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VIBRATION TESTS ON TRANSIT BUSES

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FINAL REPORT

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16. Abstract

The objective of this vibration measurement program was to quantify the vibration environment which would be experienced by Automatic Vehicle Monitoring (AVM) equipment when installed on buses during typical city route service operations. Two buses were utilized in this measurement program: a General Motors Corporation Model 3100 provided by the Southern California Rapid Transit District, and a Flxible Corporation Model 207 provided by the City Transit of Fort Worth, Texas. The approach taken involved instrumenting the buses and representative electronic hardware on the buses with calibrated accelerometers and recording the output of these accelerometers while driving the buses over selected test routes at specified speeds.

In general, the tests have provided a definition of the vibration environment typical of transit buses used in city route service. Vibration amplitudes of the levels measured in the program do not pose a threat to the satisfactory operation of equipment produced according to industrial equipment design practice and fabrication methods. The data measurement system used in this program provided data of sufficient detail to accomplish the basic objectives. In evaluating this program, the authors stated that more accurate and more extensive comparisons of the data would have been made possible by a continuous correlation of calibrated bus speed with data signals. It is recommended that this be incorporated into any future tests of this nature. Related reports are: "Evaluation of Passenger Counter System for an AVM Experiment, Volume I: Technical Report (UMTA-MA-06-0041-79-1) and Volume II: Test Data (UMTA-MA-06-0041-79-2)."

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PREFACE

During the spring of 1978, as part of the Multi-User Automatic Vehicle Monitoring (AVM) Program, under Contract DOT-TSC-1237 to the Research and Special Programs Administration, Transportation Systems Center, Gould Information Identification, Inc. of Fort Worth, Texas, conducted an evaluation of the vibration environment on two different types of transit buses. This evaluation was sponsored by the Office of Bus and Paratransit Technology of the Urban Mass Transportation Administration, Department of Transportation. The purpose of this evaluation was to quantify the vibration levels and frequencies at specific locations on the buses where AVM electronic equipment will be positioned. This quantification would then be used as part of the equipment design specifications.

The approach taken involved instrumenting the buses and representative electronic hardware on the buses with calibrated accelerometers and recording the output of these accelerometers while driving the buses over selected test routes at specified speeds. The buses used for the tests were supplied by the Southern California Rapid Transit District (SCRTD) and City Transit of Fort Worth, Texas (CITRAN). Vought Corporation of Grand Prairie, Texas, served as a subcontractor, providing the instrumentation.

A number of Gould personnel contributed to the success of this program. Particular acknowledgement is given to Mr. Homer Thomas, the project leader, and Messrs. Bobby Starks and Richard Bartholow.

Special acknowledgement is accorded to Mr. Jimmy D. Anderson of General Dynamics Corporation, Convair Division, in Fort Worth, Texas, the principal author of this document. Special acknowledgement is also given to Messrs. L. Heil and J. Bertosiwicze of CITRAN and Messrs. F. Barnes and J. Deihl of SCRTD, without whose full support this program could not have been accomplished. The support of Mr. B. Blood, the Transportation System Center's Project Monitor, and Project Engineer Mr. B. Kleim is also gratefully acknowledged.

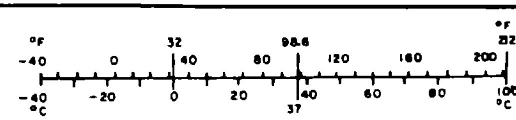
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. SUMMARY

This report describes a vibration measurement program which was performed on transit buses to quantify the vibration environment for Automatic Vehicle Monitoring (AVM) equipment. The program was conducted by Gould Information Identification, Inc., (GI^3) as part of the Multi-User AVM Program for the Transportation Systems Center, U. S. Department of Transportation. Vibration measurements were made on two different buses: a General Motors Corporation bus, Serial Number 3100, and a Flxible Corporation bus, Serial Number 207. The test routes included road conditions ranging from smooth city streets, the type encountered during the greatest majority of normal usage, to random bumpy streets. Exceptionally rough streets of the type which might be encountered on small portions of normal bus routes were also included. The buses were driven over these routes at speeds which, for the most part, represented normal usage. However, to extend the higher end of the vibration data, parts of the runs were made at speeds which were considered abnormally fast for the road condition being traversed.

Vibration was measured by recording the calibrated output signal from accelerometers on oscillograph rolls during significant combinations of road and bus operating conditions. Accelerometers were located in the three areas on the buses corresponding to the locations where AVM equipment will be positioned: the floor for the vehicle electronic unit, the dashboard for the In-Vehicle Display (IVD), and the roof for the antenna. Measurements were made during three successive days of repeated runs over the test routes while recording the output of four (sometimes five) accelerometers at a time. Vibration was also measured on components of the vehicle electronics unit while simulating passenger movement by stomping on the floor, and while simulating the action of vandals by kicking the box.

Data reduction was accomplished by visual examination of the recorded data. A uniform set of road conditions/bus operating

condition combinations was selected to implement the data reduction scheme. The oscillograph records from each bus run over the test routes were marked to identify the test condition combinations. Each test run record was subsequently searched to determine the maximum vibration level from each accelerometer at each test condition, and the levels were then tabulated to the nearest 1/4 g. Subsequent comparisons of these tables of data in various combinations, as well as detailed visual examination of parts of the records, have led to the conclusions presented in this report.

Normal operating conditions produced maximum peak-to-peak vibration levels of 2 g or less. Higher vibration levels were recorded during the program, but these were associated with unusually severe bus operating conditions or with the special stomp-and-kick tests. Both buses exhibited approximately the same vibration levels for comparable conditions. On both buses, vibration on the dashboard exhibited the highest amplitude. On the Flxible 207, vibration on the roof was next highest and the floor vibration was lowest. On the GMC 3100 the vibration on the floor was higher than that on the roof. The vibration amplitude measured at each accelerometer location was, in general, proportional to both increasing road roughness and increasing bus speed. Three response frequency ranges are observable in the data. The 1.5 to 2 Hz peaks are believed to be natural frequencies of the bus suspension. The 10 to 20 Hz frequencies are believed to be the response of the bus body. The higher frequencies, 40 to 70 Hz, are attributed to the response of local components.

Within the limitations of the recording method used and the control over test conditions, this program has supplied a definition of the vibration environment typical of transit buses used in city route service. These data have been specifically useful in establishing confidence that the components of the AVM system have been adequately designed to withstand the vibration environment in which they must operate when used in buses of this class.

2. TEST PROCEDURE

The objective of this vibration measurement program was to quantify the vibration environment which would be experienced by AVM equipment when installed on buses during typical city route service operation. It was believed that this objective could be met with adequate detail and accuracy by recording the time history of accelerometer output during significant bus operating conditions on direct-reading oscillograph records. This relatively austere approach involved the use of equipment noted for its portability, ease of setup and operation, and accuracy. The primary disadvantage of this approach is, of course, that data reduction is limited to visual examination and hand tabulation of measured amplitudes.

2.1 DESCRIPTION OF BUSES AND AVM INSTALLATION

Two buses were utilized in this measurement program: a General Motors Corporation Model 3100 provided by the Southern California Rapid Transit District (SCRTD) and a Flxible Corporation Model 207 provided by the City Transit of Fort Worth (CITRAN). Both of these buses are typically used in route service in large cities. They have a seating capacity of 51 passengers and an empty weight of 21,100 pounds (GMC) and 20,500 pounds (Flxible). The suspension systems of the two buses differ, with the GMC bus riding on air springs while the Flxible bus incorporates mechanical springs. This, as well as other minor differences in body structure, apparently had little effect on the amplitude of the data.

The Automatic Vehicle Monitoring System for which this measurement program was undertaken includes on-board components proposed to be installed at three separate locations on the buses. An 11 by 21 by 11 inch sheet metal box, appropriately called the vehicle box (VB), is to be attached to the bus floor under a seat near the front of the passenger compartment for quick and easy access. This vehicle box will contain electronic components on printed circuit (PC) cards enclosed in a card cage. The total weight of this complete unit will be approximately 20 pounds. For these tests, a prototype vehicle box with an installed card cage and unloaded PC cards was (1) bolted to the floor of the GMC bus and (2) attached by tape to the floor of the Flxible bus.

An In-Vehicle Display (IVD) is to be mounted on the bus dashboard so as to be readily visible to the bus driver. The dimensions of the IVD will be approximately 8 by 7 by 4 inches, and the estimated weight will be 4 pounds. A shell approximately the size of the IVD was attached to the dashboard of each bus for these tests; however, measurements made on the IVD shell itself are of dubious value because of its dynamic dissimilarity to the proposed complete IVD.

The third test area involved a low-profile, covered antenna to be mounted on the bus roof approximately 6 feet from the front of the bus. The base of this antenna will be 18 inches long by 2 inches wide. The height of the unit will be 3 inches and its weight 3 pounds. The measurements were made at this location without an antenna present.

2.2 TEST PLAN

To assure as much similarity as possible between data taken at different locations and different buses, all data collection was done while traversing fixed routes along the streets of Fort Worth. Three routes were selected to provide a range of road conditions that would include abnormally severe conditions as well as conditions that would typically be encountered by an operating transit bus. Maps of these routes are shown in Figures 2-1, 2-2, and 2-3. For data reduction purposes, road conditions found on these routes were grouped into seven categories. These categories and the number assigned to each for identification purposes are given in Table 2-1.

During testing, bus speed was not precisely controlled or measured, though in retrospect this would have aided a great deal in correlation of the data. By operating the bus on fixed routes,

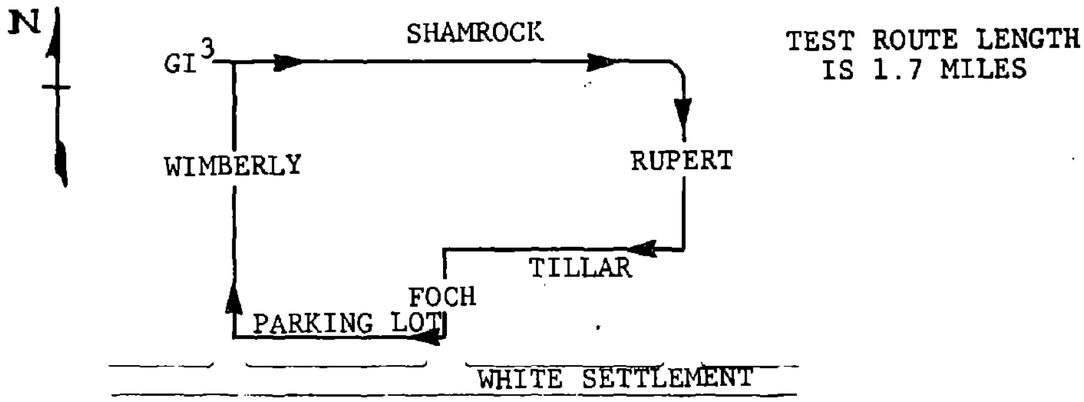

FIGURE 2-1. TEST ROUTE NUMBER 1

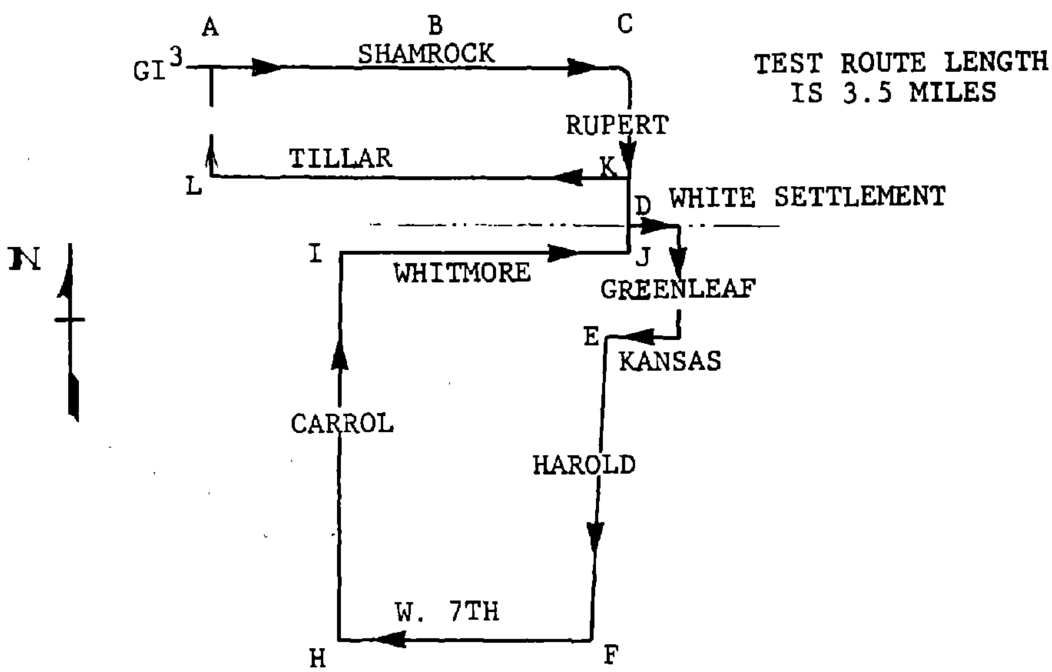

FIGURE 2-2. TEST ROUTE NUMBER 2

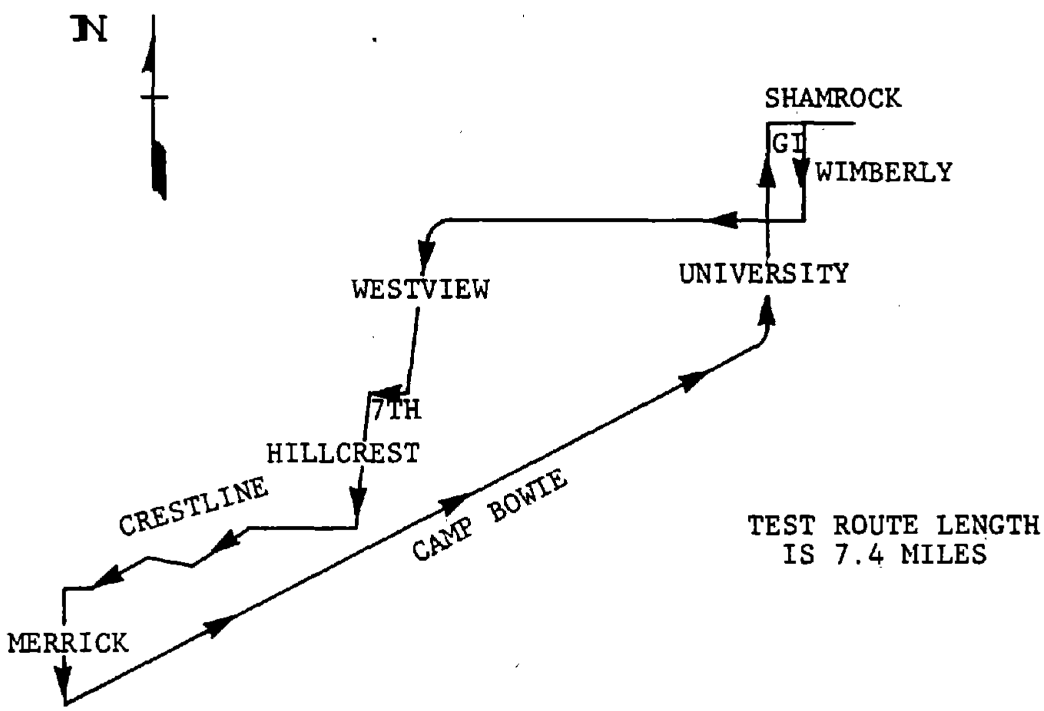

FIGURE 2-3. TEST ROUTE NUMBER 3

however, it was possible to repeat a given bus speed for a particular road condition fairly accurately. Again for data reduction purposes, bus operation was categorized in speed ranges and operating conditions. These categories and their assigned numbers are described in Table 2-2.

