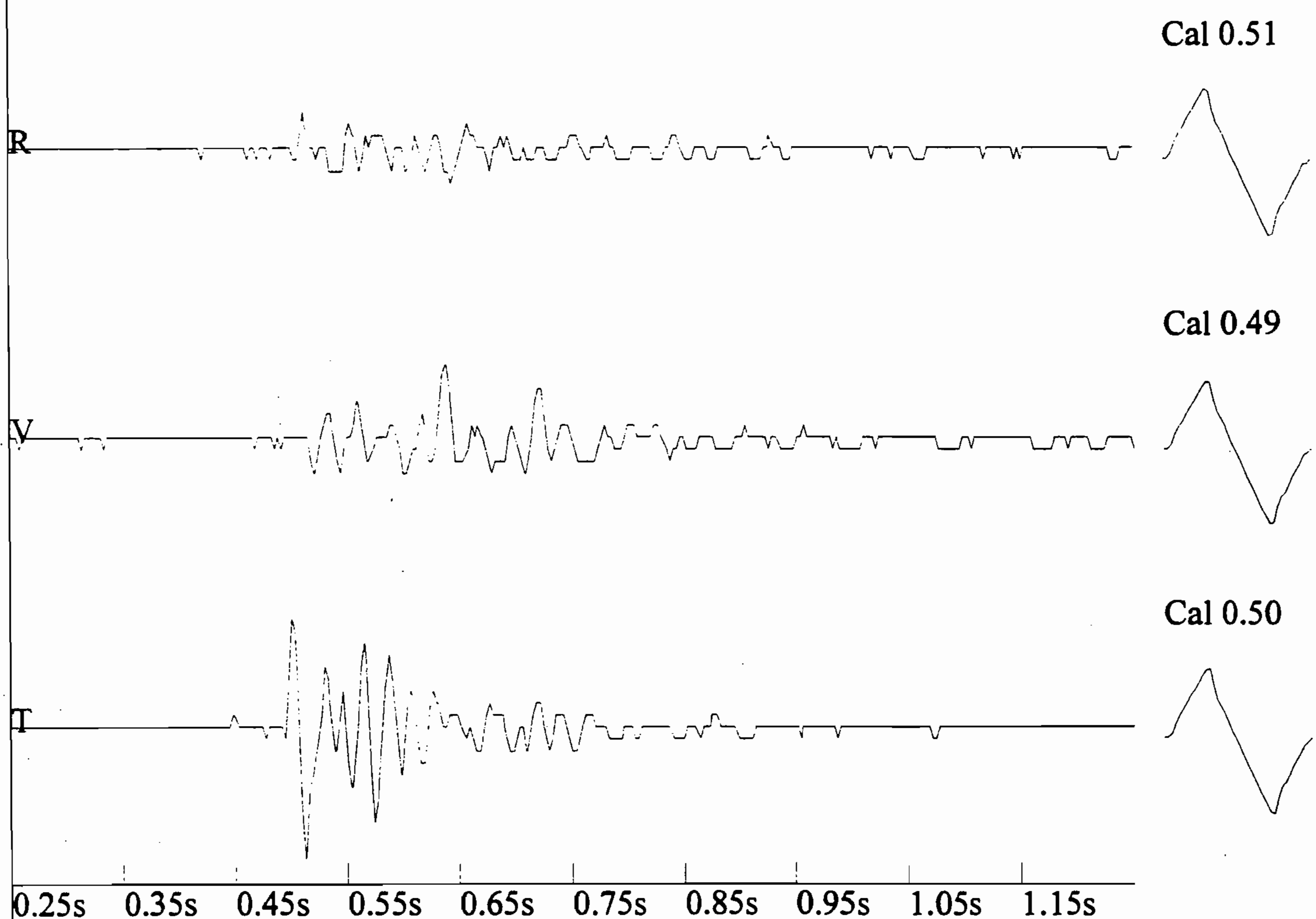


Figure 20.- Non-blast structure response event recorded at House 13. Note that the time scale has been expanded and that frequencies are relatively high.

D. E. SISKIND & ASSOCIATES (DESA)
FOR C3TS / DADE COUNTY
STUCTURE: 12
LOCATION: MIAMI LAKES

Event Number: 038 Date: 3/11/00 Time: 13:12
Acoustic Trigger: 142 dB Seismic Trigger: 0.102 in/s Serial Number: 772

Amplitudes and Frequencies

Radial: 0.64 in/s @ 85.3 Hz.

Vertical: 0.105 in/s @ 39.3 Hz.

Transverse: 0.0675 in/s @ 256.0 Hz.

Vector Sum: 0.6425 in/s

Graph Information

Duration: 0.000 sec To: 3.000 sec

Seismic: 0.64 in/s (0.16 in/s/div)

Time Lines at: 0.50 sec intervals

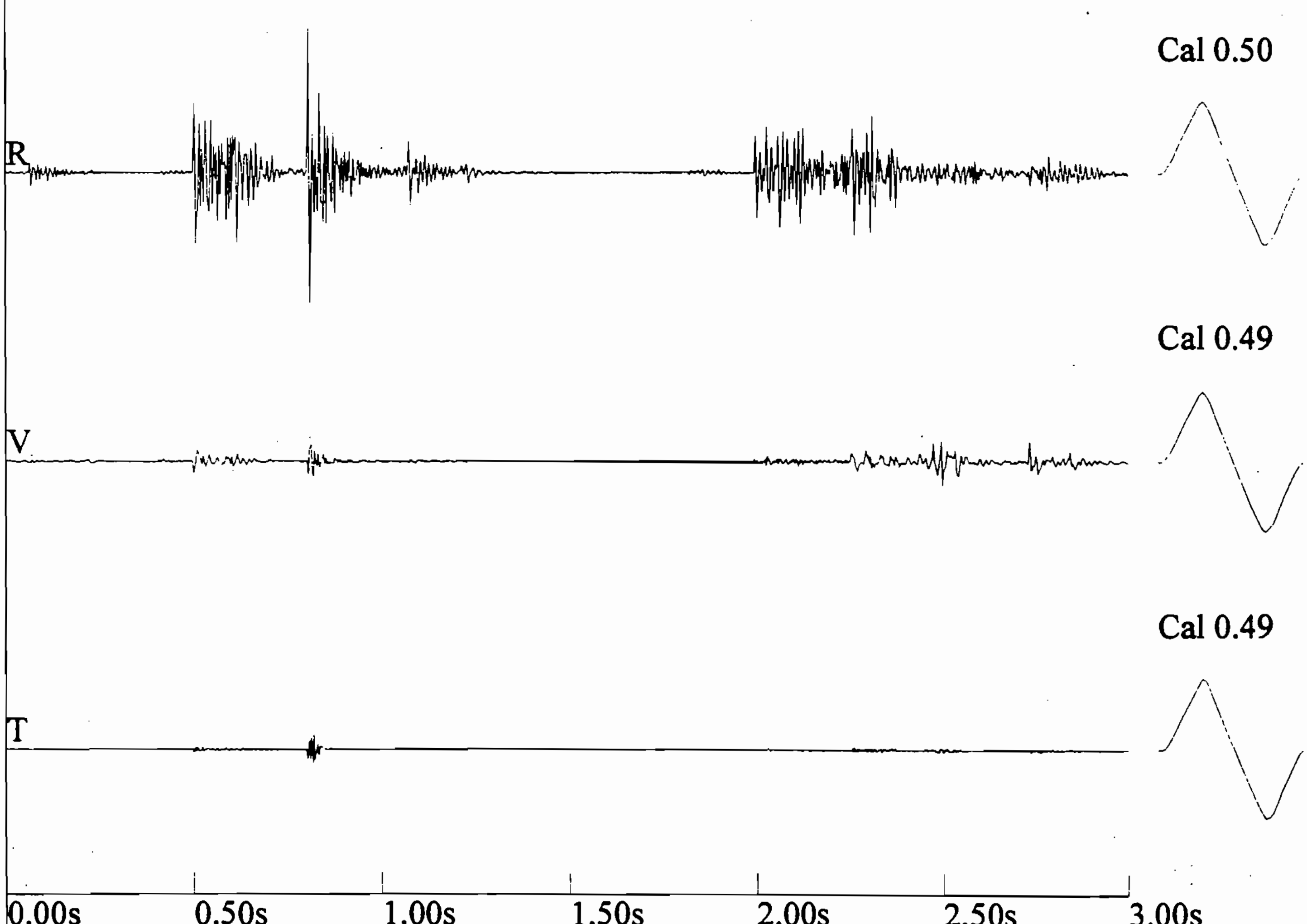


Figure 21.- Non-blast structure response event recorded at House 12. Note that the time scale has been expanded and that frequencies are relatively high.

