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13. ABSTRACT

This report documents the results of the controlled testing conducted during the first phase of a tank car operating environment program involving The Association of American Railroads, the Railway Supply Institute (formerly the Railway Progress Institute), the Federal Railroad Administration, and Transport Canada. Strain gages, accelerometers, and an instrumented coupler were installed on a stub sill tank car during this phase of testing. This car was then subjected to a series of tests applying a range of forces to the coupler. Included were the application of controlled vertical forces, car-to-car impact tests, and a short duration over-the-road test. Results showed that significant correlation could be established between strain gage output and the output from the instrumented coupler. This indicates the strong possibility that longitudinal and vertical coupler forces can be inferred only from the output from four strain gages installed on the stub sill. Results also showed a correlation between accelerometer output (in the form of a shock response spectrum) and peak longitudinal coupler forces especially for impact forces above 400,000 pounds. This indicates a possibility that shock response spectrum values from only two accelerometers can be used to infer the magnitude of peak coupler forces that occur during yard impacts. During Phase II of this investigation, this transducer system will be tested under standard in-service conditions to further prove the concept and usefulness towards establishing tank car coupler force operating environment profiles.

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.50	centimeters	cm
ft	feet	30.00	centimeters	cm
yd	yards	0.90	meters	m
mi	miles	1.60	kilometers	km
		AREA		
in^2	square inches	6.50	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.80	square meters	m^2
mi^2	square miles	2.60	square kilometers	km^2
	acres	0.40	hectares	ha
		MASS (weight)		
oz	ounces	28.00	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.90	tonnes	t
		VOLUME		
tsp	teaspoons	5.00	milliliters	ml
Tbsp	tablespoons	15.00	milliliters	ml
fl oz	fluid ounces	30.00	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.80	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0 76	cubic meters	m^3
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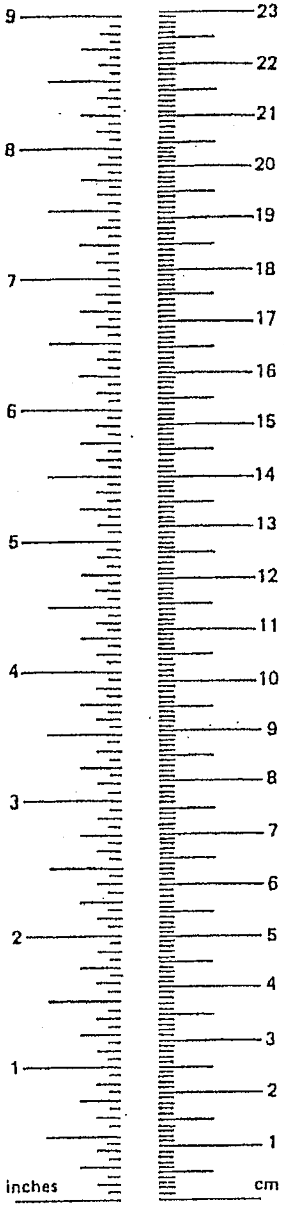
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.40	inches	in
m	meters	3.30	feet	ft
m	meters	1.10	yards	yd
km	kilometers	0.60	miles	mi
		AREA		
cm^2	square centim.	0.16	square inches	in^2
m^2	square meters	1.20	square yards	yd^2
km^2	square kilom.	0.40	square miles	mi^2
ha	hectares (10,000 m^2)	2.50	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	2.10	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36.00	cubic feet	ft^3
m^3	cubic meters	1.30	cubic yards	yd^3
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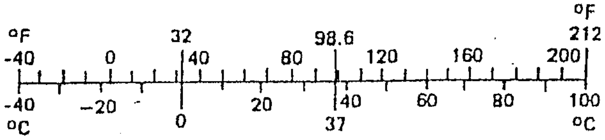
°C	Celsius° temperature	9/5 (then add 32	Fahrenheit temperature	°F



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* 1 in. = 2.54 cm (exactly)

EXECUTIVE SUMMARY

The Association of American Railroads, the Railway Supply Institute (formerly the Railway Progress Institute), the Federal Railroad Administration, and Transport Canada are participating in a cooperative investigation of the operating environment of tank cars. There are two technical groups cooperating on this project.