The numbering system for these conditions of road condition and bus operation was maintained throughout the tests, data reduction, and reporting. Some conditions will not be found in the final form of the reduced data because, in the course of performing the test or reducing the data, these conditions were judged to be insignificant. In these cases, the data were either not identified or were included in another, more general, category. A list of the conditions handled in this manner is included in the data reduction section.

2.3 INSTRUMENTATION

The data collection system utilized in these tests consisted of a portable 12-VDC 115-VAC inverter, a 5-track direct-writing oscillograph recorder, accelerometers, and associated signal conditioning amplifiers. During testing, each accelerometer was attached to the structure whose vibration characteristics were desired. A voltage proportional to acceleration amplitude was produced by the accelerometer as it was moved by the vibration of the structure to which it was attached. This voltage signal was amplified and used to deflect a galvanometer in the recorder. As the galvanometer was moved by variations in the signal voltage, the reflection of a light beam by a mirror attached to the galvanometer changed position on the recorder paper. As the light-sensitive recorder paper was moved at a controlled speed, the varying position of the light beam was recorded on it, providing a time history of vibratory acceleration. Calibration signals were also recorded on the paper to relate the amplitude of the trace deflection on the paper to absolute vibration amplitude.

The recording system and operating personnel were provided by Vought Corporation, under a rental contract to Gould Information Identification, Inc. The instrumentation engineer was

TABLE 2-1. ROAD CONDITIONS

Number	Condition	Description
0		Used when road condition was not applicable
1	Smooth	Asphalt or concrete pavement in good repair
2	Bumpy	Uneven, broken or patched asphalt or concrete
3	RR Tracks in Street	Tracks with switches running along roadway (industrial district spurs and sidings)
4	RR Crossing	Single or multiple tracks crossing roadway
5	Speed Bumps	3" high x 6" wide rounded asphalt bumps placed in parking lot to slow motorists
6	Brick	Brick pavement - smooth to bumpy
7	Dip	Dip in road bed crossing road for drainage purposes

TABLE 2-2. BUS OPERATING CONDITIONS

Number	Condition	Explanation
0	Slow	Bus moving under 15 miles per hour
1	Idle	Bus stopped, motor running at idle speed
2	Acceleration	Applying power to increase speed
3	15-20 MPH	
4	20-25 MPH	
5	25-35 MPH	
6	Intermittent Braking	Applying brakes momentarily several times in rapid succession to slow bus
7	Normal Stop	Smooth application of brakes for stop
8	Panic Stop	Sudden and forceful application of brakes for minimum distance stop

Mr. Tom Evans, Project Engineer, assisted by an instrumentation technician, Mr. Andy Pierson. A detailed listing of the recording system components is provided in Table 2-3.

2.4 DATA COLLECTION

Vibration data were collected during multiple runs by the two buses on the three prescribed routes. The signals from four (or five) accelerometers were recorded simultaneously during each test run. The accelerometer locations and orientations were selected from the list given in Table 2-4. The schedule of tests as they were conducted is given in Table 2-5.

The recording system components were secured in a bus seat. Each accelerometer was fastened to its test location with either double-backed tape or dental cement.

Route point identification was written by hand on the paper record by the instrumentation engineer in charge of the tests. Instructions regarding time of recording and paper speed were also given by the instrumentation engineer.

The GMC bus was driven by a GI^3 employee and the Flxible bus was driven by a driver provided by CITRAN.

2.5 DATA REDUCTION

Reduction of the vibration data to concise, usable form was accomplished through visual examination and hand tabulation of amplitudes and frequencies observed for given test conditions. The data records were first marked in areas of significant test conditions by the two-part test condition code identifying that condition. The code consists of the number corresponding to the bus operating condition followed by a hyphen and the number corresponding to the road condition. Automatic recording of bus operating speed correlated with the vibration records would certainly have enhanced the value of these data.

The maximum amplitude associated with each accelerometer for each significant test condition encountered in each test run was tabulated. This was felt to be a conservative application of the

TABLE 2-3. RECORDING SYSTEM COMPONENTS

Unit Name	Manufacturer	Model
Oscillograph	Honeywell	906C Visicorder M 100-350 Galvo
Amplifier	Vought Corporation	Special Purpose
Accelerometer	Statham	ASA-25-350

TABLE 2-4. ACCELEROMETER POSITIONS

Number	Orientation	Location
1	Vertical	Bus floor adjacent vehicle box
2	Vertical	Wall of vehicle box
3	Vertical	Card cage side wall
4	Vertical	Mother board in card cage
5	Vertical	Printed circuit card in card cage
6	Horizontal	Top of bus dashboard
7	Vertical	Top of bus dashboard
8	Horizontal	In-Vehicle Display
9	Vertical	In-Vehicle Display
10	Vertical	Bus Roof

TABLE 2-5. SCHEDULE OF BUS VIBRATION TESTS

Test Number	Bus	Route	Transducer Location (Vertical Except Where Noted)				
			Trk 1	Trk 2	Trk 3	Trk 4	Trk 5
1	GMC	1	(Preliminary Run Only - No Data)				
2	GMC	1	Floor	V. B. Wall	Mother Board	PC Card	
3	GMC	1	Floor	V. B. Wall	Mother Board	PC Card	
4	GMC	2	Floor	V. B. Wall	Mother Board	PC Card	
5	GMC	3	Floor	V. B. Wall	Mother Board	PC Card	
6	GMC	2	Floor	IVD	Dash	Roof	
7	GMC	1	Floor	IVD	Dash	Roof	
8	GMC	3	Floor	IVD	Dash	Roof	
9	GMC	3	Dash (F&A)	IVD	Dash	IVD (F&A)	
10	GMC	1	Dash (F&A)	IVD	Dash	IVD (F&A)	
11	GMC	2	Dash (F&A)	IVD	Dash	IVD (F&A)	
12	GMC	1	Floor	V. B. Wall	Card Cage	Mother Board	PC Card
13	GMC	2	Floor	V. B. Wall	Card Cage	Mother Board	PC Card
14	GMC	3	(Run Aborted - Low Accelerometer)				
15	GMC	3	Floor	V. B. Wall	Card Cage	Mother Board	PC Card
16	GMC	3	Floor	V. B. Wall	Card Cage	Mother Board	PC Card
17	FLX	1	V. B. Wall	Card Cage	Mother Board	PC Card	Floor
18	FLX	2	V. B. Wall	Card Cage	Mother Board	PC Card	Floor
19	FLX	3	V. B. Wall	Card Cage	Mother Board	PC Card	Floor
20	FLX	1	Roof	Dash	IVD	IVD (F&A)	Floor
21	FLX	2	Roof	Dash	IVD	IVD (F&A)	Floor
22	FLX	3	Roof	Dash	IVD	IVD (F&A)	Floor

data, providing a definition of the upper bound of vibration which would be experienced in the buses in actual service. These lists were subsequently compared and combined in various ways to illustrate constants or contrasts. A list of the test conditions from the original numbering system which are not included in the tabulated data is provided in Table 2-6. This table also indicates the reason for eliminating these conditions.

TABLE 2-6. TEST CONDITIONS NOT USED IN TABULATED DATA

Test Number	Condition	Reason For Not Using
Bus Operating Conditions		
2	Acceleration	Buses governed so acceleration is very slow and smooth. Only bus speed is significant.
6	Intermittent Braking	Not a significant bus operating mode.
7	Normal Stop	Not significantly different from slow speed operation.
Road Conditions		
6	Brick Road	Not detectably different from concrete or asphalt surface.

In addition to the amplitude-versus-test condition data, some vibration frequency counting was accomplished. Timing marks on the paper records correspond to one-second intervals of elapsed time. When the paper speed was sufficiently fast to separate the vibration traces into individual peaks, the number of peaks in an interval divided by the elapsed time of the interval gives the frequency of the vibration signal. The accuracy of this procedure is somewhat controlled by the clearness of the vibration signal, which is really a composite of all the frequencies present in the vibration (within the frequency range of the recorder) superimposed on each other. However, the vibrating structure usually has distinct resonances which dominate the signal.

Examples of amplitude determination and frequency counting are given in Figures 2-4 and 2-5, respectively.

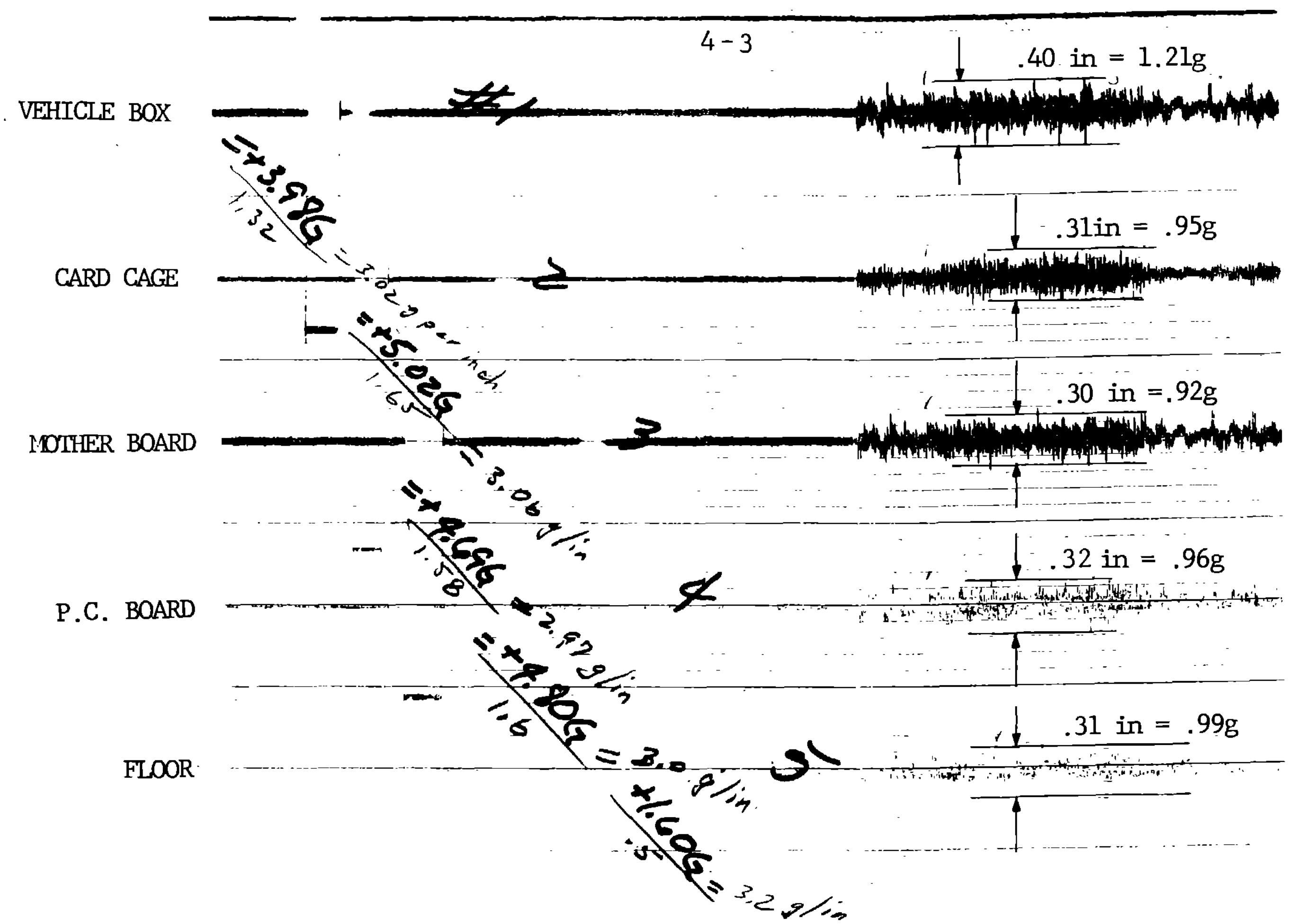

FIGURE 2-4. AMPLITUDE DETERMINATION (FROM TEST NO. 17 - FLXIBLE BUS)