DESA monitoring of structure responses were hampered by several factors. Some seismograph memories filled early because of many non-blast events, likely human habitation excitation, wind responses, and other unknowns. Others were affected directly by the outdoor site conditions such as rainwater and possibly high heat in attic spaces. Trigger levels were raised to reduce the number of non-blast events recorded during the Phase II trip, April 8 and 9, 2000.

WALL STRAINS FROM STRUCTURE RESPONSE MEASUREMENTS

Structure response records are additionally useful in that they provide the data needed to estimate in-plane shear strains and theoretical cracking potential. As discussed previously, such analyses supplement observations of cracking versus non-cracking and also provide guidance in cases where data are not available.

Whole-house shear strains can approximated from:

$$\varepsilon = (\Delta D/L) \sin\varphi\cos\varphi$$

where φ is the angle of the diagonal in the wall's plane of deformation, ΔD is the maximum horizontal displacement L is the vertical distance over which the displacement occurs (Appendix B, C ,and Stagg, 1984).

Having structure response velocities (V) and frequencies (f), displacements can be calculated through the relationship: $D = V(2\pi f)$.

<u>NW area of Miami Lakes and Palm Springs North</u>: strains are based on the worst-case predicted vibration of 0.18 in/s, the highest amplification factors of 6.1 at 10 Hz and 1.92 at 2.25 Hz, and an assumed approximate height of the 2nd floor attic for House 6 of 24 ft.

Approximating the $\sin\varphi\cos\varphi$ function as 0.5, the high frequency and low frequency responses are 31 and 42 $\mu\varepsilon$, respectively for House 6. These are sufficiently below the minimum masonry cracking thresholds of 100 $\mu\varepsilon$ to not be a possibility. Higher vibrations and/or higher responses could, however, be a problem. House 13 has lower amplifications, less displacement and hence less strain.

<u>West area of Dural Landings and Shoma Homes:</u> Here, the quarries and neighboring homes are closer and a reliable estimate of the highest vibration amplitudes are less reliable. Assuming the quarries use the same charge weights as the did for DESA-monitored blasts when they are blasting closest to the homes, vibrations as large as 0.35 in/s are possible. Based on the few measurements obtained and

the assumption that they will reduce charge weights in their eastern most part of the permit area, vibrations will likely not exceed 0.12 in/s. Strain calculations based on the possible 0.35 in/s vibration amplitude, the highest amplification factor of 3.6x, and the corresponding response frequency of 8.0 Hz gives a predicted maximum strain of 65 με. This is higher than the prediction for House 6 mainly because of the closer distances, but it is still below the initial CMU global cracking threshold of 100 με. Additional ground vibration and response data for this area would be useful.

WIND-INDUCED STRUCTURAL RESPONSES

Winds and thunder are the only significant sources of short-period dynamic responses, besides blasting, making historical winds impacting south Florida homes germane to possible causes of superstructure wall cracks.

The Building Officials & Code Administers International, Inc. (BOCA, 1996) specifies a general requirement that residences be built to withstand wind-induced pressures of 10 psf (lbs/ft^2). The code gives the standard relationship between wind speed and pressure on a vertically-walled building:

$$P = .00256V^2$$

where P is in psf and V is mph.

Using this relationship, 10 psf is equivalent to a wind of 62.5 mph. (Note: The author believes that Florida requirements are higher than this, at about 110 mph.)

Measurements of pressure (airblast in this case) and vibration response of homes has provided the following relationship:

$$SR_{in/sec} = 0.0274 + 18.8\ P_{lb/in^2} \quad \text{(Siskind, 1980a, Siskind 2000)}$$

From this relationships, the BOCA wind tolerance requirement (of 62.5 mph) is equivalent to a structure response of 1.31 in/s and a 110-mph wind equivalent to about 4.04 in/s.

For Dade County homes, highest predicted ground vibrations in the NW area are about 0.18 in/s, from Table 2. Based on the amplification factors of Table 4, responses for these worst-case vibration amplitudes would be about 1.10 in/s for the two story house (6.1x) and 0.43 for the one-story (2.2x). These are equivalent to wind-induced responses from gusty winds of 57 and 30 mph, respectively.

Corresponding values in the west areas of Dural Landings and Shoma/Superior Homes are 0.35 in/s and 3.6x, giving possible response amplitudes of 1.26 in/s. This is equivalent to winds of 61 mph. These are wind velocities corresponding the wind-induced responses which are equal to the worst case vibration-induced responses.

This area has experienced severe storms, e.g., Andrews in 1992 and Irene in 1999. These storms were measured to have gusts to 150 and 70 mph, respectively, at the Miami airport. However, there is no way to know how much wind these or any specific houses experienced with the complexities of sheltering structures and turbulence. It is not unreasonable to assume that the homes have received winds close to 60 mph since built and the influence of such winds on the structures is possibly and even probably greater than the blasting.

STRUCTURAL INSPECTIONS BY DESA

This section is a house-by-house description and analysis of the cracking and other damages observed by DESA personnel during their inspections in February and April, 2000. The purpose is to address questions #3 and 4 on the nature of the damage and likely causes.

Most of the inspection effort for all homes was a search for structural cracks. These are cracks which suggest stress and movement and are described in Appendix B , C and D. The movement could be response to dynamic events such as blast vibrations, winds, and thermal and humidity response stresses or long-term such as differential settlement, material curing and drying, and soil forces.

Researchers have found dynamic amplifications of house superstructures in their horizontal responses from vibrations originating in the foundations or bases (eg, from blast vibrations). The highest motions are found high up on the superstructures and strains which can cause cracking arise from the differential displacements between the upper parts and the bases. These strains can cause cracks around openings and other weakness areas in vertical load-bearing walls, which are first sign of blasting damage. However, they are not a guarantee of blast damage because of the other dynamic causes listed above can also cause wall strains. Most important as a diagnostic is the *absence* of such cracks. No such cracks is strong evidence that blasting hasn't caused any of the existing cracking or other damage. The nature and patterns of the cracking revile or at least suggest the cause or causes.

Although some of the homes have extensive cracking, none appears to be structural in the sense that utility or structural integrity is in question. These cracks are of the type found in most homes regardless of the presence of blasting. The main departure from historical blast damage studies are the below-window horizontal cracks. These appear to be a construction-related feature in this area possibly aggravated by strong thermal responses or water intrusion and damage.

A total of 107 photos of the houses and most cracked areas in them are in Appendix E. References to figures in the next section pertain to this Appendix.

ASSESSMENTS OF CRACKS AND OTHER DAMAGES IN DADE COUNTY HOMES

HOUSE 6

This two-story home is the farthest north. Like most of the homes inspected, it has a stucco exterior and a clay tile roof. Only one structural crack was found, beneath the exterior south wall window (Figure E4). The width of this vertical-oriented crack was measured in two places and had narrowed between each of the three sets of inspections (Table 5). The cracking around the interior sill area of this window suggests expansion response of the wood sill framing (inside the wall) which likely also produced the external crack. Most of the houses had this problem, e. g., House 13.

A few interior cracks exists at places suggesting normal wood responses to humidity or thermal-caused shrinkage such as the door frame molding joints in the first floor bathroom, second floor hall, and the master bedroom. The wood door frame in the bathroom off the master BR is also cracked at floor level.