One of the groups, known as the Tank Car Operating Environment Task Force (TCOE-TF), is evaluating a possible inverse relationship between the costs associated with the design/construction of tank cars and handling/operation of those cars. The TCOE-TF would like to establish the credibility of a reasonably priced device that would collect reliable data for use in investigating the magnitude and direction of the largest forces encountered by tank cars during over-the-road service. The second group, the Stub Sill Working Group (SSWG), is investigating the use of failure analysis to predict the proper inspection interval for stub sill tank cars. The SSWG has a need to verify the full range of forces tank cars experience in the railroad operating environment.

This investigation is part of an ongoing assessment of necessary components for a complete system optimization (i.e., to assure safety while minimizing total cost). Since the research needs are so closely related, the two groups have agreed to work together to achieve both objectives.

The test program, designed with the requirements of these two groups in mind, was initially divided into three phases. Phase I, completed in April 2003, addressed the development and proof of a methodology to infer peak longitudinal and vertical coupler forces from data collected using a relatively inexpensive set of transducers. Also included in Phase I was the development of the inexpensive transducer and data collection package. Phase II is designed to follow Phase I and to provide further data collection system development and further validation of a correlation process by eventually subjecting as many as five cars with the minimal transducer package to an uncontrolled over-the-road service environment. If Phases I and II are successful, Phase III would implement the installation of the inexpensive transducer packages on a larger number of tank cars to collect a more comprehensive set of environment data. This report addresses the results of the following testing that was completed under Phase I:

1. A series of controlled, car-to-car impact tests while recording acceleration versus time and strain versus time data from transducers mounted at numerous locations on the tank car. Longitudinal coupler force (LCF) was also recorded during each impact. The data from these tests was processed in an effort to determine if, under controlled impact conditions, a sufficient degree of correlation could be established between measured acceleration response and peak coupler forces (both longitudinal and vertical), or between strain output and peak coupler forces. The acceleration response versus coupler force correlation was analyzed using two methods:
    - Coupler force (longitudinal and vertical) versus peak acceleration values.
    - Longitudinal and vertical coupler force versus shock response spectrum (SRS) curves generated from the peak acceleration values.

2. A series of tests applying upward vertical forces to the end of the tank car while recording the acceleration and strain output from the set of transducers. The vertical forces were designed to simulate the vertical coupler forces produced during over-the-road operations. Again, the data from these tests was processed in an effort to determine if, under controlled conditions, a degree of correlation could be established between measured vertical acceleration response and peak coupler forces (both longitudinal and vertical) or between strain output and peak coupler forces.

3. The final task of Phase I was to operate the test car in a train to record similar accelerometer and strain gage responses while the instrumented tank car was used in conditions more closely approximating over-the-road service. It was intended that completion of this task would meet the following objectives:
    - Confirm that relationships between strain gage or accelerometer output and peak coupler force can also be established for the lower magnitude coupler forces produced by normal train action. The results of the impact tests had allowed the study of these relationships for peak compressive forces greater than 250,000-300,000 pounds. It had also established the validity of such relationships for both tensile and compressive forces with magnitudes from near zero to 250,000-300,000 pounds.
    - Develop and prove the reliability of a power generation system (in a relatively controlled environment) that can provide consistent, long-term power for the onboard data acquisition hardware while being hidden from casual observation.

The results of the Phase I testing have shown that strain values from gages strategically mounted to the stub sill can be used to calculate the magnitude of vertical and longitudinal coupler forces during standard over-the-road operations, as well as during yard impact events. The results also indicate this to be the preferred method for calculating coupler forces to be used in fatigue life predictions or damage tolerance analysis. The results also show that it is definitely possible to use SRS data to calculate or predict peak longitudinal and vertical coupler forces occurring as a result of car-to-car impacts. This method, however, is most effectively used for impact events resulting in longitudinal coupler forces above 400,000-500,000 pounds. The preferred location for accelerometers to be used in this prediction process is near the longitudinal center of the car attached to the top of the tank structure. Accelerometers alone, however, are not suitable for the prediction of longitudinal and vertical coupler forces that result from normal over-the-road operations.

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1.0 INTRODUCTION

1.1 Background

The Association of American Railroads (AAR), the Railway Supply Institute (formerly the Railway Progress Institute), the Federal Railroad Administration (FRA), and Transport Canada (TC) are funding a cooperative investigation of the operating environment of tank cars. AAR subsidiary Transportation Technology Center, Inc. (TTCI) is conducting this evaluation at the FRA's Transportation Technology Center (TTC), Pueblo, Colorado.