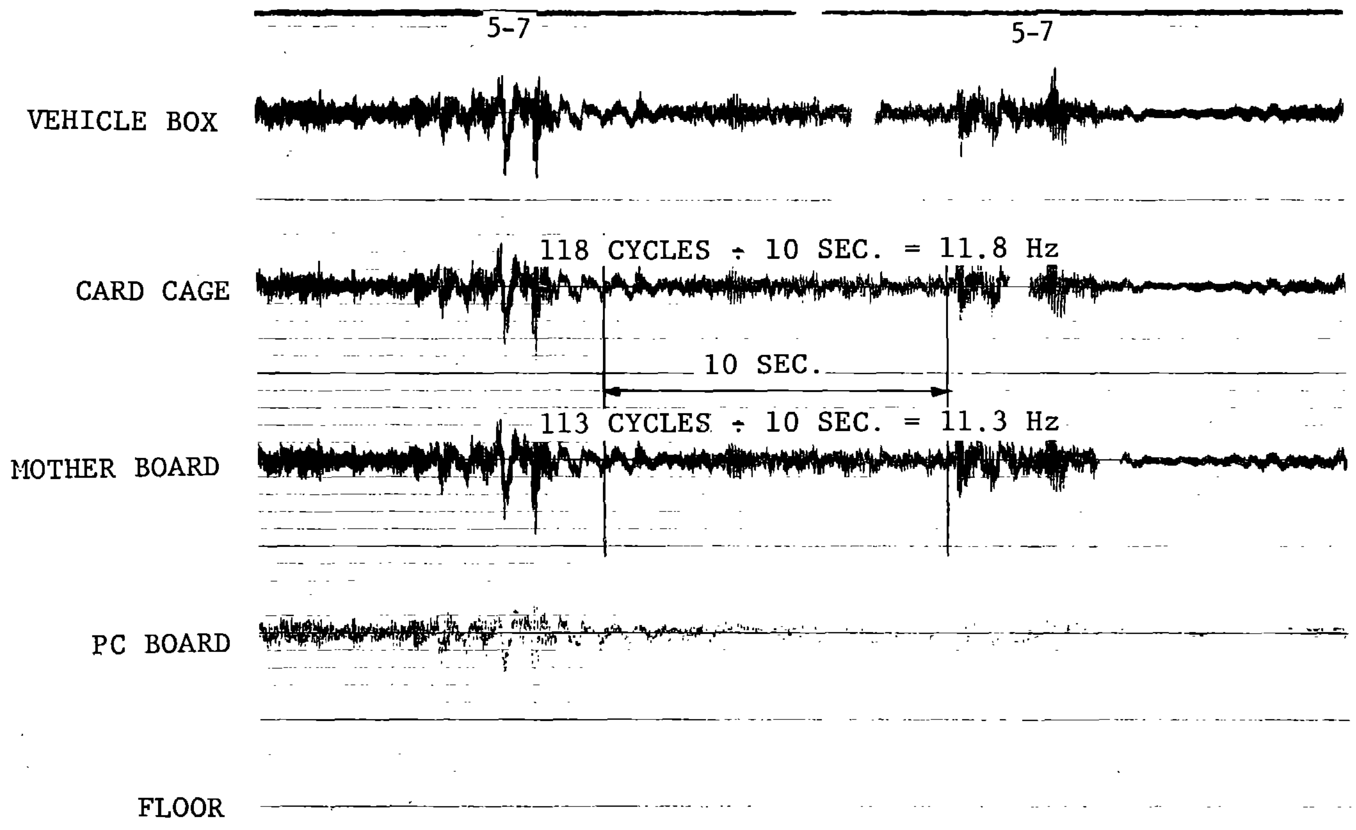

FIGURE 2-5. FREQUENCY COUNTING (FROM TEST NO. 18 - FLXIBLE BUS)

3. RESULTS

3.1 CHARACTERISTICS OF THE VIBRATION AMPLITUDES

The vibration time history records are characterized by amplitudes that vary with the operating and road conditions. As the bus tires roll along the roadway, surface irregularities are encountered which impart vibratory acceleration forces into the bus structure. The structure vibrates at its resonant frequencies until the damping inherent in the structure dissipates the energy or until more energy is added to the system from further surface irregularities. The amplitude of the vibration is a function of the energy input, which is controlled by the speed of the bus and the roughness scale or height of the surface irregularities. A single abrupt stop in the surface causes a few cycles of high amplitude response, which die away quickly. A series of irregularities traversed rapidly causes a relatively constant amplitude of vibrating motion as new energy is continuously fed into the system.

Generally speaking, the vibration amplitude will vary in proportion to the roughness scale of the road and the speed of the bus. This is not invariably true, since a mechanical structure always acts essentially as a tuned filter, thereby exhibiting the greatest response to excitation frequencies which are at or near its natural resonant frequencies.

Short segments of the vibration time history records are presented in Figures 3-1 through 3-12 to illustrate the variation of the vibration characteristics with test conditions.

3.2 FREQUENCIES OF VIBRATION RESPONSE

Basically, three response frequency ranges are observable in the data from both buses, though some differences exist between the two. The lowest frequency is noticed when the bus rolls over a series of closely spaced bumps and is believed to be the natural frequency of the suspension system. The second and third frequencies are observed generally throughout the data rising and falling

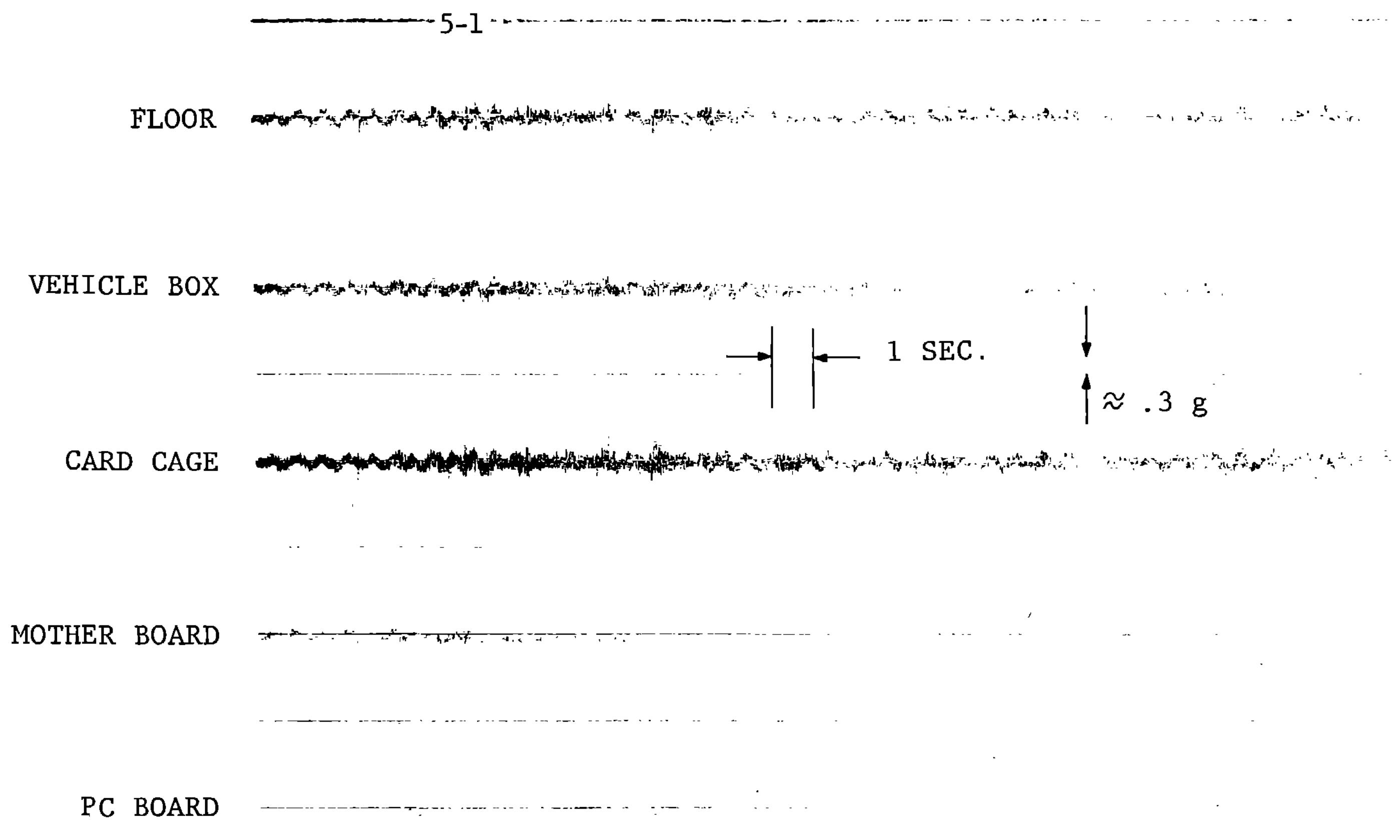

FIGURE 3-1. VIBRATION TIME HISTORY, 25-35 MPH - SMOOTH STREET (FROM TEST NO. 13 - GMC BUS)

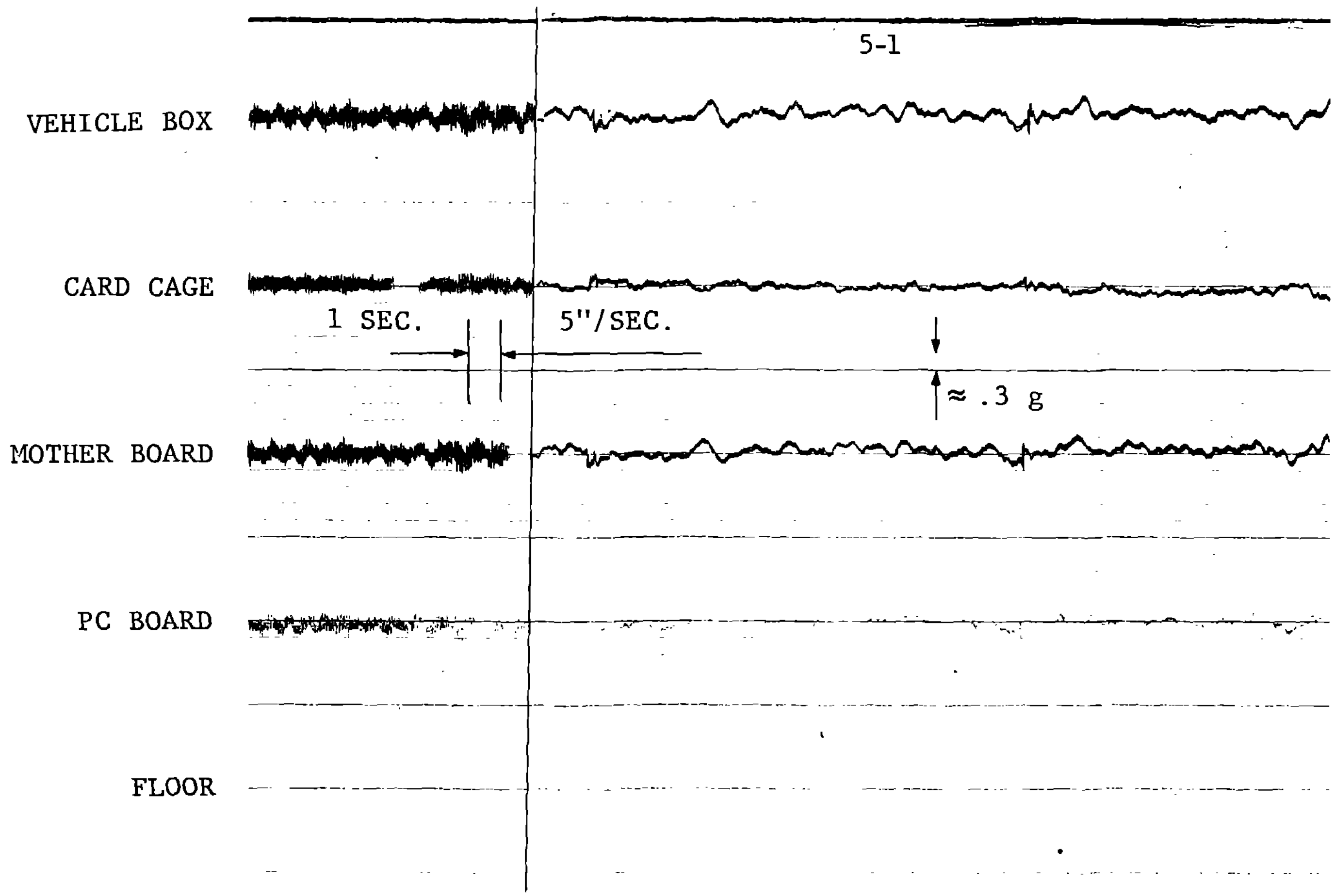

FIGURE 3-2. VIBRATION TIME HISTORY, 25-35 MPH - SMOOTH STREET
(FROM TEST NO. 18 - FLXIBLE BUS)

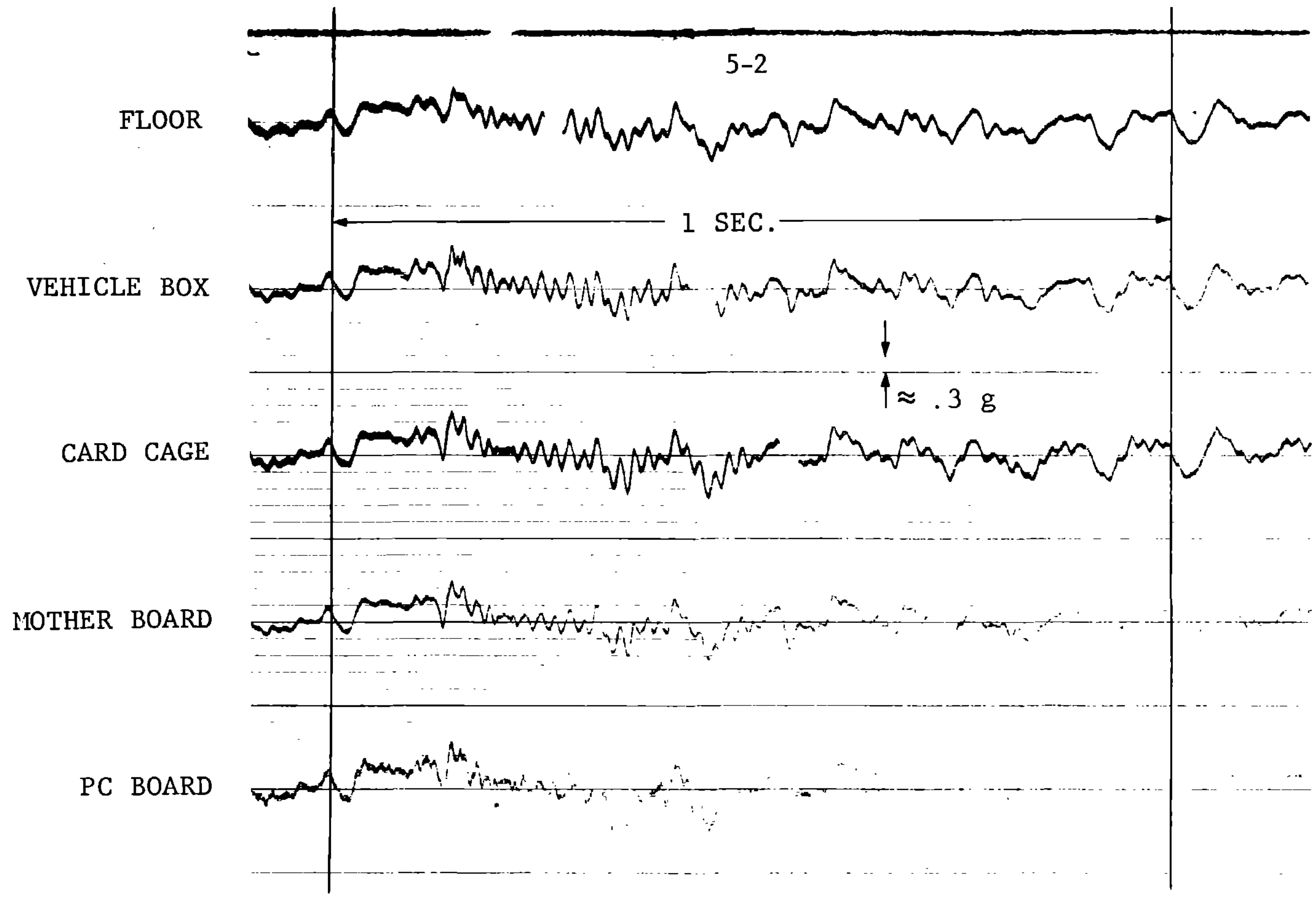

FIGURE 3-3. VIBRATION TIME HISTORY, 25-35 MPH - BUMPY STREET
(FROM TEST NO. 13 - GMC BUS)