As with all the homes in the NW area, GeoSonics, Inc. had done an inspection in response to blasting complaints and provided a list of specific claim items to DESA via the County offices. House #6 descriptions include claims of displaced roof tiles (also mentioned by the homeowner to DESA personnel) and floor cracks in the bathroom. The roof is difficult to analyze as past blasting studies did not examine the responses of such heavy roofs. Generally, roofs structures move as rigid units, specially is response to the more serious vibration components, the horizontal vibrations and corresponding horizontal structure responses. If the roof surface is specially flexible rather than rigid from the triangulated truss structures, it might flex from vibration response but would also be specially responsive to wind forces (AISG, 1990). Without having run any kind of test to evaluate the roof tiles, it is still most likely that the shifted roof tiles are workmanship issues and not related to the blasting.

Tile floor cracks are an issue in many of the homes. There are no experimental nor theoretical basis for ground vibrations of anywhere near the worst case amplitudes present in Dade County homes being responsible for such cracks. Strains from ground vibrations are orders of magnitude to small to produce such cracks either directly of through effects on the soils. These cracks are most likely related to concrete shrinkage or inadequate sub-floor preparation. Appendix B contains experimental results and theoretical treatment of what would be required to crack floor surfaces.

Summarizing for this house: It is in fine condition, having far less cracking than most homes inspected by DESA regardless of the proximity of blasting. There is a general lack of angled and symmetric in-wall cracks around doors and windows that would suggest in-plane shear forces from dynamic loading, blasting or otherwise. The kinds of cracks expected from blasting damage are absent and the few cracks which are present are not characteristic of blasting, indicating with high certainty that damages in this house are not blasting-related.

HOUSE 13

This single-story house had two distinct types of exterior cracks on different walls and almost a total lack of interior cracks in over 100 critical areas that were inspected.

The exterior north wall has horizontal cracks beneath the three larger windows through the storm shutter bolts (Figure E10). These are likely related to material response (e.g., thermal or water) and not blasting-caused motions. The mechanism for this damage is lateral expansion of the sill which responds by bowing upward and producing a horizontal tensile crack beneath the window. Compression at the ends produces local crushing and tensile cracks between the wallboard panel at the end of the sill and beneath the window. Hence, vertical cracks can form or initiate at these lower window corners). The cause is either from thermal expansion or from water-caused swelling, with the latter more likely. Note: The explanation for this was not totally the authors' but developed from discussions with Dr. LeRoy Thompson. However, the cracking and response patterns are exactly those observed by the authors in rock mechanics studies of material responses to compressive loading. These are: crushing damage at the ends from axial compressive forces plus transverse expansion (bowing outward) and tensile failure with open cracks parallel to the compressive axis.

The east and south walls are far more complex with the most serious cracks being horizontal along the lowest course of CMU (concrete blocks). In these two walls, there are also stucco cracks mostly below rather than all around window openings (Figures E13 to 18). The nature of these mostly horizontal and vertical (rather than angled) cracks in the east and south walls suggest static movement rather than whole-house responses to transients such as blasts (or wind). This is particularly so because of the absence of similar cracks in the north and west walls. It was noted that all crack edges showed considerable weathering suggesting they are not recent.

The effect of sun-caused heating is a possibility as only the east and south walls get any appreciable sun exposure (the west wall is shaded by the carport). Another possibility is settlement of the NE and SE corners from soil shrinkage (drying), suggested by the downward angling of the wall cracks towards the house's center lines on both east and south walls. However the most likely cause for the lower coarse block cracks is shrinkage of the concrete pad, a scenario which could be tested by determining if the blocks are laid on and attached to this pad rather than on independent footings.

The only notable interior crack was above a window in the NE corner (Figure E21), consistent with the exterior cracking in this corner (Figure E18).

The homeowner reported rain water had entering at the SE corner during storms. No obvious crack could be seen on the inside, however outside cracks existed there including the horizontal lower block course. This suggests that the crack, at least in this area, was all the way through the wall, and not a surface crack, and likely wider on the outside than on the inside. This is also consistent with shrinkage of the floor and the resulting bowing outward of the lower course.

Summarizing for House 13: Dynamic responses (e.g., blasting and wind) as causes for cracking appears unlikely but not with certainty. The cracks on the east and south sides are not inconsistent with such forces but their absence on the two other walls makes this unlikely. The exact cause of all cracks is ambiguous but both the localized nature of each kind of cracking and the general absence of dynamic cracks make dynamic sources unlikely to be the cause.

HOUSE 15

This older single-story house has cracks with patterns similar to House 13. There are stucco cracks in all exterior walls except the north and, with very few exceptions, they are below windows and notably absent above windows and doors. This pattern is not consistent with blast vibration responses.

Horizontal cracks directly below windows both outside and inside and vertical cracks at the lower window corners suggest sill boards being placed in too tight and expanding from thermal- or moisture-related responses. (The damage mechanism was described under Houses #6 and 13, except at this house, the vertical cracks at the ends are very evident and both inside and outside). These below-window cracks follow wallboard joints. This same mechanism would be responsible for the cracks and displacements in the interior window sill tiles.

In addition, the pattern of cracks at the NW and SE corners suggests differential settlement (e. g., from soil shrinkage), again similar to House 13. Other cracks are on the west side wall are below steel posts in the wall and are likely environmental (thermal). Five external and one internal crack widths were measured 2-25 and again 4-8. Two of the outside cracks had narrowed during the period, for example 0.1 mm to 0.05 mm (Table 5). The widest was 0.15 mm which is 6 thousandths of an inch (0.006 in). Although noticeable, most cracks are what are called "hairline" or less than 0.002 in, and of the type not uncommon in most homes.

Other cracks in this home were in ceilings in the SE corner BR and the kitchen. While cracks between wallboard panels in ceilings are common from load and support problems, they are not characteristic of responses from vibrations.

Summarizing for this House: Blasting (or wind responses) related damage appears unlikely from both the patterns and locations of each kind of cracking and the general absence of dynamic forces-related cracks. But, as with House 13, there remains some ambiguity on the exact cause of some of the cracks. Two of the corners in particular appear to have support problems such as would result from settlement. The damage beneath almost all windows is likely related to the construction features there and responses to water intrusion (as per Houses #6 and 13 and others later examined).

HOUSE 4

This modern one story house with vaulted ceilings and a clay tile roof. Most of the external wall cracking was on the north side including a significant crack in the garage wall of 0.5 mm width visible both inside and outside (Figures E38, 39 & 50). The pattern of the cracks in this wall is consistent with differential settlement of the corners (slope downward towards the centerline from both sides). As with the previous three homes, cracks were absent above windows in this wall but did exist in the east wall above and below one window (the SE corner, Figures E 41 & 42) and above the east wall sliding door (Figure E40).

There was a general lack on interior cracks around windows and doors with an exception being the SE corner of the master BR. This is the same SE corner with outside wall cracks shown in Figures 41 & 42.

On the nature of the crack damage, this house is more ambiguous than the previous ones examined. The cracking in the north house wall is unlikely from blast vibrations as are the MBR bathroom wall and floor tiles. The north wall cracks are consistent with static failure and not characteristic of structural responses from vibration. The floor tile damage is totally inconsistent with the worst case floor responses (Appendix B & C).

However, the cracks in the east wall, the west wall window at the SW corner, and minor cracks in the south wall are difficult to diagnose. In particular, the direction of cracks in the SE corner and east wall are *not* consistent with differential settlement. The homeowner had reported repeatedly fixing problems in this area of the home.

Summarizing for House 4: In this author's opinion, SE corner cracks could be the result from dynamic responses with blasting and wind storms being the most obvious possibilities. Other cracks and damages are not likely related to dynamic forces.