There are two technical groups cooperating on this project. One of the groups, known as the Tank Car Operating Environment Task Force (TCOE-TF), is evaluating a possible inverse relationship between the costs associated with the design/construction of tank cars and handling/operation of those cars. The TCOE-TF would like to establish the credibility of a reasonably priced device that would collect reliable data that could be used to investigate the frequency and magnitude of the largest forces encountered by tank cars during over-the-road service. The second group, the Stub Sill Working Group (SSWG), is investigating the use of failure or durability analysis to predict the proper inspection interval for stub sill tank cars. The SSWG has a need to verify the full range of forces that tank cars experience in the railroad operating environment.

This investigation is part of an ongoing assessment of what is necessary for a complete system optimization (i.e., to assure safety while minimizing total cost). Since the research needs are so closely related, the two groups have agreed to work together to achieve both objectives.

1.2 Objectives

This report addresses the results of Phase I of a possible three-phase program. The testing in Phase I had the following objectives:

1. Study, through controlled, on-track testing, the feasibility of estimating or calculating coupler force using only car-mounted accelerometer or strain readings. The body of data must show that such a correlation is possible with an acceptable degree of accuracy. The acceleration versus coupler force correlation will be tested using a minimum of two methods:
    - Coupler force (longitudinal and vertical) versus peak acceleration values.
    - Longitudinal and vertical coupler force versus shock response spectrum (SRS) curves generated from the peak acceleration values.
2. If the initial testing conducted in Phase I indicated a good possibility that reliable relationships can be defined, effort would then be directed toward the assembly and demonstration of an acquisition system that could be used to efficiently and reliably record and broadcast, or download, such data from one or more cars placed in extended over-the-road service.

It was also very important that the above objectives be met using a system that was as compact, simple, "stealthy," and inexpensive as possible.

1.3 Approach

The test program, designed with the requirements of these two groups in mind, was initially divided into three phases. Phase I, completed in April 2003, addressed the development and proof of a methodology to infer peak longitudinal and vertical coupler forces from data collected using a relatively inexpensive set of transducers. Also included in Phase I was the development of the inexpensive transducer and data collection package. The results of Phase I are discussed in this report. Phase II is designed to provide further data collection system development and further validation of a correlation process by eventually subjecting as many as five cars with the minimal transducer package to an uncontrolled over-the-road service environment. If Phases I and II are successful, Phase III would implement the installation of the inexpensive transducer packages on a possibly much larger number of tank cars to collect a more comprehensive set of environment data. The objectives of Phase I to successfully relate accelerometer or strain gage output to coupler force were attempted using the following methods:

- Peak coupler force (longitudinal and vertical) versus peak output from accelerometers.
- Peak longitudinal and vertical coupler force versus SRS curves generated from the peak acceleration values.
- Longitudinal and vertical coupler force versus output from a small number of strategically placed strain gages.

Before a large-scale test program was undertaken, an initial or exploratory test was conducted in an effort to better establish some of the important parameters to be used in the subsequent Phase I testing and gain more confidence in the validity of the correlation between acceleration data and coupler force or strain data and coupler force. During the initial testing, a large number of accelerometers and strain gages were placed at widespread locations on the tank car. This was done because of the uncertainty of which locations would provide the best correlation with coupler force. The primary focus, therefore, was to eventually eliminate most of the transducers and establish only a small number of accelerometer or strain measurement locations that could provide the best correlation. This step was vital if system complexity and expense were to be minimized.

1.4 Scope

Phase 1 testing included the controlled application of vertical force pulses to the end of the stub sill with the tank car empty and fully loaded, as well as the following impact sequences:

- **Sequence 1:** Empty, instrumented tank car rolling into loaded stationary three-car anvil string at velocities of 2, 4, 6, and 8 mph. The hand and air brakes were set on the two stationary cars farthest from the impact
- **Sequence 2:** Loaded, instrumented tank car rolling into loaded stationary three-car anvil string at velocities of 2, 4, 6, and 8 mph. The hand and air brakes were set on the two stationary cars farthest from the impact.
- **Sequence 3**: Loaded, hopper car rolling into instrumented, loaded stationary tank car at velocities of 2, 4, 6, and 7 mph. Tank car was not coupled to any other cars. The hand and air brakes were set on the stationary tank car.
- **Sequence 4**: Loaded, hopper car rolling into instrumented, loaded stationary tank car at velocities of 2, 4, 6, and 6.5 mph. Tank car was the lead car in a loaded five-car anvil string. The hand and air brakes were set on all of the stationary cars.