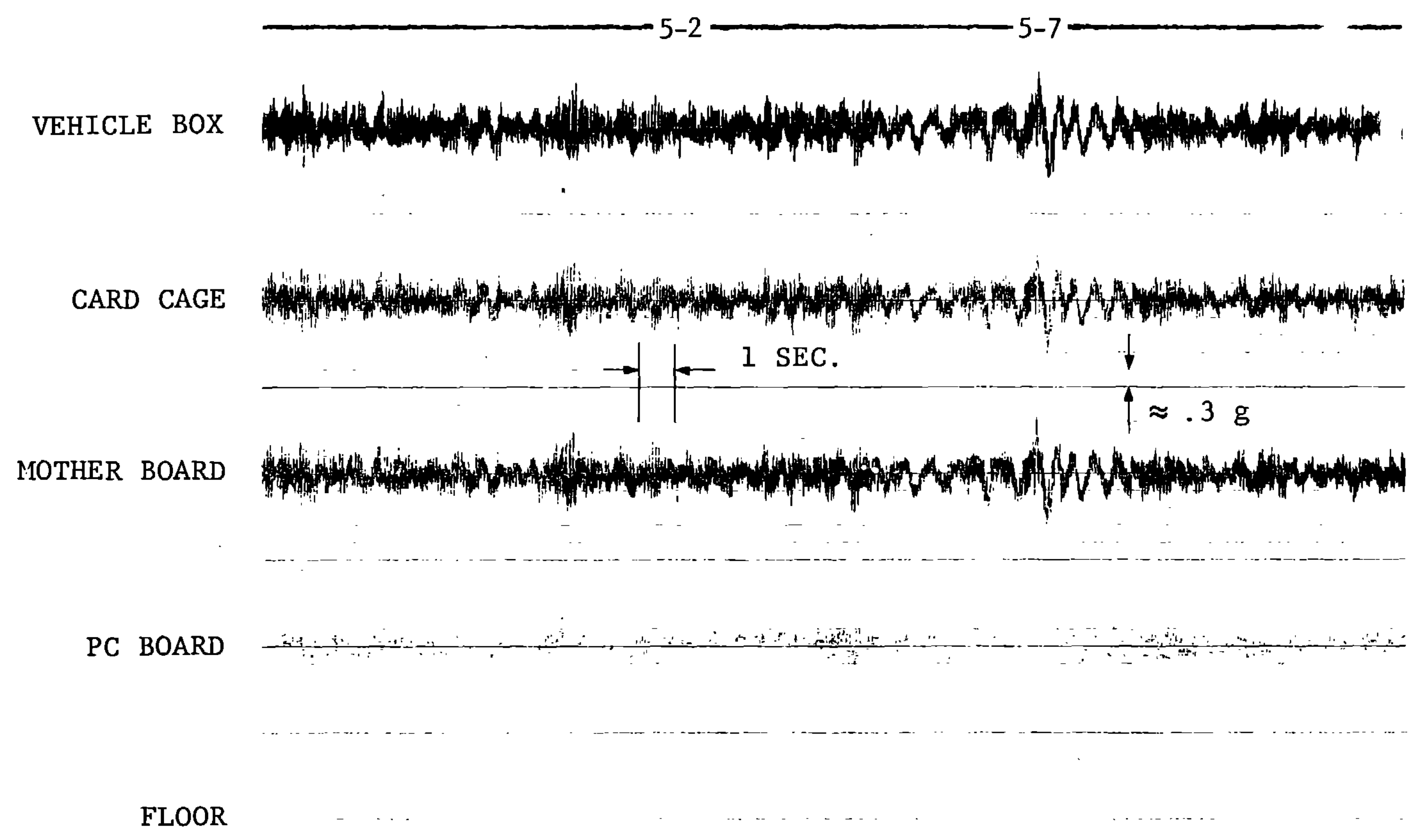

FIGURE 3-4. VIBRATION TIME HISTORY, 25-35 MPH - BUMPY STREET
(FROM TEST NO. 19 - FLXIBLE BUS)

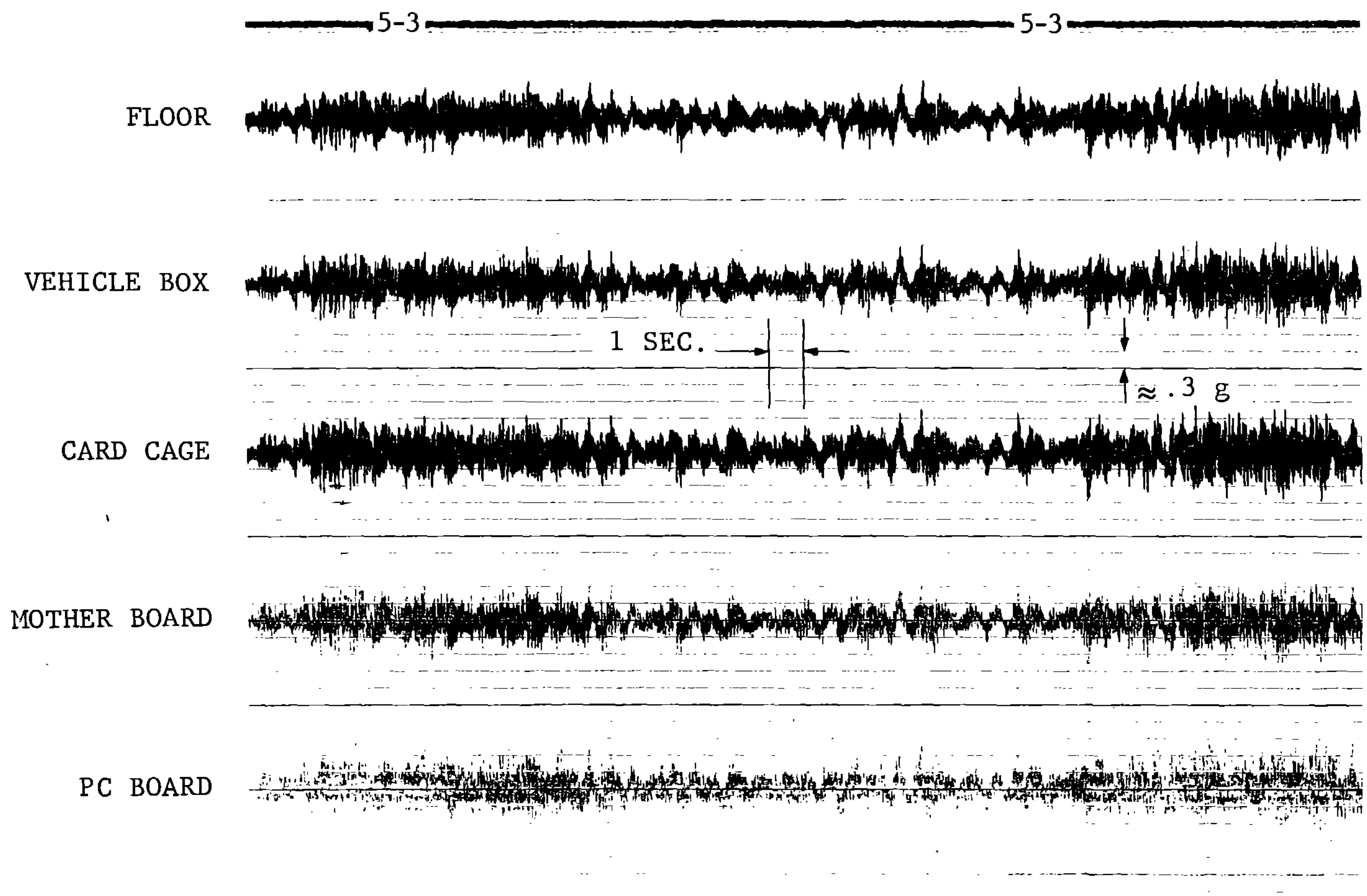

FIGURE 3-5. VIBRATION TIME HISTORY, 25-35 MPH - RR TRACKS IN STREET
(FROM TEST NO. 13 - GMC BUS)

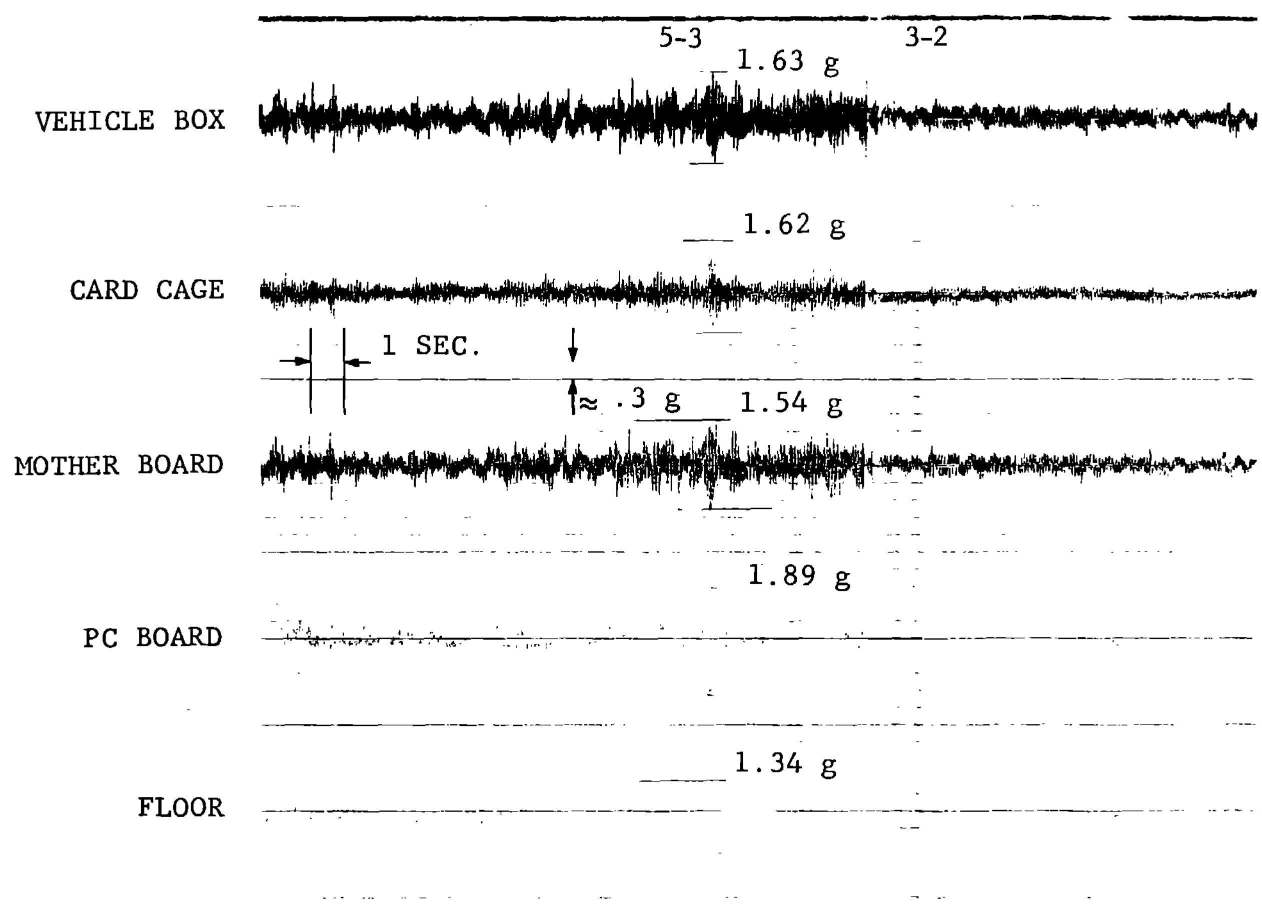

FIGURE 3-6. VIBRATION TIME HISTORY, 25-35 MPH - RR TRACKS IN STREET (FROM TEST NO. 17 - FLXIBLE BUS)

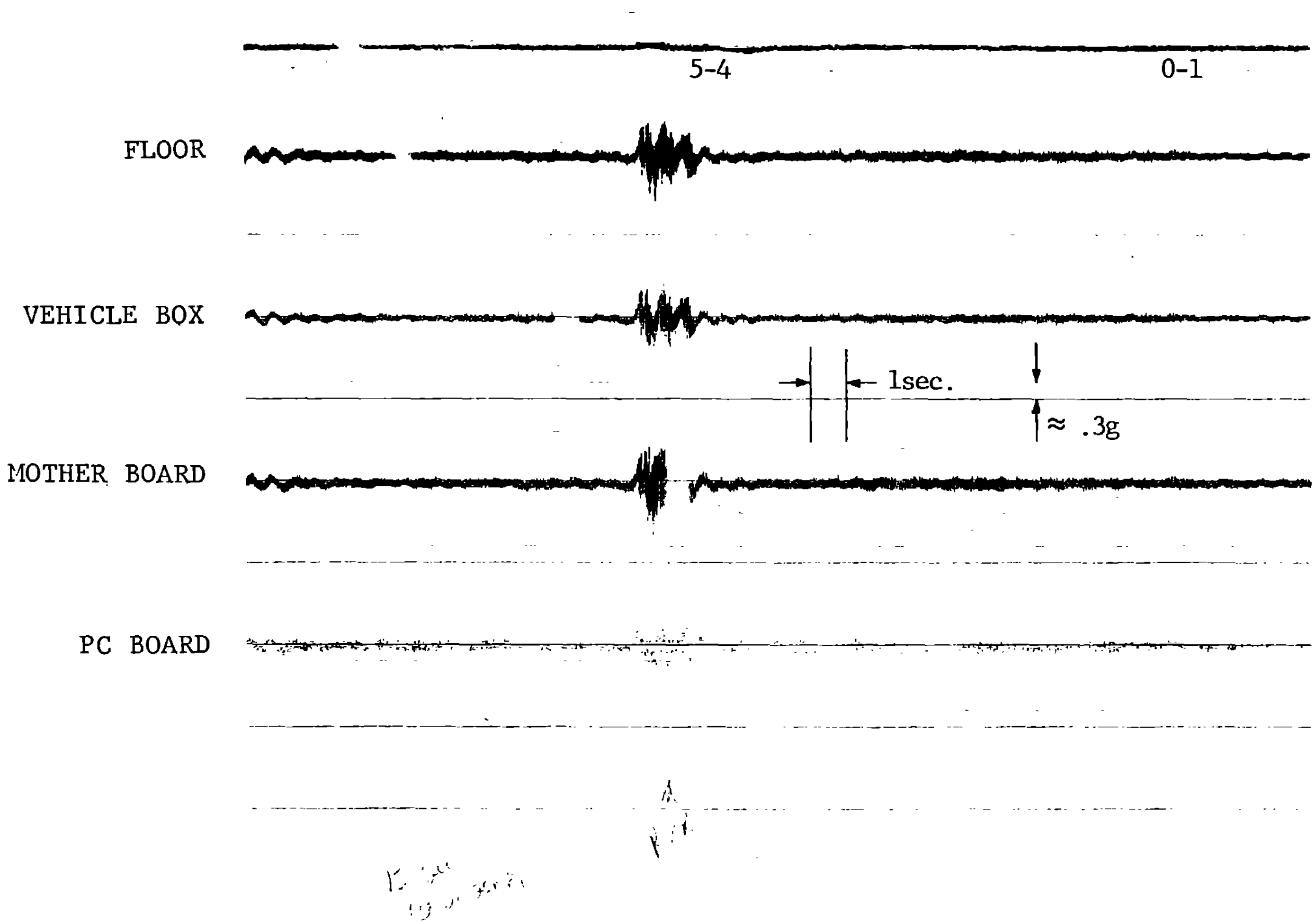

FIGURE 3-7. VIBRATION TIME HISTORY, 25-35 MPH - RR CROSSING
(FROM TEST NO. 3 - GMC BUS)