HOUSE 12

This is also modern one story house with vaulted ceilings and a clay tile roof. This home had relatively few cracks and, like previous homes (#6, 13, 15), the ones which were found were generally below windows. These cracks initiated as vertical cracks at the ends of the sills (Figures E55 & 56) and were also visible inside the house (Figures E59 to E61). This is almost certainly the same problem and cracking mechanism as described for House 13 and others.

One north wall crack-width was measured 2-26 at 0.20 mm and 4-8 at 0.25, a change of .05 mm (or 0.002 in). This is near the resolution limit but could signify a minor thermal response between the two dates (Table 5).

The entrance alcove archways had hairline cracks in the inside corners. This is typical of humidity shrinkage of the wood used to frame the archway. The crack at the ceiling-wall joint is normal for locations where structural components are joined. The garage floor crack is the normal response to shrinkage. Floor responses and the possibility of floor cracks and other damage to floors is discussed in Appendix B.

Summarizing for House 12: The patterns and locations of each kind of cracking and the general absence of dynamic cracks make blasting vibrations unlikely to be the cause of cracks in this home. There was a lack of cracking in this structure consistent with what would be expected from dynamic responses. Like the previous homes, damage beneath the windows appears related to the construction features there and possible responses to water intrusion.

HOUSE 11

This is a very large and unique home located about one mile farther east (farther away) than the other NW area homes. Most of the external windows were either in protective alcoves or too far away to detect any existing hairline cracks. Few external opening cracks were noted, over a second floor door in the east-facing wall and over the left-hand garage door.

Most serious were horizontal cracks beneath windows and vertical cracks and compression damage at sill ends in the kitchen, SW ground floor bedroom, living room west wall (tower), spiral stairway west wall, master BR east-end on 2nd floor, south-central BR 2nd floor, and west-end BR on 2nd floor (Figures E69 to 73). This is certainly the same phenomena and mechanism found in Houses #6, 13, 15, and 12 and described in the House 13 analyses. In this case, compression was severe enough to visible bow the marble sill plate upward, break it in places, and open cracks in the wallboard strips beneath the windows of up to 1/2 inch width. There are water stains in some of these areas suggesting swelling form water leaks may have been one or possibly the main cause of there damages.

Much less clear is what has happened in the garage (Figures E74 to E77). This triple block-walled garage had cracks in every wall above all seven doors (four wall through and three garage doors) and three windows, but not noticed below those windows. This extensive cracking is not inconsistent with dynamic response from wind and/or blasting. The question is how a home so far from the blasting sites could have had enough vibration response (0.6 to 4.8 in/s) to have generated the 120 to 1,000 $\mu\varepsilon$ required to crack such masonry walls (Appendices B). Visible cracks in non-reinforced shear-loaded block walls were produced in Bureau of Standards tests at 470 $\mu\varepsilon$. This is would be comparable to 1.5 in/s structure response at a low frequency of 4 Hz (Siskind, 2000).

Summarizing for House 11: Damages in the house are not dynamic response-related which includes blasting. The garage is more ambiguous, and based on crack pattern alone. could be from dynamic responses.

HOUSE 45

This is a modern two-story home with clay tile roof was instrumented for structure response. It is close enough to another home under study (#42) that the ground vibration measured there can represent the "vibration input" for both structures.

This house has cracks around all doors and ground-floor external windows (Figures E80 to E85). Second-floor windows were too far for inspection from the ground but appear to be uncracked. The patterns and presence on all corners and that they run at angles consistent with shear forces is consistent with dynamic loading, of which wind and blast vibrations are the most likely causes. The large window on the south wall is a good example with ≈45° hairline cracks at three corners and a larger crack at the lower left hand corner (Figure E82). A series of vertical cracks are also beneath this window.

There are few inside cracks. One is to the left of the entrance door. It does not match up with the outside crack above this door but that does not eliminate a causal relationship. The only other internal wall crack found was above the master BR east-wall window. This home has marble sill windows as found in most of the previously inspected homes (#6, 13, 12, 11). Most of the windows are undamaged however, the one in Family Room east-wall has that same characteristic below-window damage noted in most other homes and, in the worst way, in House #11. The sill here is warped and there is local wallboard crushing at the right end, consistent with expansion of the underlying sill structure.

There is a crack in the garage floor which is certainly not vibration related as per the discussions for Houses #6 and 4.

Summarizing for House 45: Wall cracks could be the result of dynamic loading based on their character and locations. Below-window cracking and concrete garage floors cannot be vibration-related.

HOUSE 34

This is the first of two similar single-story homes in the same neighborhood, the other being the next in this report, #33. Externally, the worst cracks are at the NE corner window. These are both on the outside and inside and resemble those in almost all the other homes, likely from window sill-end stresses. The difference is that the crack below the window on the outside extends to the ground (Figures E34 & 35). About half of the remaining windows and doorways have corner cracks (Figures E91 & 92) but with no consistency or pattern. For example, cracks on the west wall all run the same way, down toward the left. This would be consistent with differential settlement. Unfortunately, the south wall was not accessible to examine any pattern there to support this.

As with many of the homes, there were horizontal wall cracks near the ground, appearing to be the separation between the slab and the first course of blocks. This was most evident on the west wall where there were also cracks in the concrete pool deck.

This house could be susceptible to response from ground vibration (and also winds) based on the large number of major openings. For example, the back side or west-facing wall has a large opening for the porch alcove and two large sliding doors. This, and all the openings in the front or east wall, could make this structure have relatively low stiffness in the N-S direction. Such construction existed at Weston and the USBM study there found relatively high blast responses (Siskind, 1996). Instrumenting for structure response would have shown if this was the case but, unfortunately, that wasn't done.

In the front are a post and lintel structure forming a covered entrance. The post has cracks which could be from dynamic response (Figure E87 & E88), although they appear to only be in the surface coating. The lintel has a series of vertical cracks that are not likely motion related but simple shrinkage of the stucco coating. Only the post or post-lintel joint would experience any stress from dynamic horizontal structure responses.

Summarizing for House 34: Like many of the other houses, some of the cracks are ambiguous with regard to cause. There are 12 door and window openings in outside walls, a total of 38 accessible corners. Twenty six are uncracked. Of the remainder, six have the characteristic sill damage which is definitely not from shaking response, blasting or wind. The 10 remaining areas have cracks which appear consistent with dynamic loading, many of which are below sliding doors (Figures E94 & E95). There appears to be no settlement pattern to the cracks, so dynamic forces remain a possibility.

HOUSE 33

This home is just south of #34 and of similar construction (Figure E96). Of the four outside walls, only the north one has window or door opening corner cracks (Figures E 97 & E98). The two larger windows in this wall have those same below-window cracks observed nearly everywhere else although there is no damage visible on the inside. There are also cracks above all three windows in this wall consistent with possible dynamic responses.

Only one inside wall crack was noticed in 44 inspected areas which excludes a few that were inaccessible. That was a wallboard joint crack over a door in the

MBR bathroom. The homeowner pointed out a major tile floor crack which extended from the main bathroom into the hall and had a maximum width of about 0.5 mm. This crack, as well as outside concrete patio cracks, cannot be from dynamic forces for the reasons given in previous analyses and described in Appendix B.

Summarizing for this house: The presence of cracks in only one wall suggests workmanship issues rather than whole-structure responses to dynamic loading. Based on their character alone, the north wall cracks could be from shaking- or wind-induced stress. However, they lack the general symmetry usually found from such responses (and described for House 45). There is also a total lack of internal cracks which are traditional blast-damage signs. In total, damages appear not dynamically-related in this house.

HOUSE 42

This house was near House 45 but differed in being a central unit in a row of town houses (Figure E99). The north and south walls were common to neighboring town houses and had no windows or doors.

The front was east-facing and had only one wall crack which could be structurally-related, between the roof structure over the entryway and the second-floor window (Figure E100). Other cracks were in trim around all the windows and doors in this east wall, Figure E101 being an example. These cosmetic cracks are most certainly from shrinkage of the surface coating.