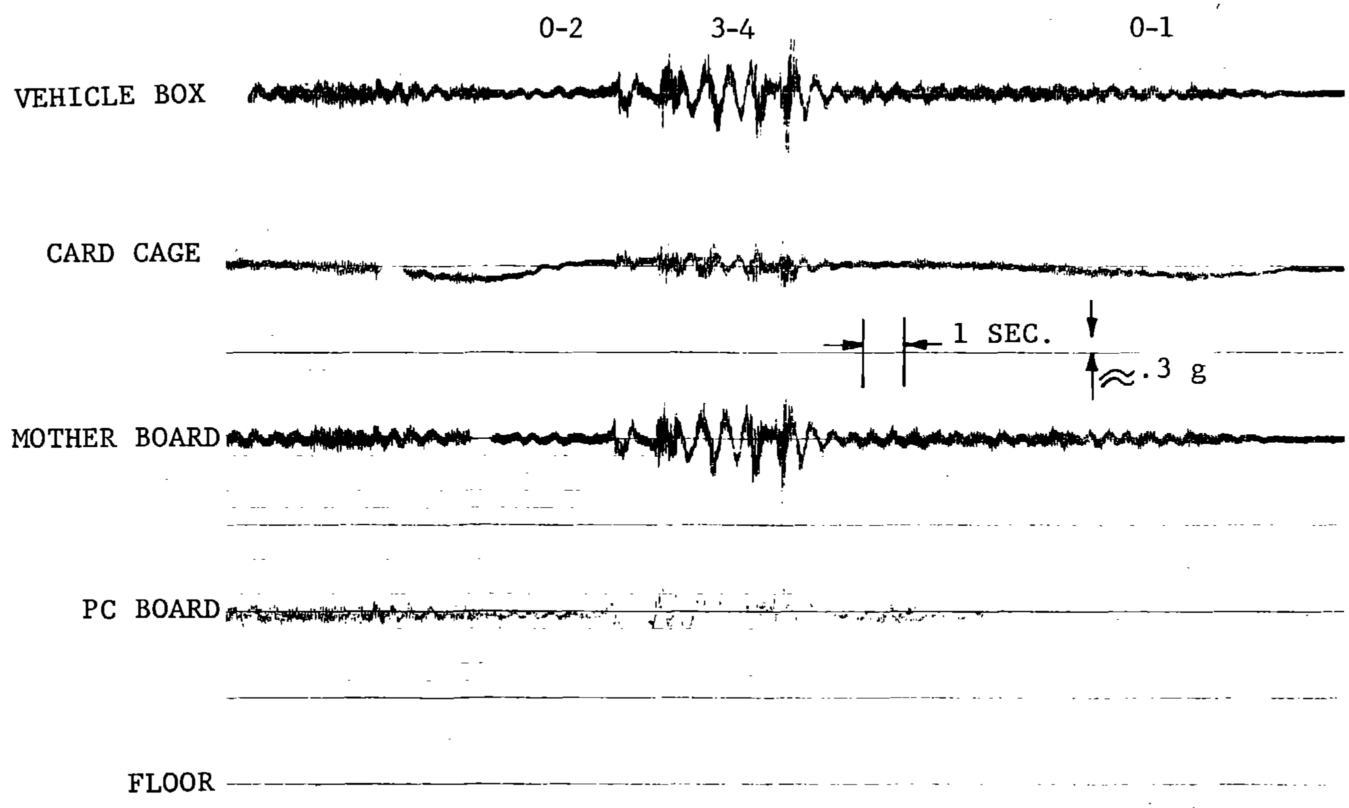

FIGURE 3-8. VIBRATION TIME HISTORY, 15-20 MPH - MULTIPLE RR CROSSING (FROM TEST NO. 18 - FLXIBLE BUS)

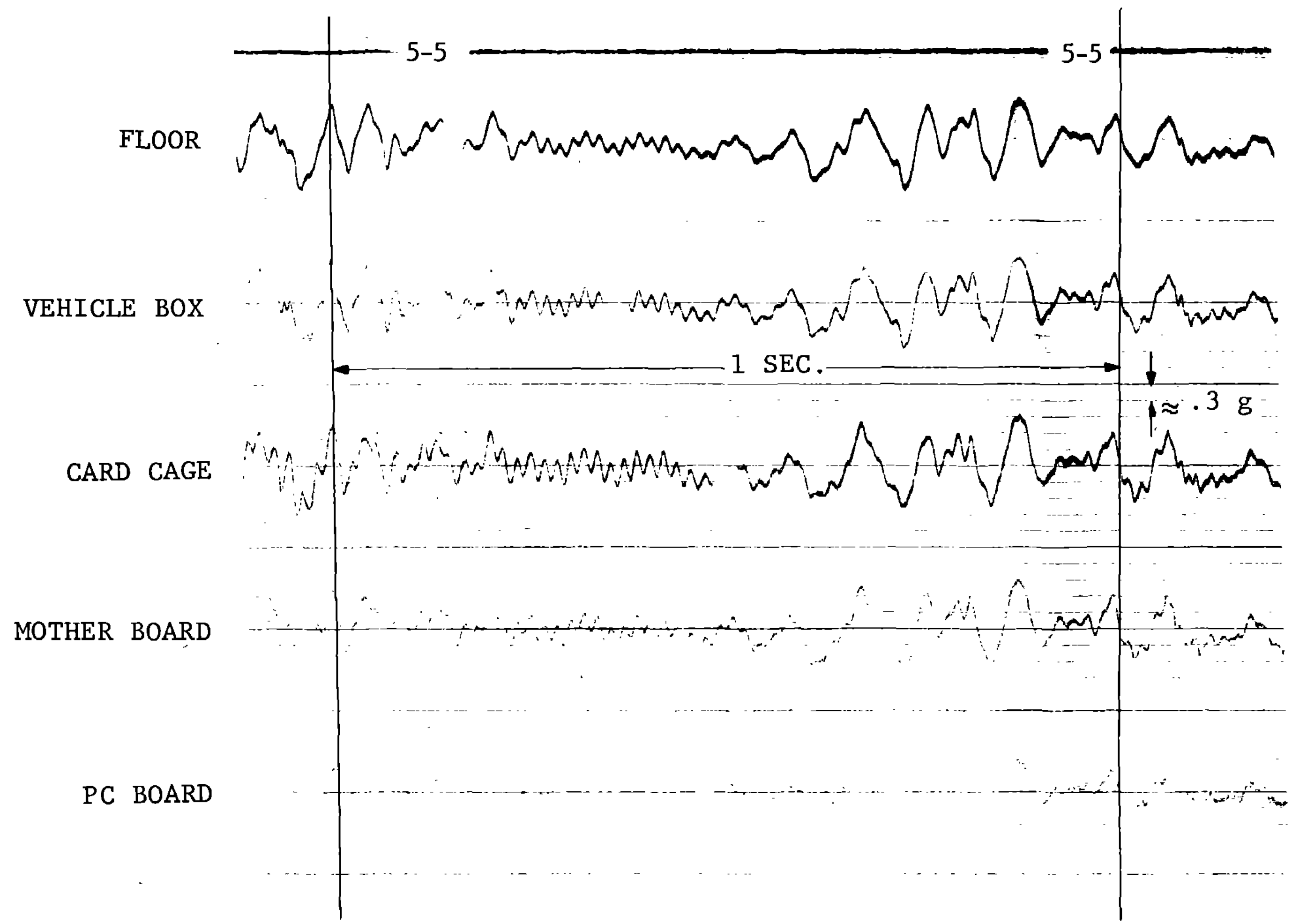

FIGURE 3-9. VIBRATION TIME HISTORY, 25-35 MPH - SPEED BUMPS
(FROM TEST NO. 12 - GMC BUS)

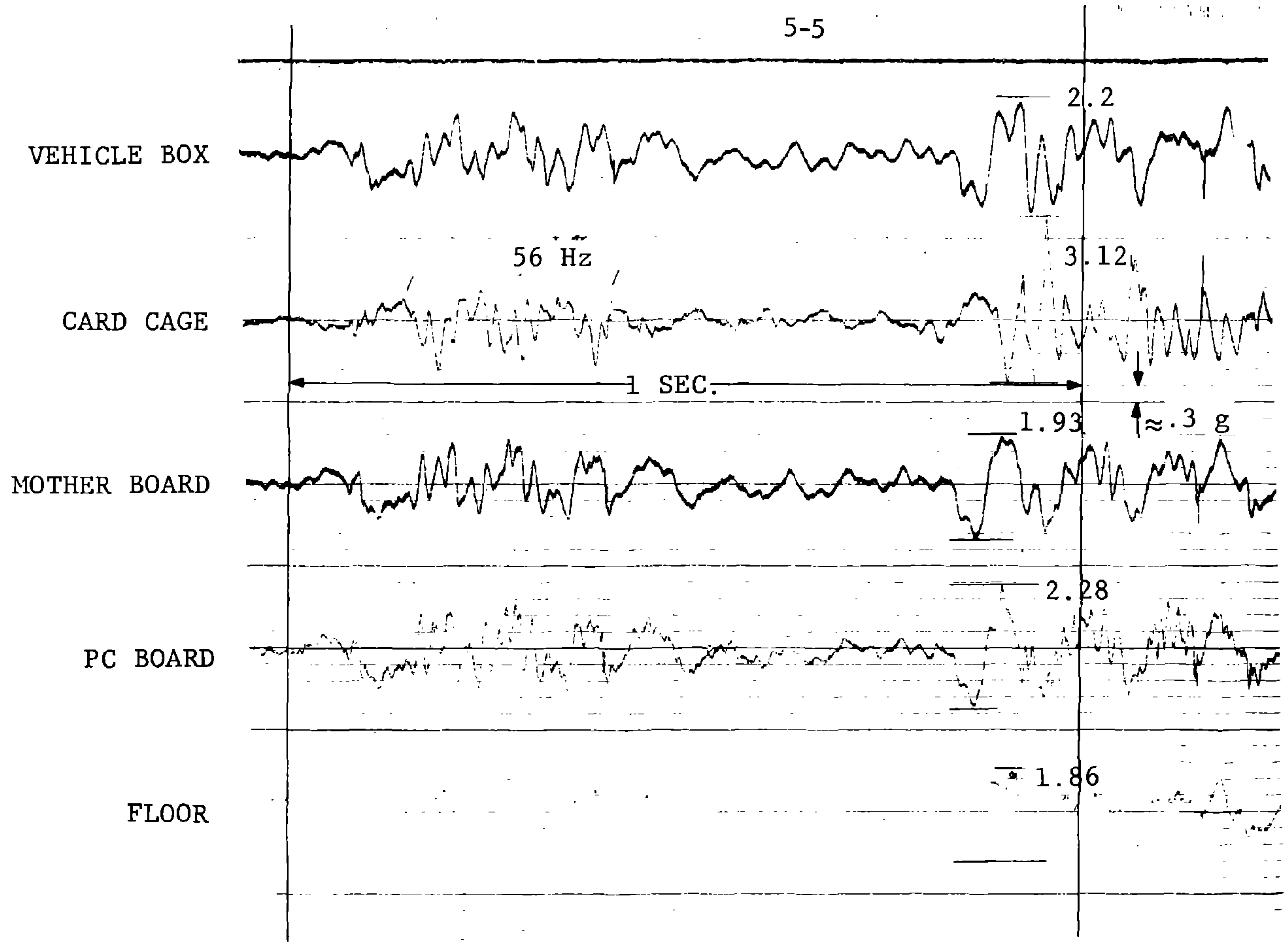

FIGURE 3-10. VIBRATION TIME HISTORY, 25-35 MPH - SPEED BUMPS
(FROM TEST NO. 17 - FLXIBLE BUS)

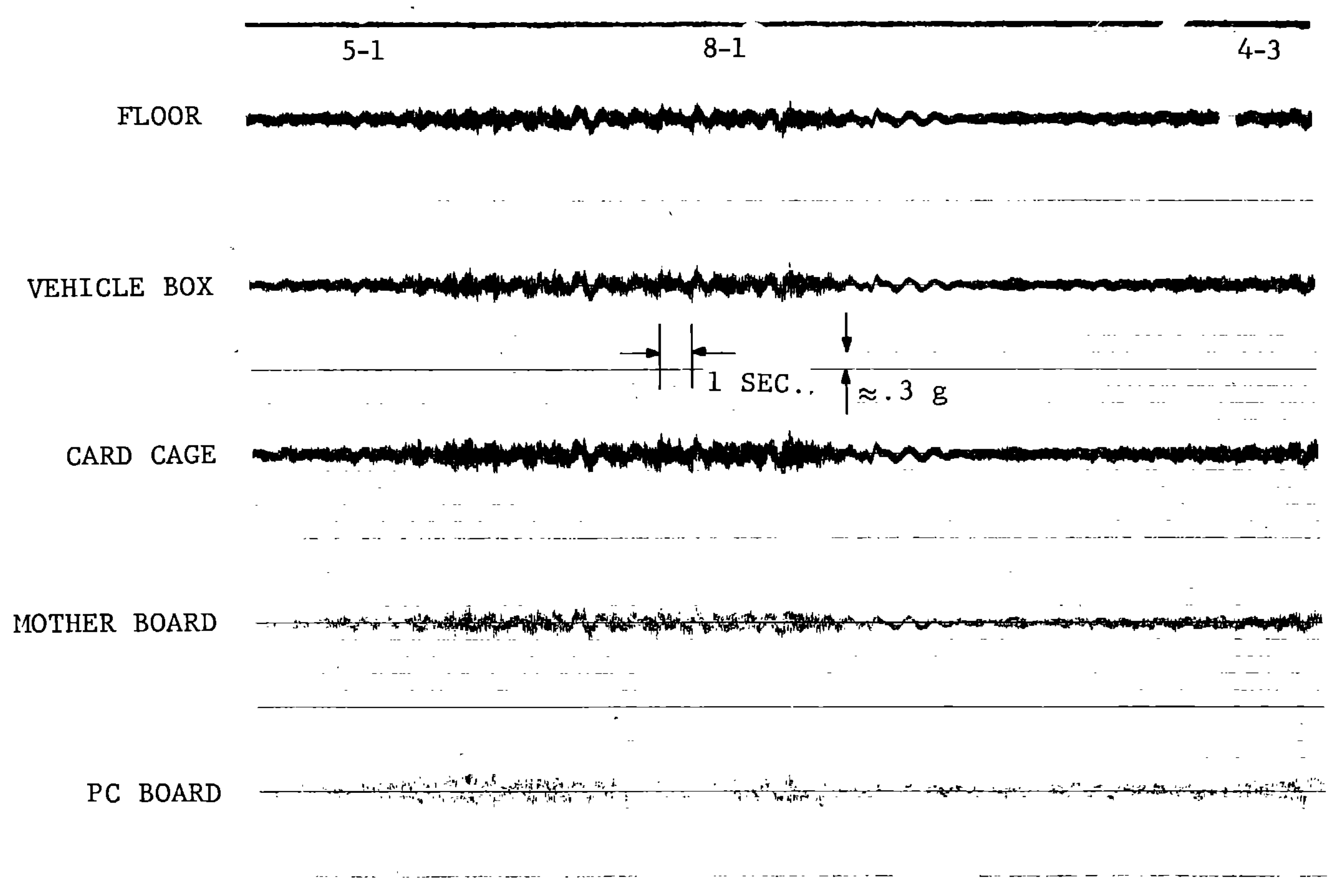

FIGURE 3-11. VIBRATION TIME HISTORY, PANIC STOP - SMOOTH STREET (FROM TEST NO. 13 - GMC BUS)

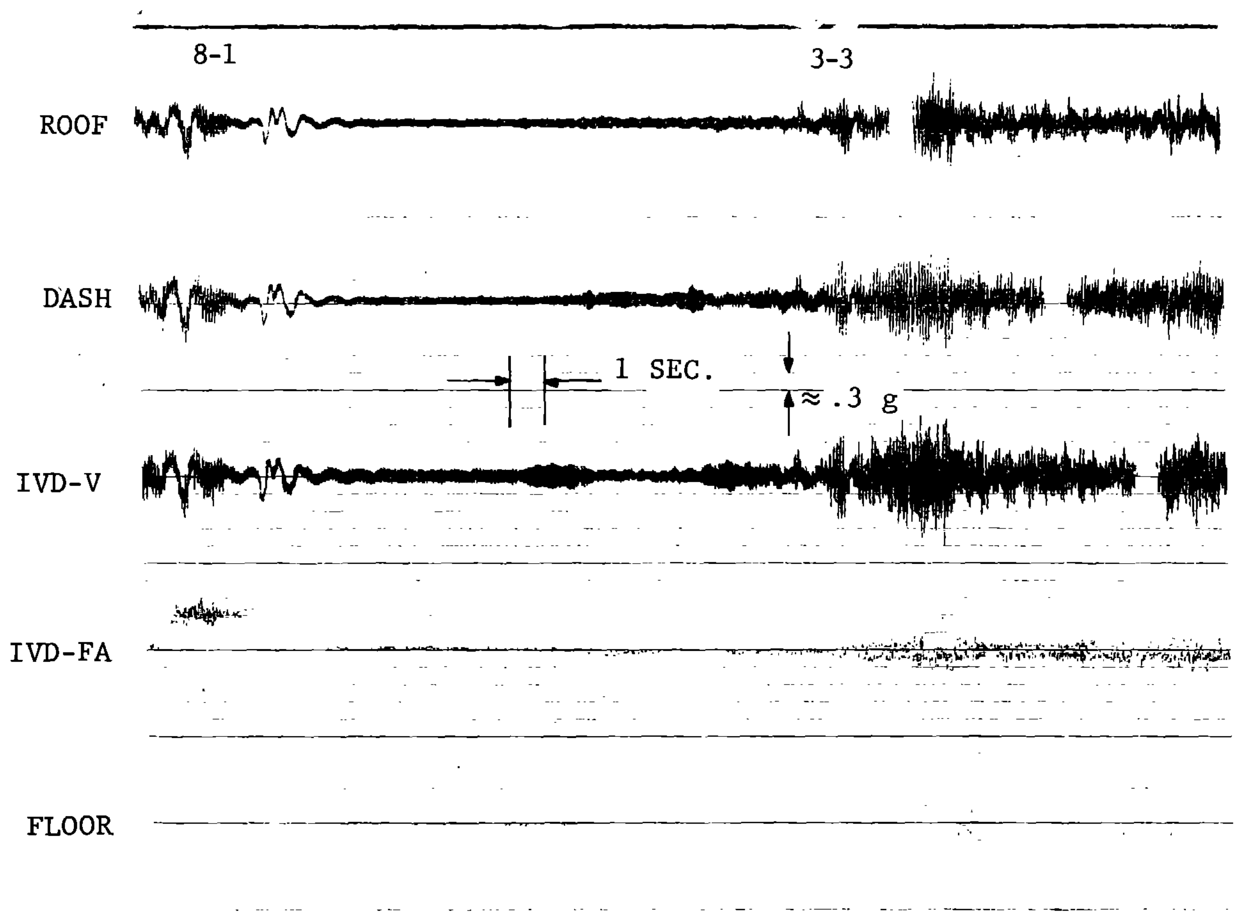

FIGURE 3-12. VIBRATION TIME HISTORY, PANIC STOP - SMOOTH STREET
(FROM TEST NO. 20 - FLXIBLE BUS)

in amplitude in proportion to the bus speed or the roughness of the road or both. These frequencies are believed to be the predominant natural frequency of the bus body and the response frequency of the local component to which the accelerometer is attached. This latter frequency can only be detected in the records produced when the paper travels at a speed of 5 inches per second, although it is present during all operations. It is also not nearly as constant as the lower frequencies. Figures 3-13 and 3-14 are examples of data records which illustrate some of the identifiable frequencies. Table 3-1 lists the frequency ranges observed on the two buses.

TABLE 3-1. RECURRING FREQUENCIES OF THE DATA

Bus	Suspension	Body	Component
Flxible 207	2.0 Hz	11-13 Hz	40-70 Hz
GM 3100	1.5 Hz	16-18 Hz	60-70 Hz

3.3 MAXIMUM VIBRATION LEVEL VERSUS TEST CONDITION

A comparison of the data reduced to tabulations of maximum vibration level observed for each test condition gives rise to the major conclusions reached in this test program. The first step in the data reduction scheme, after marking the test condition numbers on the records, was to tabulate the maximum level observed at each accelerometer position during each test condition during each test run. These tables were then combined into tables of maximum level at each accelerometer position for each test route. In cases in which a data point was reported, the highest level was retained. Tables 3-2, 3-3, and 3-4 contain data corresponding to the GMC bus for Routes 1, 2, and 3, respectively. Tables 3-5, 3-6, and 3-7 present the corresponding data for the Flxible bus. Data on all three routes for the GMC bus are combined in Table 3-8, again retaining the highest level for

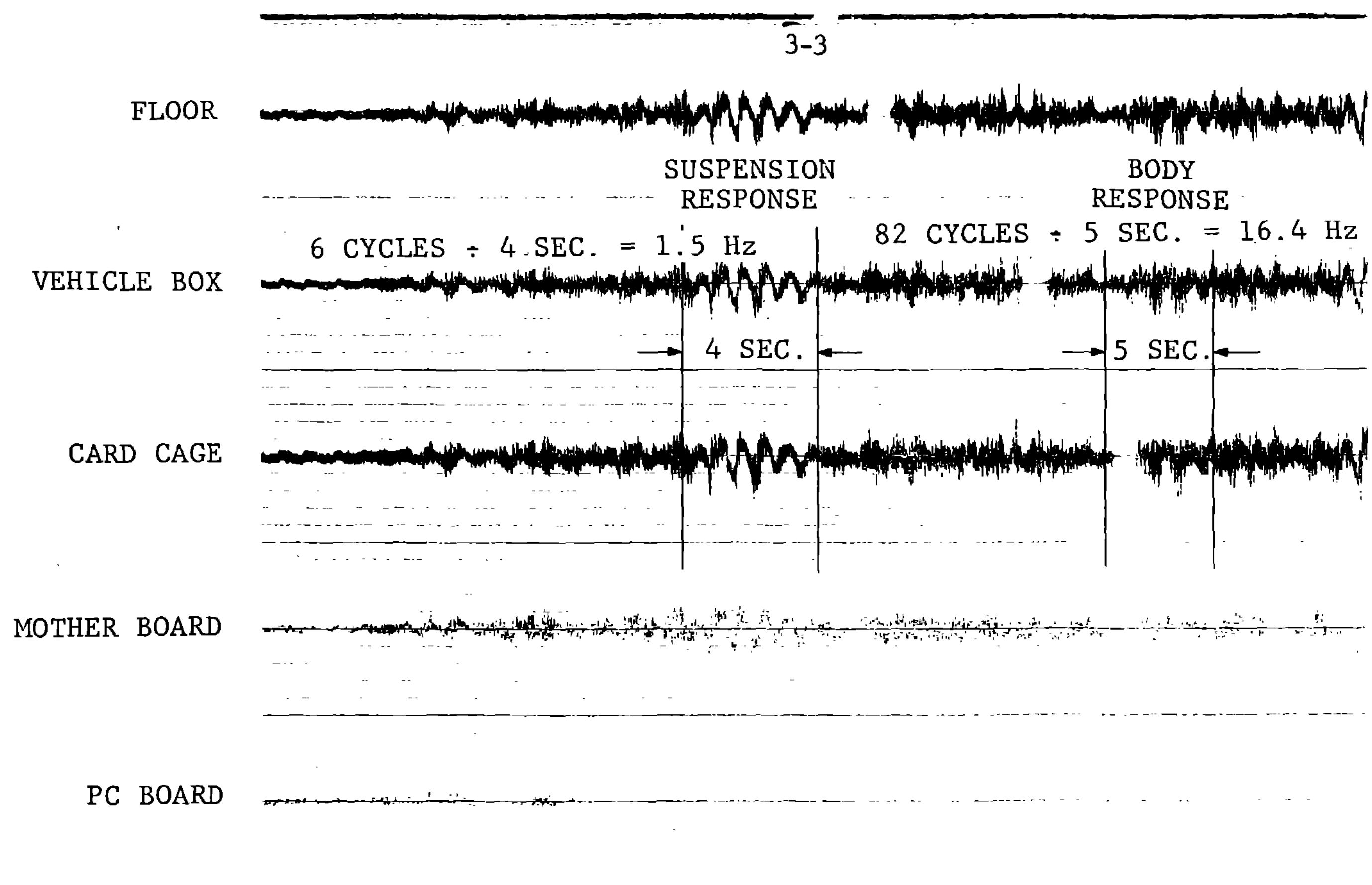

FIGURE 3-13. SUSPENSION AND BODY FREQUENCIES (FROM TEST NO. 12 - GMC BUS)

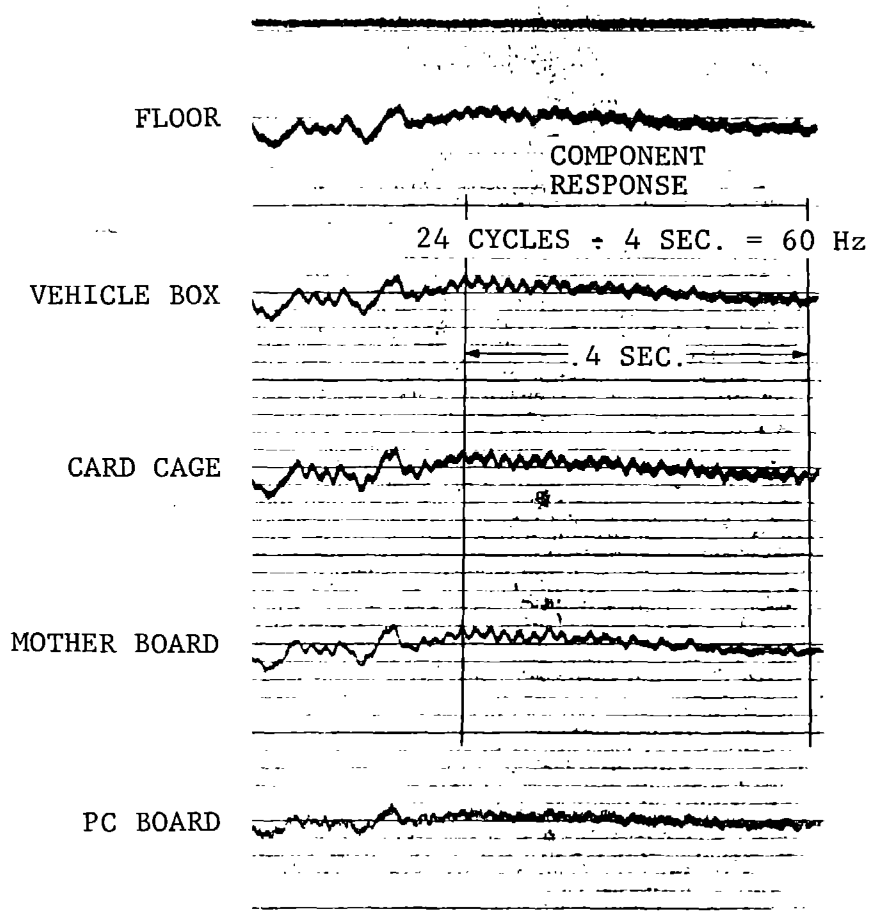

FIGURE 3-14. COMPONENT FREQUENCY (FROM TEST NO. 12 - GMC BUS)

each given data point. Data from the three routes for the Flxible bus are combined in Table 3-9.