The rear or west-facing wall has corner cracks on the right side of the window, top and bottom, and upper right side of the sliding door (Figures E102 & E103). Although these could possibly be dynamically related, it is difficult to envision the significant N-S response that would be required to place these walls in shear deformation, considering that the Town house unit's long axis runs N-S. Overall torsional response is a possibility. That these cracks are dynamically related has to remain a possibility. Another possibility is suggested by the crack directions: relative settlement of the south side. In retrospect, this could have been investigated by examining the neighboring unit to the south.

Inside cracks were very few. The west-facing window in the kitchen/family room is undamaged in contrast to the cracks outside. There are wallboard joint cracks in the second floor bathroom (sink room), in internal rather than external load-bearing walls. The shower part of the second floor bathroom has tile grout which the homeowner reported had been fixed and had reappeared, and a cracked tile

(Figures E 104 & 105). There were gaps along the grout lines suggesting either major grout shrinkage or static movement opening these cracks. Repairs with flexible grout seems to have solved this problem, however, the cause is unknown.

Summarizing for this structure: Dynamic forces are a possibility for the cracks in this home including the shower tiles on the second floor.

STRUCTURE 49

This was a one-story school and was not inspected for cracks.

CRACK WIDTH MEASUREMENTS

DESA visual measurements: Selected cracks were measured by DESA in most homes to see if any long term changes would be noticeable. Results are given in Table 5 and discussed in the sections on each house. Many of these cracks gradually closed between the three inspections and during the two month study. This suggests a seasonal behavior to increasing temperatures.

Crack monitoring: In addition to occasional checks on selected crack widths, one significant crack in House #4 was instrumented for both long-term response (e.g., thermal effects) and also for transient responses. The long-term monitor sampled continuously and recorded the 24-hour temperature response cycles (Figure 22). The daily crack-width changes ranged from 2.34 to 4.54 mils and averaged 3.31 mils (thousandths of an inch). The minimums and maximums occurred in the early morning and late afternoon, as would be expected from daily outside temperatures. The low and high temperatures for April 11 were 70 and 79 degrees.

Transient responses for this crack were low and produced only one large enough to measure (Figure 23). This was for the blast of 4-11 which also triggered the House 4 seismograph. The crack-width change and ground vibration amplitudes were 0.230 mils (± about 30 pct) and 0.028 in/s, respectively. This blast produced only 1/10 as much response as that day's temperature response (based on peaks in both cases). Assuming the crack behavior is proportional to vibration amplitude, a ground vibration of 0.28 in/s would produce the same crack-width changes in this particular crack as the response from the temperature change of only nine degrees.

Seismic Analysis

SN: 3262 Event: 64

Date: 04/11/2000 Start Time: 10:21:00 File Size: 1440 minutes

Client: Operation:

SSU Location: Distance: 0. ft

Operator: Comments:

Interval Max PPV: 0.424 Volts Interval Max DB: 78 db

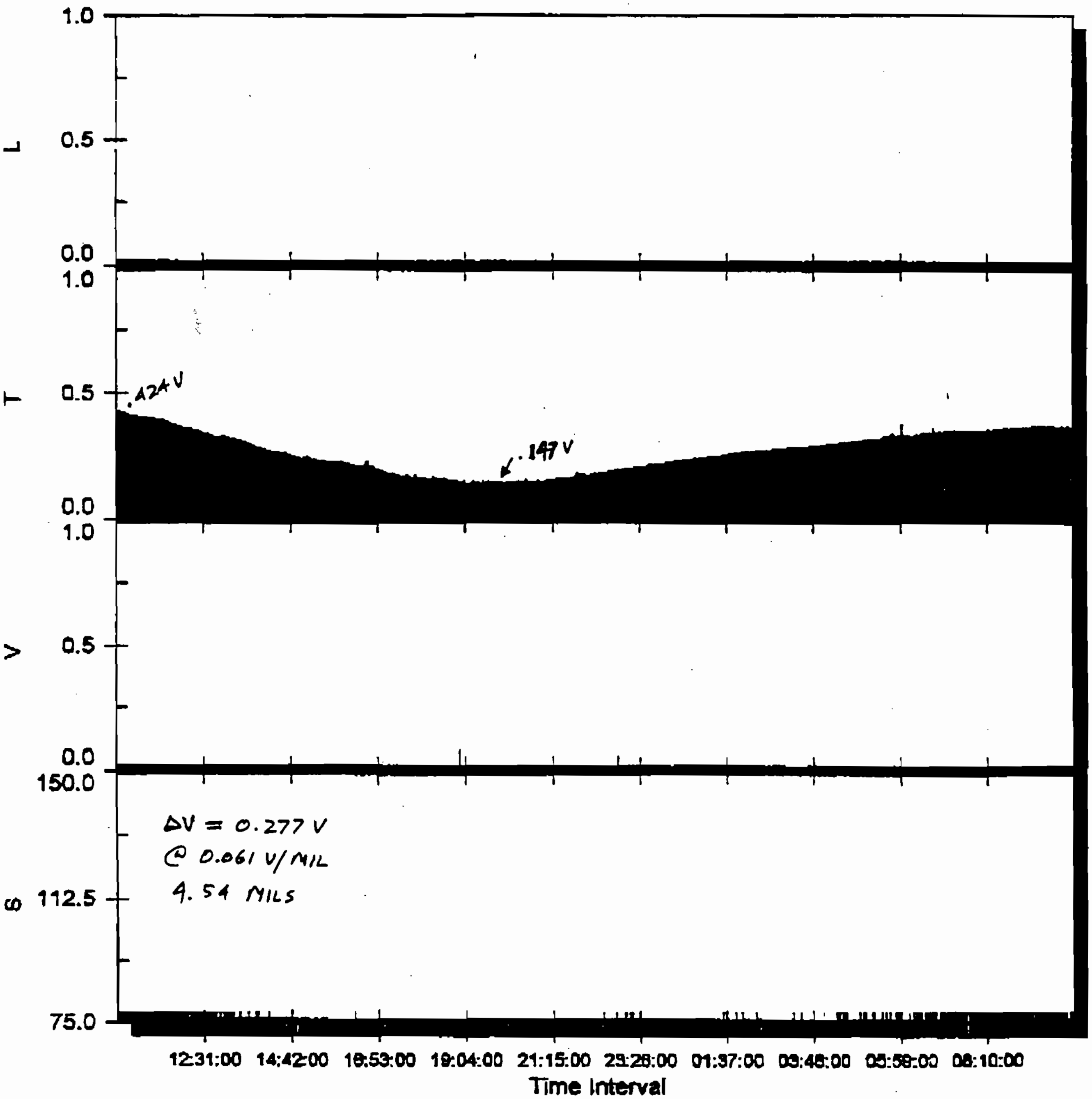
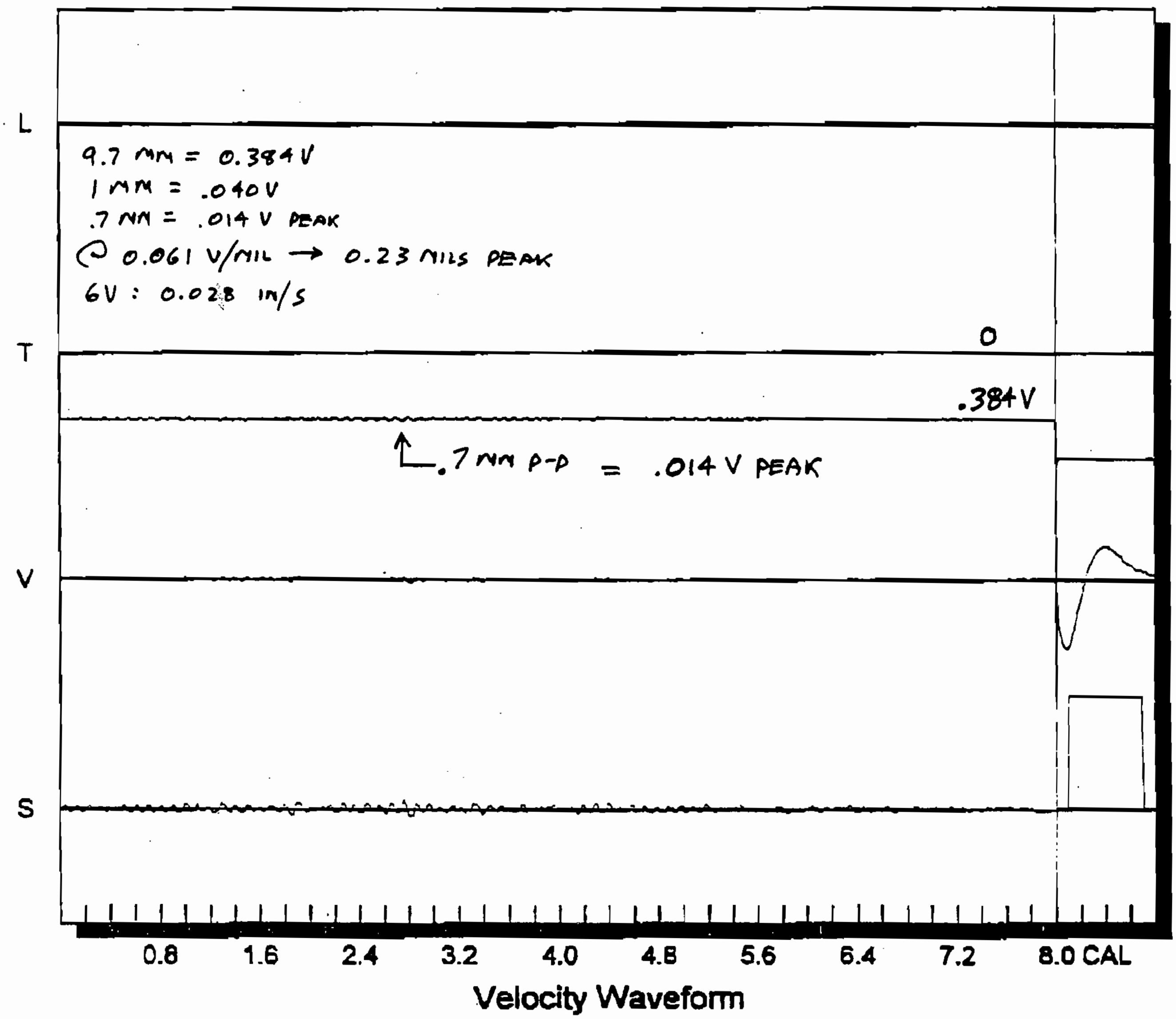