These data are plotted in bar graph form in Figures 3-15, 3-16, and 3-17 for the floor, dashboard, and roof accelerometers. The establishment of maximum vibration amplitudes observed in the data for various accelerometer positions during any of the test runs is believed to describe an upper bound for vibration levels which can be expected of AVM system component locations on buses in normal city route service.

3.4 RESULTS OF SPECIAL TESTS

The special stomp-and-kick tests associated with the vehicle box were intended to measure the effect of such action by vandals or unruly passengers. The stomp test consisted of stomping the floor alongside the vehicle box. The kick test was accomplished simply by repeatedly kicking the box in the forward direction. The results of these tests are contained in Table 3-10.

TABLE 3-2. MAXIMUM VIBRATION AMPLITUDE - PEAK-TO-PEAK G LEVEL

GMC 3100 ROUTE #1

Test Condition	Accelerometer Position Number (Reference Table 4)									
	1	2	3	4	5	6	7	8	9	10
0-1	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25
0-2	.50	.50	.75	.50	.50	.50	.75	.50	.75	
0-3	1.00	1.00	.25	1.00	1.25	.75	1.25	.75	1.25	
0-4					.25	.75	1.25	.75	1.50	
1-0	.25	.25	.25	.25	.25	.25	.25	.25	.25	
3-1	.75	1.00		1.00	1.00		.25			.25
3-2	1.00	1.00	1.00	1.00	1.50	.75	1.50	.75	1.00	1.00
3-3	1.50	1.25	1.25	1.50	1.50	2.25	1.25	2.50	1.75	.75
3-4	1.50	1.50	1.25	1.00	1.50	2.00	1.50	2.50	1.75	1.00
3-5	1.75	1.00			1.25		2.50			2.25
3-7										
4-1	.50	.50	.50	.50	.50		.25			.25
4-2	.75	.75	.50	.75	1.00		.50			.50
4-3	2.00	1.75	1.75	1.75	2.00		2.00			1.50
4-4										
4-5	2.00	2.00	1.75	2.25	2.50	3.25	3.00	4.50	3.25	2.75
4-7										
5-1	.50	.75	.75	.75	.75		.50			.50
5-2										
5-3	1.25						1.25			1.00
5-4	1.75	1.50	1.75	1.75	2.00		1.50			1.25
5-5	2.25	2.00	2.25	2.25	3.00	4.25	3.25	5.75	3.75	2.00
5-7										
8-1	1.00	1.00	1.00	1.00	1.00	.75	.75	1.00	1.00	.50

TABLE 3-3. MAXIMUM VIBRATION AMPLITUDE - PEAK-TO-PEAK G LEVEL

GMC 3100 ROUTE #2

Test Condition	Accelerometer Position Number (Reference Table 4)									
	1	2	3	4	5	6	7	8	9	10
0-1	.25	.25	.25	.25	.25					
0-2	.75	.75	.50	.75	.75	.50	.75	.50	.75	.50
0-3	1.00	1.25	1.00	1.00	1.00		.50		.50	.25
0-4	1.75	1.75	1.75	1.75	2.00		1.75		2.00	1.50
1-0	.25	.25	.25	.25	.25	.25	.25	.25	.50	.25
3-1						1.00	1.25	1.25	1.50	
3-2	1.00	1.00	1.00	1.00	1.25	1.00	1.75	1.50	2.25	.50
3-3	1.25	1.25	1.50	1.25	1.50	1.50	1.50	1.75	1.75	1.00
3-4	2.00	2.00	2.25	2.00	2.25	2.00	2.00	2.25	2.00	1.75
3-5										
3-7						2.00	1.25	2.25	2.00	
4-1	.50	.50		.50	.50		.25		.25	.25
4-2	1.25	1.25	1.50	1.50	1.75		1.50		1.75	1.50
4-3	2.00	2.00	2.25	2.25	2.50		1.75		1.75	1.00
4-4	1.50	1.50	1.75	1.50	1.75		1.75		2.25	1.50
4-5										
4-7	1.50	1.75	2.00	1.50	2.00					
5-1	.50	.50	.50	.50	.50		5.0		.7	.50
5-2	1.50	1.50	1.50	1.50	1.75		1.50		1.50	1.00
5-3	1.75	1.75	1.75	1.75	1.75		1.00		1.50	1.00
5-4	1.50	1.50		1.75	2.00					
5-5										
5-7	1.50	1.50	1.75	1.50	1.75		1.50		1.75	1.25
8-1	.75	.75	1.00	.75	.75	1.00	.75	1.25	1.00	.50

TABLE 3-4. MAXIMUM VIBRATION AMPLITUDE - PEAK-TO-PEAK G LEVEL

GMC 3100 ROUTE #3

Test Condition	Accelerometer Position Number (Reference Table 4)									
	1	2	3	4	5	6	7	8	9	10
0-1	.50	.50	.25	.50	.50	.25	.50	.25	.50	.50
0-2	.75	.75	.50	.75	1.00	.25	.75	.25	.75	.50
0-3										
0-4										
1-0	.25	.25	.25	.25	.50	.25	.25	.25	.25	.25
3-1	.75	.50		.50	.50	.25	.25	.25	.25	.25
3-2	1.00	1.00	1.25	1.00	1.25	.75	.50	1.00	1.00	.50
3-3										
3-4										
3-5										
3-7	1.50	1.00	1.00	1.00	1.00	.50	1.75	.75	1.75	1.25
4-1	.50	.50	.50	.50	.50					
4-2	1.25	1.25	1.25	1.25	1.50	.75	1.00	.75	1.25	1.25
4-3	1.25	1.50	1.75	1.75	1.50					
4-4	1.50	1.25	1.50	1.25	1.50	1.50	1.25	2.25	3.50	1.25
4-5										
4-7										
5-1	.50	.50		.75	.75	.25	.25	.25	.50	.25
5-2	1.50	1.75	2.00	1.75	2.00	1.00	1.50	1.00	1.50	1.00
5-3										
5-4	1.75	1.75		1.75	2.00					
5-5	.75	.50		1.00	1.00					
5-7	1.75	2.00	2.00	2.00	2.25	1.25	2.00	.150	2.25	1.75
8-1	1.25	1.00		1.25	1.25	1.00	1.00	.75	1.25	

TABLE 3-5. MAXIMUM VIBRATION AMPLITUDE - PEAK-TO-PEAK G LEVEL

FLXIBLE 207 ROUTE #1

Test Condition	Accelerometer Position Number (Reference Table 4)									
	1	2	3	4	5	6	7	8	9	10
0-1	.50						.50	.50	.75	.50
0-2		.25	.25	.25	.25		1.00	.50	1.25	.75
0-3										
0-4	1.00	1.00	.50	1.00	1.00		1.00	.50	1.00	.50
1-0	.25	.25	.25	.25	.25		.25	.25	.25	.25
3-1										
3-2	.75	.50	.25	.50	.50		1.00	.75	1.00	.75
3-3	1.25						2.50	2.00	2.50	1.75
3-4	1.00	1.25	1.00	1.25	1.25					
3-5	1.50						1.75	2.25	2.75	1.75
3-7	.75	.75	.75	.75	1.00					
4-1										
4-2	.25	.50	.25	.50	.50					
4-3	.75	1.25	1.00	1.00	1.50					
4-4										
4-5	2.00	2.25	3.00	2.25	2.25					
4-7										
5-1										
5-2	.25	.25	.25	.25	.25					
5-3	1.25	1.75	1.75	1.75	2.00					
5-4										
5-5	1.75	2.25	2.25	1.75	2.00		4.25	5.25	5.25	2.25
5-7										
8-1	.75	.75	.50	.75	.75		1.50	1.25	1.50	1.25

TABLE 3-6. MAXIMUM VIBRATION AMPLITUDE - PEAK-TO-PEAK G LEVEL

FLXIBLE 207 ROUTE #2

Test Condition	Accelerometer Position Number (Reference Table 4)									
	1	2	3	4	5	6	7	8	9	10
0-1		.50	.25	.50	.50		.25	.25	.25	.25
0-2		.25	.25	.25	.25		.50	.25	.50	.50
0-3	.50	.50	.25	.50	.50		.50	.50	.50	.50
0-4	1.00	1.00	1.00	1.00	1.25		1.00	.50	1.00	.75
1-0	.25	.25	.25	.25	.25		.25	.25	.25	.25
3-1										
3-2	.50	.75	.50	.75	.75		1.00	.50	1.25	.75
3-3										
3-4	1.75	2.25	1.50	2.25	2.25		2.50	2.25	3.00	2.25
3-5										
3-7										
4-1										
4-2	1.25	1.50	1.25	1.25	1.50		2.00	1.25	2.25	1.50
4-3	1.50	1.75	1.75	1.75	2.00		1.25	1.50	1.75	1.00
4-4	1.25	1.50	1.25	1.25	1.25		1.00	.50	1.00	.75
4-5										
4-7										
5-1	.50	.75	.75	.75	.50		1.00	.50	1.00	.75
5-2	1.00	1.25	1.00	1.00	1.25		1.25	1.50	1.50	1.00
5-3	1.00	1.50	1.25	1.50	1.50		2.75	2.25	3.00	1.50
5-4										
5-5										
5-7	1.75	2.00	2.00	2.00	2.00		2.25	2.50	3.50	1.25
8-1	.50	.75	1.00	.50	.50					

TABLE 3-7. MAXIMUM VIBRATION AMPLITUDE - PEAK-TO-PEAK G LEVEL

FLXIBLE 207 ROUTE #3

Test Condition	Accelerometer Position Number (Reference Table 4)									
	1	2	3	4	5	6	7	8	9	10
0-1	.25	.25	.25	.25	.25		.25	.25	.50	.25
0-2	.50	.50	.50	.50	.50		.50	.50	.50	.50
0-3										
0-4										
1-0	.25	.25	.25	.25	.25					
3-1	.25	.50	.50	.50	.50		1.00	.25	.50	.25
3-2	1.00	1.25	1.25	1.25	1.25		1.50	1.00	1.75	1.25
3-3										
3-4										
3-5										
3-7	1.25	1.50	1.50	1.50	1.50		1.25	1.00	1.50	1.00
4-1										
4-2	1.25	1.50	1.25	1.50	1.25		2.25	1.25	2.00	1.50
4-3										
4-4	1.25	1.25	1.00	1.00	1.25		1.75	2.00	2.00	1.25
4-5										
4-7										
5-1	.25	.25	.25	.25	.25		.25	.25	.25	.25
5-2	1.50	1.75	1.75	1.75	1.75		2.00	1.75	2.75	1.25
5-3										
5-4										
5-5										
5-7	1.75	2.00	2.00	2.00	2.25		2.75	.75	3.00	2.25
8-1										

TABLE 3-8. MAXIMUM VIBRATION AMPLITUDE - PEAK-TO-PEAK G LEVEL

GMC 3100 - **ALL ROUTES**

Test Condition	Accelerometer Position Number (Reference Table 4)									
	1	2	3	4	5	6	7	8	9	10
0-1	.50	.50	.25	.50	.50	.25	.50	.25	.50	.50
0-2	.75	.75	.75	.75	1.00	.50	.75	.50	.75	.50
0-3	1.00	1.25	1.00	1.00	1.25	.75	1.25	.75	1.25	.25
0-4	1.75	1.75	1.75	1.75	2.00	.75	1.75	.75	2.00	.50
1-0	.25	.25	.25	.25	.50	.25	.25	.25	.25	.25
3-1	.75	1.00		1.00	1.00	1.00	1.25	1.25	1.50	.25
3-2	1.00	1.00	1.25	1.00	1.50	1.00	1.75	1.50	2.25	1.00
3-3	1.50	1.25	1.50	1.50	1.50	2.25	1.50	2.50	1.75	1.00
3-4	2.00	2.00	2.25	2.00	2.25	2.00	2.00	2.50	2.00	1.75
3-5	1.75	1.00			1.25		2.50			2.25
3-7	1.50	1.00	1.00	1.00	1.00	2.00	1.75	2.25	2.00	1.25
4-1	.50	.50	.50	.50	.50		.25			.25
4-2	1.25	1.25	1.50	1.50	1.75	.75	1.50	.75		1.50
4-3	2.00	2.00	2.25	2.25	2.50		2.00			1.50
4-4	1.50	1.50	1.75	1.50	1.75	1.50	1.75	2.25	3.50	1.50
4-5	2.00	2.00	1.75	2.25	2.50	3.25	3.00	4.50	3.25	2.75
4-7	1.50	1.75	2.00	1.50	2.00					
5-1	.50	.75	.75	.75	.75	.25	.50	.25	.75	.50
5-2	1.50	1.75	2.00	1.75	2.00	1.00	1.50	1.00	1.50	1.00
5-3	1.75	1.75	1.75	1.75	1.75		1.25			1.00
5-4	1.75	1.75	1.75	2.25	2.00		1.50			1.25
5-5	2.25	2.00	2.25	2.00	3.00	4.25	3.25	5.75	3.75	2.00
5-7	1.75	2.00	2.00	2.00	2.25	1.25	2.00	1.50	2.25	1.75
8-1	1.25	1.00	1.00	1.25	1.25	1.00	1.00	1.00	1.25	.50

TABLE 3-9. MAXIMUM VIBRATION AMPLITUDE - PEAK-TO-PEAK G LEVEL

FLXIBLE 207 - ALL ROUTES

Test Condition	Accelerometer Position Number (Reference Table 4)									
	1	2	3	4	5	6	7	8	9	10
0-1	.50	.50	.25	.50	.50		.50	.50	.75	.50
0-2	.50	.50	.50	.50	.50		1.00	.50	1.25	.75
0-3	.50	.50	.25	.50	.50		.50	.50	.50	.50
0-4	1.00	1.00	1.00	1.00	1.25		1.00	1.50	1.00	.75
1-0	.25	.25	.25	.25	.25		.25	.25	.25	.25
3-1	.25	.50	.50	.50	.50		1.00	.25	.50	.25
3-2	1.00	1.25	1.25	1.14	1.25		1.50	1.00	1.75	1.25
3-3	1.25						2.50	2.00	2.50	1.75
3-4	1.75	2.25	1.50	2.25	2.25		2.50	2.25	3.00	2.25
3-5	1.50						1.75	2.25	2.75	1.75
3-7	1.25	1.50	1.50	1.50	1.50		1.25	1.00	1.50	1.00
4-1										
4-2	1.25	1.50	1.25	1.50	1.50		2.25	1.25	2.25	1.50
4-3	1.50	1.75	1.75	1.75	2.00		1.25	1.50	1.75	1.00
4-4	1.25	1.50	1.25	1.25	1.25		1.75	2.00	2.00	1.25
4-5	2.00	2.25	3.00	2.25	2.25					
4-7							3.50	2.75	3.50	2.50
5-1	.50	.75	.75	.75	.50		1.00	.50	1.00	.75
5-2	1.50	1.75	1.75	1.75	1.75		2.00	1.75	2.75	1.25
5-3	1.25	1.75	1.75	1.75	2.00		2.75	2.25	3.00	1.50
5-4										
5-5	1.75	2.25	2.25	1.75	2.00		4.25	5.25	5.25	2.25
5-7	1.75	2.00	2.00	2.00	2.25		2.75	2.50	3.50	2.25
8-1	.75	.75	1.00	.75	.75		1.50	1.25	1.50	1.25