Figure 22.- Thermal response of garage wall crack in House 4. All the long-term measurements had 24-hour cycles. The difference between high and low of 0.277 volts corresponds to a crack width change of 4.54 mils.

Seismic Analysis

SN: 3209 v2.58 Event: 5

Date: 04/11/2000	Time: 14:34:03		Summary Data			
Event: 5	Record Time: 8.0 s		L	T	V	
Client:		PPV Volts	0.016	0.384	0.020	DC OFFSET IS .384 V
Operation:		PD na	0.05	1.35	0.52	
SSJ Location:		PPA na	0.007	0.007	0.013	
Distance to blast: 0. ft		FREQ (Hz)	500.0	500.0	8.3	
Operator:		RESULTANT PPV Volts :		0.380		
Comments:		PEAK AIR PRESSURE (dB):		89		
Trigger level: 5.0 Volts		na :		0.0002		



Velocity Waveform Graph Scale	Shaketable Calibrated: 02/23/2000
Time = 0.200 s	By GeoSonics Inc.
Seismic = +/- 0.64Volts	P.O. Box 779
Sound = +/- 0.0023 psi	Warrendale, PA 15095 U.S.A.
	TEL: 724.934.2900 FAX: 724.934.2999

Figure 23.- Transient response of crack width from 4-11-00 blast at 14:34 with a peak amplitude of about 0.23 mils. The PPV for this blast was 0.028 in/s.

Table 5.- Crack-width measurements by DESA, February to April, 2000

House no.	Location of measurement	Width measured, mm Meas#1	Meas#2	Meas#3
6	S-wall window, lower l. corn (upper)	.25	.10	<.10
	S-wall window, lower l. corn (lower)	.10	.05	closed
13	N-wall, left window, lower l. corner	.15	.15	<.10
	N-wall, second window, lower l. corner	.10	.10	<.10
	N-wall, right window, low center	.15	.10	.10
	E-wall, left window, lower l. corner	.15	.10	.10
	E-wall, sec. window, lower r. corner	.10	<.10	<.10
15	E-wall, below l. window	.10	<.05	NM
	N-wall betw door & window	.10	.10	NM
	W-wall, below r. window	.15	.15	NM
	S-wall, right window, lower l. corner	.10	<.05	NM
	Bathrm, S-wall window well	.35	.35	NM
4	S-wall of garage	.50	.50	NM
12	W-wall, left window, lower l. corner	.05	NM	NM
	N-wall, second window, lower rt. corn.	.20	.25	NM
45	S-wall, left window, lower l. corner	NM	.30	.30
	E-wall, left window, lower l. corner	NM	.10	.15
	Inside, MBR Bath Rm, window, lower rt	NM	.80	.70
34	N-wall, right window, lower l. corner	NM	.10	.10
	N-wall, right window, lower r. corner	NM	.20	.20
33	N-wall, ctr. window, lower r. corner	NM	.10	.10

NM = not measured
All cracks are exterior unless indicated otherwise
Meas#1 was 2-24, 2-25 or 2-26
Meas#2 was 4-8 or 4-9
Meas#3 was 4-29 or 4-80

SUMMARIZING STRUCTURAL INSPECTIONS AND ANALYSES

Some of the items in the above house-by-house analysis are consistent with dynamically-produced cracking, i.e., structure responses to transient forces. Blast vibrations are one possible source and gusty storm winds are the most obvious other. Specifically, there are cracks in load-bearing superstructure walls of the type and pattern that would be expected from vibration- and wind-caused racking. Much if not all of the other damages observed and claimed by homeowners appear to be workmanship-related, water intrusion damages, normal material curing and shrinkage, and material responses to humidity and thermal cycles.

The crack-width behavior suggests that slow or long-term cyclic responses are present. Many cracks experienced gradual closing over the two months, suggesting thermal effects from the warming of the season.

Only one house has a crack which the authors would call "structural" and which in traditional definitions would exceed "minor." That is the House #4's north garage wall. This particular crack was instrumented for response to both long-term and transient responses and found to be far more sensitive to temperature than the vibrations measured there.

CONCLUSIONS

Dade County residences have some justification for their concerns about blast vibrations. They have been experiencing long duration and low frequency vibrations and their effects on structure responses noticeable at large distances from the many active quarries operating west of the built-up areas.

Some high response amplifications suggest that at least some of the homes respond more than those previously studied by the USBM and others and used to establish the widely accepted and adopted safe level criteria. Some adjustments are needed to insure protection of the public from the worst of these combinations of vibrations and responses. The exact and appropriate adjustments require additional research beyond the short study done by DESA and represented by this report. In terms of expertise, capability and scientific impartiality, the best organization to do this would have been the U.S. Bureau of Mines. The Bureau's Blasting Research Group had the expertise and objectiveness to run such a study. This capability is now lost and such problems must now be addressed and funded at the local governmental levels of which this study is a good example.

This author recommends against an arbitrary adjustment to the County standards, however, there is justification for a 50 pct reduction to a range of 0.38 in/s to 0.50 in/s based on the amplification factor of 6.1x found in one case.

All findings are summarized in the Executive Summary section.

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APPENDICES

Appendix A. - DESA blast vibration data, February to April 2000.
Appendix B. - Characteristics of blast damage.
Appendix C. - Ground vibration effects on structures by D. E. Siskind. Paper presented at the 24th annual conference on Explosives and Blasting Technique, International Society of Explosives Engineers. February 8-11, 1998, New Orleans, LA, pp. 1-14.
Appendix D. - Diagnosing crack damage in residential structures, a catalog of observations and causes of cracks in homes. DESA Consultants, DR-40, 9 pp.
Appendix E. - Photographs taken by D. E. Siskind during structural inspections.
Appendix F. - Resume of David E. Siskind and DESA client list.

Appendix A.- Dade County blast vibration measurements by DESA, February to April 2000.

Date	Time	Quarry	lbs/del	House	Dist. ft	SRSD	Max PPV, in/s	R	V	T
2-24	12:02	RinkerFEC	576	6			NT	NT	NT	NT
				13			NT	NT	NT	NT
				15			NT	NT	NT	NT
				4			NT	NT	NT	NT
				12			NT	NT	NT	NT
				11			NT	NT	NT	NT
2-25	14:46	WRQ#7	1,242	6	12,600	358	.073	.053	.068	.073
				13	13,900	394	.055	.045	.055	.055
				15	16,500	468	.055	.055	.045	.040
				4			NT	NT	NT	NT
				12			NT	NT	NT	NT
				11			NT	NT	NT	NT
2-28	15:15	WRQ#7	1,242	6	12,600	358	.070	.070	.068	.048
				13	13,900	394	.055	.055	.045	.050
				15	16,500	468	.055	.055	.035	.040
				4	15,200	431	.043	.038	.025	.043
				12	16,500	468	.051	.025	.021	.051
				11			SR	SR	SR	SR
3-3	13:55	Tarmac	1,347	6			Down			
				13			NT	NT	NT	NT
				15			NT	NT	NT	NT
				4			NT	NT	NT	NT
				12			NT	NT	NT	NT
				11			SR	SR	SR	SR
3-7	13:30	WRQ#7	698	6			Down			
				13	13,900	526	.055	.055	.030	.025
				15	16,500	625	.030	.025	.030	.025
				4	15,200	575	.030	.025	.023	.030
				12	16,500	625	.025	.011	.011	.025
				11			NT	NT	NT	NT
3-7	14:40	Tarmac	1,347	6			Down			
				13			NT	NT	NT	NT
				15			NT	NT	NT	NT
				4			NT	NT	NT	NT
				12			NT	NT	NT	NT
				11			NT	NT	NT	NT
3-8	13:40	RinkerFEC	576	6			Down			
				13			NT	NT	NT	NT
				15			NT	NT	NT	NT
				4			NT	NT	NT	NT
				12			NT	NT	NT	NT
				11			NT	NT	NT	NT

All airblasts were less than the trigger settings of 118 to 120 dB

NT = no trigger (< 0.020 in/s for ground vibration)

Appendix A.- Dade County blast vibration measurements by DESA, February to April 2000, cont.

Date	Time	Quarry	lbs/del	House	Dist. ft	SRSD	Max PPV,in/s	R	V	T
3-10	14:30	Tarmac	1,347	6			Down			
				13			NT	NT	NT	NT
				15			NT	NT	NT	NT
				4			NT	NT	NT	NT
				12			NT	NT	NT	NT
				11			NT	NT	NT	NT
3-14	14:30	WRQ#7	698	6			Down			
				13	13,900	526	.045	.040	.045	.025
				15	16,500	625	.035	.035	.025	.025
				4	15,200	575	.033	.033	.018	.020
				12	16,500	625	.031	.019	.015	.031
				11			NT	NT	NT	NT
3-15	13:18	RinkerFEC	576	6			Down			
				13			NT	NT	NT	NT
				15			NT	NT	NT	NT
				4			NT	NT	NT	NT
				12			NT	NT	NT	NT
				11			NT	NT	NT	NT
3-16	15:10	Tarmac	1,347	6			Down			
				13			NT	NT	NT	NT
				15			NT	NT	NT	NT
				4			NT	NT	NT	NT
				12			NT	NT	NT	NT
				11			NT	NT	NT	NT
3-20	11:24	Sunshine	447	6			Down			
				13			NT	NT	NT	NT
				15			NT	NT	NT	NT
				4			NT	NT	NT	NT
				12			NT	NT	NT	NT
				11			NT	NT	NT	NT
3-22	10:37	Rinker Lk	413	6			Down			
				13	12,000	590	.025	.015	.025	.015
				15	14,200	699	.020	.020	.015	.020
				4	11,600	571	.033	.025	.033	.015
				12	12,350	608	.021	.015	.021	.013
				11			NT	NT	NT	NT
3-23	11:04	WRQ#7	698	6			Down			
				13	13,900	526	.040	.040	.035	.040
				15	16,500	625	.035	.035	.025	.030
				4	15,200	575	.030	.030	.018	.030
				12	16,500	625	.033	.016	.014	.033
				11			NT	NT	NT	NT

All airblasts were less than the trigger settings of 118 to 120 dB

NT = no trigger (< 0.020 in/s for ground vibration)

Appendix A.- Dade County blast vibration measurements by DESA, February to April 2000, cont.

Date	Time	Quarry	lbs/del	House	Dist. ft	SRSD	Max PPV,in/s	R	V	T
3-24	10:40	Rinker Lk	413	6			Down			
				13			NT	NT	NT	NT
				15	14,200	699	.025	.025	.020	.025
				4	11,600	571	.028	.028	.023	.015
				12			NT	NT	NT	NT
				11			NT	NT	NT	NT
3-27	14:33	WRQ#7	1,242	6			Down			
				13	13,900	394	.080	.080	.055	.055
				15	16,500	468	.070	.070	.060	.050
				4	15,200	431	.055	.053	.048	.055
				12	16,500	468	.051	.035	.030	.051
				11			SR	SR	SR	SR
3-28	11:20	RinkerFEC	576	6			Down			
				13			NT	NT	NT	NT
				15			NT	NT	NT	NT
				4			NT	NT	NT	NT
				12			NT	NT	NT	NT
				11			NT	NT	NT	NT
3-29	10:30	Rinker Lk	413	6			Down			
				13	12,000	590	.030	.015	.025	.030
				15	14,200	699	.020	.020	.020	.020
				4	11,600	571	.035	.035	.015	.023
				12			NT	NT	NT	NT
				11			NT	NT	NT	NT
3-29	13:03	Tarmac	1,347	6			Down			
				13			NT	NT	NT	NT
				15			NT	NT	NT	NT
				4			NT	NT	NT	NT
				12			NT	NT	NT	NT
				11			NT	NT	NT	NT
3-31	11:34	Sunshine	447	6			Down			
				13			NT	NT	NT	NT
				15			NT	NT	NT	NT
				4			NT	NT	NT	NT
				12			NT	NT	NT	NT
				11			NT	NT	NT	NT
4-3	13:58	RinkerFEC	1,347	6						
				13	29,300	798	.025	.025	.015	.010
				15	31,200	850	.045	.045	.010	.015
				4	25,200	687	.033	.033	.013	.015
				12	26,800	730	.026	.026	.010	.019
				11			NT	NT	NT	NT

All airblasts were less than the trigger settings of 118 to 120 dB

NT = no trigger (< 0.020 in/s for ground vibration)

Appendix A.- Dade County blast vibration measurements by DESA, February to April 2000, cont.