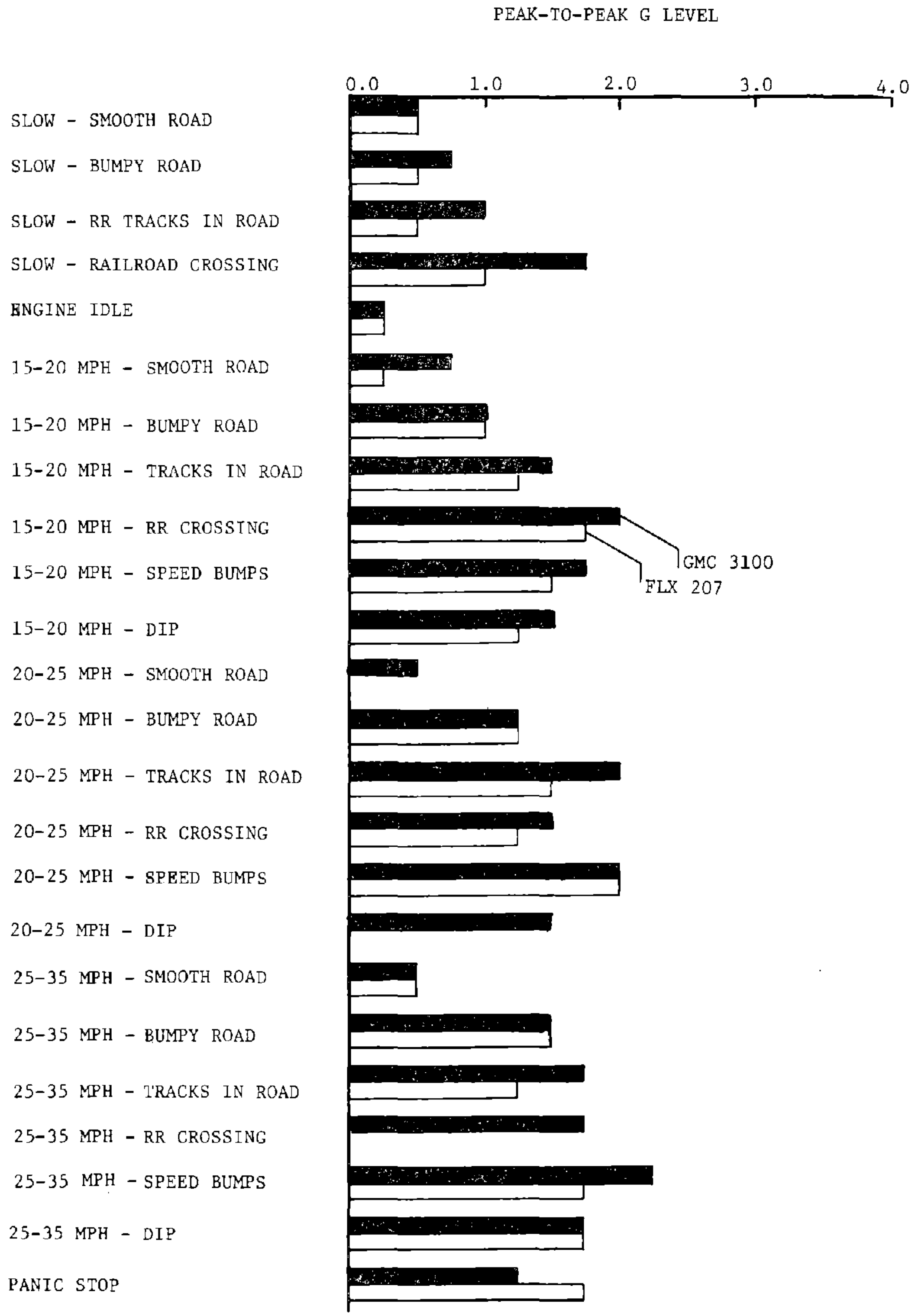

FIGURE 3-15. MAXIMUM VIBRATION LEVELS - FLOOR VERTICAL ACCELEROMETER

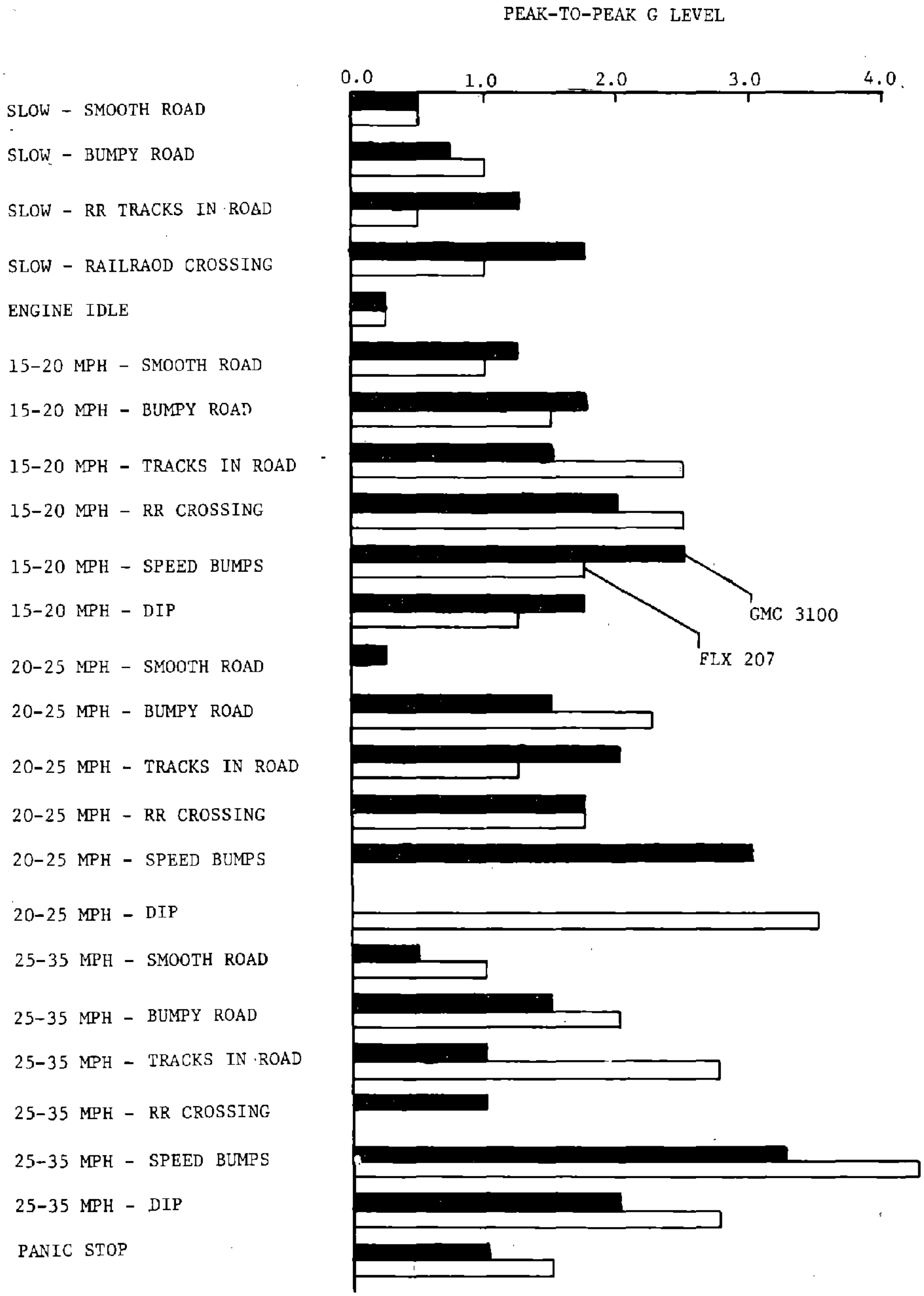

FIGURE 3-16. MAXIMUM VIBRATION LEVELS - DASHBOARD VERTICAL ACCELEROMETER

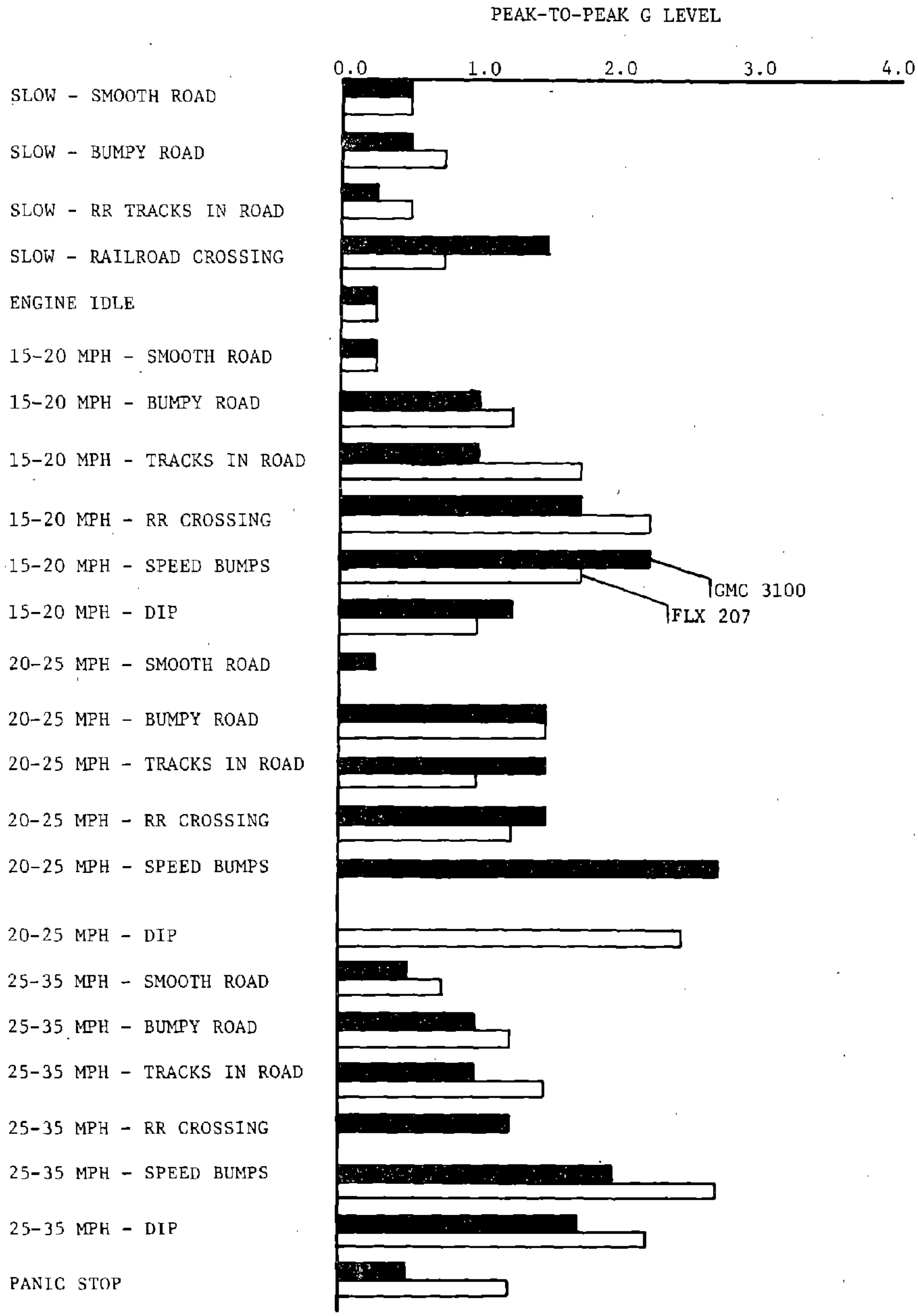

FIGURE 3-17. MAXIMUM VIBRATION LEVELS - ROOF VERTICAL ACCELEROMETER

TABLE 3-10. MAXIMUM VIBRATION DURING SPECIAL TESTS

Peak-to-Peak G Level

GMC Bus Run 15

Vertical Transducers	Stomp Test	Kick Test
Floor	2.78	3.42
Vehicle Box	6.34	6.76
Card Cage	5.11	5.20
Mother Board	5.85	5.52
P. C. Card	11.61	6.15

FLXIBLE Bus Run 17

Vertical Transducers	Stomp Test	Kick Test
Floor	4.07	1.99
Vehicle Box	4.38	3.96
Card Cage	7.32	2.97
Mother Board	8.16	3.06
P. C. Card	10.93	3.47

4. CONCLUSIONS

The vibration environment at locations which are suitable for mounting AVM system components on city buses has been shown to be relatively benign. Vibration amplitudes of the levels measured in this program do not pose a threat to the satisfactory operation of equipment produced according to industrial equipment design practice and fabrication methods. Nor is the vibration history expected to cause fatigue or wear-out failures of the equipment.

Maximum vibration levels were observed during the special stomp-and-kick tests of the vehicle box (reference Table 3-10). These levels can reasonably be expected to be reduced through the damping influence of the full contents of the box when installed. It is evident, however, that the equipment could be purposely destroyed by vandals, though not through casual action. Vibration induced in the equipment by bus operation did not exceed a 2 g peak-to-peak level at any measurement location except during conditions considered to be more severe than would be encountered in normal usage, i.e., running the bus at 25 to 35 MPH over a series of parking lot speed bumps. This condition produced levels on the bus dashboard up to 4 1/4 g, where the highest levels were consistently seen.

Vibration levels during bus operation are proportional both to bus speed and road roughness scale, with the latter factor possibly dominant. Differences in vibration amplitude between the two buses are inconsequential, leading to the conclusion that these data can be extended in a general fashion to represent all buses of this type and size.

The data measurement system used in this program, although limiting the scope of the data characterization, provided data of sufficient detail to accomplish the basic objectives of the program. In evaluation of the program, it is seen that more accurate and more extensive comparisons of the data would have been made possible by a continuous correlation of calibrated bus speed with data signals. It is recommended that this be incorporated into any future tests of this nature.

APPENDIX

REPORT OF NEW TECHNOLOGY

The work performed under this contract has led to no new inventions. However, it is believed that this report documents the first definitive analysis of the vibration environment of a transit bus in operation on city streets to measure its potential impact on installed electronic equipment.

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