Date	Time	Quarry	lbs/del	House	Dist. ft	SRSD	Max PPV,in/s	R	V	T
4-4	15:11	WRQ#7	1,242	6			Down			
				13	13,900	394	.060	.050	.040	.060
				15	16,500	468	.050	.050	.035	.035
				4	15,200	431	.045	.035	.043	.045
				12	16,500	468	.044	.033	.029	.044
				11			SR	SR	SR	SR
4-5	11:03	Sunshine	447	6			Down			
				13			NT	NT	NT	NT
				15			NT	NT	NT	NT
				4			NT	NT	NT	NT
				12			NT	NT	NT	NT
				11			NT	NT	NT	NT
4-9	11:21	RinkerFEC	576	6			NT	NT	NT	NT
				13			NT	NT	NT	NT
				4			NT	NT	NT	NT
				45			SR	SR	SR	SR
				34			NT	NT	NT	NT
				33			NT	NT	NT	NT
				42			NT	NT	NT	NT
				49			NT	NT	NT	NT
4-10	11:33	Miami Cr Rk	473	6			NT	NT	NT	NT
				13			NT	NT	NT	NT
				4			NT	NT	NT	NT
				45			SR	SR	SR	SR
				34			NT	NT	NT	NT
				33	16,900	777	.021	.014	.016	.021
				42	8,100	372	.103	.103	.073	.041
				49			NT	NT	NT	NT
4-11	14:32	RinkerFEC	1,347	6			NT	NT	NT	NT
				13			NT	NT	NT	NT
				4	25,000	681	.028	.028	.015	.013
				45			SR	SR	SR	SR
				34			NT	NT	NT	NT
				33			NT	NT	NT	NT
				42			NT	NT	NT	NT
				49			NT	NT	NT	NT
4-12	13:10	Miami Cr Rk	473	6			NT	NT	NT	NT
				13			NT	NT	NT	NT
				4			NT	NT	NT	NT
				45			SR	SR	SR	SR
				34			NT	NT	NT	NT
				33	16,900	777	.020	.008	.009	.020
				42	8,100	372	.085	.085	.058	.028
				49			NT	NT	NT	NT

All airblasts were less than the trigger settings of 118 to 120 dB
NT = no trigger (< 0.020 in/s for ground vibration). SR = Structure response. See Table 3.

Appendix A.- Dade County blast vibration measurements by DESA, February to April 2000, cont.

Date	Time	Quarry	lbs/del	House	Dist. ft	SRSD	Max PPV,in/s	R	V	T
4-13	15:42	Miami Cr Rk	473	6			NT	NT	NT	NT
				13			NT	NT	NT	NT
				4			NT	NT	NT	NT
				45			SR	SR	SR	SR
				34			NT	NT	NT	NT
				33	16,900	777	.025	.008	.010	.025
				42	8,100	372	.051	.051	.035	.024
				49			NT	NT	NT	NT
4-14	15:12	Tarmac	1,347	6			NT	NT	NT	NT
				13			NT	NT	NT	NT
				4			NT	NT	NT	NT
				45			SR	SR	SR	SR
				34			NT	NT	NT	NT
				33			NT	NT	NT	NT
				42			NT	NT	NT	NT
				49			NT	NT	NT	NT
4-17	13:57	Florida Rock	421	6			NT	NT	NT	NT
				13			NT	NT	NT	NT
				4			NT	NT	NT	NT
				45			SR	SR	SR	SR
				34			NT	NT	NT	NT
				33	10,900	531	.066	.019	.050	.066
				42	10,800	526	.053	.044	.053	.038
				49			NT	NT	NT	NT
4-17	13:58	Tarmac	1,347	6			NT	NT	NT	NT
				13			NT	NT	NT	NT
				4			NT	NT	NT	NT
				45			SR	SR	SR	SR
				34			NT	NT	NT	NT
				33			NT	NT	NT	NT
				42			NT	NT	NT	NT
				49			NT	NT	NT	NT
4-17	16:57	Sunshine	447	6			NT	NT	NT	NT
				13			NT	NT	NT	NT
				4			NT	NT	NT	NT
				45			SR	SR	SR	SR
				34			NT	NT	NT	NT
				33			NT	NT	NT	NT
				42			NT	NT	NT	NT
				49			NT	NT	NT	NT

All airblasts were less than the trigger settings of 118 to 120 dB
NT = no trigger (< 0.020 in/s for ground vibration)
SR = Structure response. See Table 3.

Appendix A.- Dade County blast vibration measurements by DESA, February to April 2000, cont.

Date	Time	Quarry	lbs/del	House	Dist. ft	SRSD	Max PPV.in/s	R	V	T
4-18	11:33	????	????	6	????	????	.033	.028	.033	.025
				13	????	????	.040	.040	.030	.025
				4	????	????	.033	.033	.023	.025
				45			SR	SR	SR	SR
				34			NT	NT	NT	NT
				33			NT	NT	NT	NT
				42			NT	NT	NT	NT
				49			NT	NT	NT	MT
4-19	13:00	Tarmac	1,347	6			NT	NT	NT	NT
				13			NT	NT	NT	NT
				4			NT	NT	NT	NT
				45			SR	SR	SR	SR
				34			NT	NT	NT	NT
				33			NT	NT	NT	NT
				42			NT	NT	NT	NT
				49			NT	NT	NT	NT
4-21	13:00	Tarmac	1,347	6			NT	NT	NT	NT
				13			NT	NT	NT	NT
				4			NT	NT	NT	NT
				45			SR	SR	SR	SR
				34			NT	NT	NT	NT
				33			NT	NT	NT	NT
				42			NT	NT	NT	NT
				49			NT	NT	NT	NT
4-21	16:01	Sunshine	447	6			NT	NT	NT	NT
				13			NT	NT	NT	NT
				4			NT	NT	NT	NT
				45			SR	SR	SR	SR
				34			NT	NT	NT	NT
				33			NT	NT	NT	NT
				42			NT	NT	NT	NT
				49			NT	NT	NT	NT
4-24	11:50	WRQ#7	1,242	6	12,700	360	.025	.025	.023	.023
				13	14,000	397	.030	.030	.025	.025
				4			NT	NT	NT	NT
				45			SR	SR	SR	SR
				34			NT	NT	NT	NT
				33			NT	NT	NT	NT
				42			NT	NT	NT	NT
				49			NT	NT	NT	NT

All airblasts were less than the trigger settings of 118 to 120 dB
NT = no trigger (< 0.020 in/s for ground vibration)
SR = Structure response. See Table 3.

Appendix A.- Dade County blast vibration measurements by DESA, February to April 2000, cont.

Date	Time	Quarry	lbs/del	House	Dist. ft	SRSD	Max PPV,in/s	R	V	T
4-24	15:15	WRQ#11	199?	6			NT	NT	NT	NT
				13			NT	NT	NT	NT
				4			NT	NT	NT	NT
				45			SR	SR	SR	SR
				34			NT	NT	NT	NT
				33			NT	NT	NT	NT
				42			NT	NT	NT	NT
				49			NT	NT	NT	NT
4-25	13:53	Rinker FEC	576	6			NT	NT	NT	NT
				13			NT	NT	NT	NT
				4			NT	NT	NT	NT
				45			SR	SR	SR	SR
				34			NT	NT	NT	NT
				33			NT	NT	NT	NT
				42			NT	NT	NT	NT
				49			NT	NT	NT	NT
4-26	13:04	Florida Rock	430	6			NT	NT	NT	NT
				13			NT	NT	NT	NT
				4			NT	NT	NT	NT
				45			SR	SR	SR	SR
				34	10,450	504	.068	.020	.040	.068
				33	10,900	526	.079	.025	.040	.079
				42	10,800	521	.030	.030	.026	.026
				49			NT	NT	NT	NT
4-28	10:41	Sunshine	447	6			NT	NT	NT	NT
				13			NT	NT	NT	NT
				4			NT	NT	NT	NT
				45			SR	SR	SR	SR
				34			NT	NT	NT	NT
				33			NT	NT	NT	NT
				42			NT	NT	NT	NT
				49			NT	NT	NT	NT
4-28	13:44	Tarmac	1,347	6			NT	NT	NT	NT
				13			NT	NT	NT	NT
				4			NT	NT	NT	NT
				45			SR	SR	SR	SR
				34			NT	NT	NT	NT
				33			NT	NT	NT	NT
				42			NT	NT	NT	NT
				49			NT	NT	NT	NT

All airblasts were less than the trigger settings of 118 to 120 dB
NT = no trigger (< 0.020 in/s for ground vibration)
SR = Structure response. See Table 3.