The final task of Phase I was to record similar accelerometer and strain gage response while the instrumented tank car was used in over-the-road conditions. It was intended that completion of this task would meet the following objectives:

- Confirm that relationships between strain gage or accelerometer output and peak coupler force can also be established for the lower magnitude coupler forces produced by normal train action. The results of the impact tests have allowed the study of these relationships for peak compressive forces greater than about 250,000- 300,000 pounds. It is important to establish the validity of such relationships for both tensile and compressive forces with magnitudes from near zero to 250,000- 300,000 pounds.
- Develop and prove the reliability of a power generation system (again in a controlled environment) that can provide consistent, long-term power for the onboard data acquisition hardware while being hidden from casual observation.

2.0 TEST DESCRIPTION

2.1 Test Car

The tank car used in this study had the following characteristics:

- Manufacturer: American Car and Foundry (pictured in Figure 1)
- Car number: VICX 1725 (Certificate of Construction No. 21826)
- Empty Weight: 75,400 pounds
- Maximum weight with payload of water: 262,272 pounds
- Tank design: ACF 4-B-7188, 22,500-gallon capacity
- Underframe design: ACF 4-B-7190 stub sill
- Coupler design: 6 1/4×8 Type "E", Top and Bottom Shelf
- Draft gear design: Cardwell Westinghouse Mark 50 all-steel design (friction wedges plus springs)

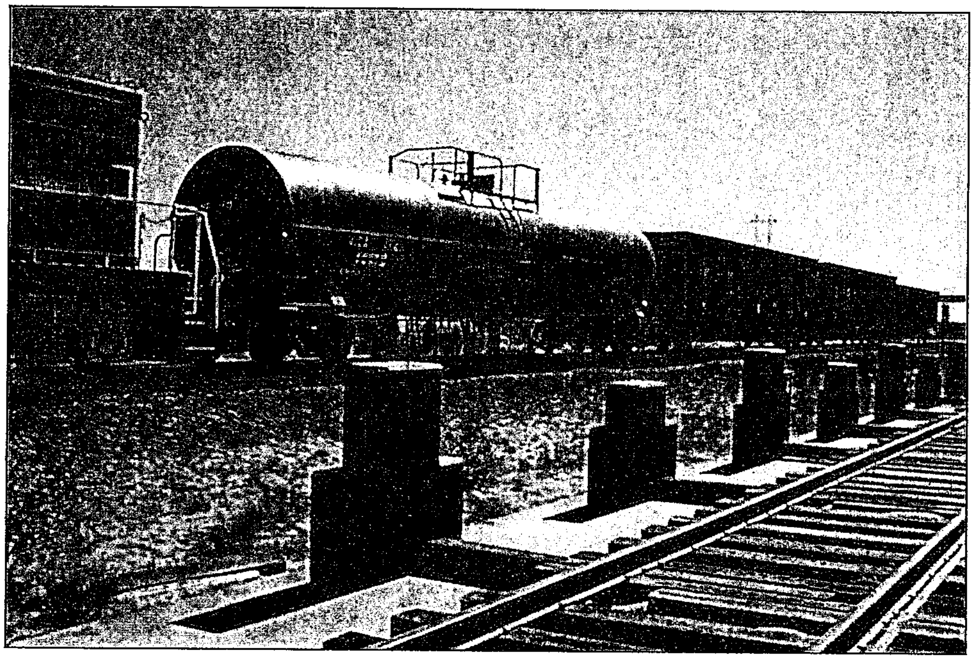


Figure 1. VICX 1725 Tank Car Set Up for Impact Test

2.2 Test Method

2.2.1 Low Frequency Vertical Forces Applied To Sill, Simulating In-Train Forces

A vertical force pulse was applied to the end of the sill in the upward direction. This test was conducted with the car both empty and loaded with water. A hydraulic cylinder created the force pulse, and the shape of this pulse was essentially one-half of a sine wave. Tables 1 and 2 provide the duration of the half-sine wave shapes as well as the peak amplitude of the vertical force applied. See Figure 2 for an illustration of a typical force versus time trace and the term "t/2." Each test condition was repeated at least three times.

Table 1. Amplitude and Duration of Applied Vertical Force, Car Empty

Peak Force (pounds)	t/2 (seconds)
10,000	.25
10,000	.50
10,000	1.0
15,000	.25
15,000	.50
15,000	1.0
20,000	.25
20,000	.50
20,000	1.0

Table 2. Amplitude and Duration of Applied Vertical Force, Car Loaded

Peak Force (pounds)	t/2 (seconds)
21,800	.25
30,900	.50
35,800	.25
51,600	.50

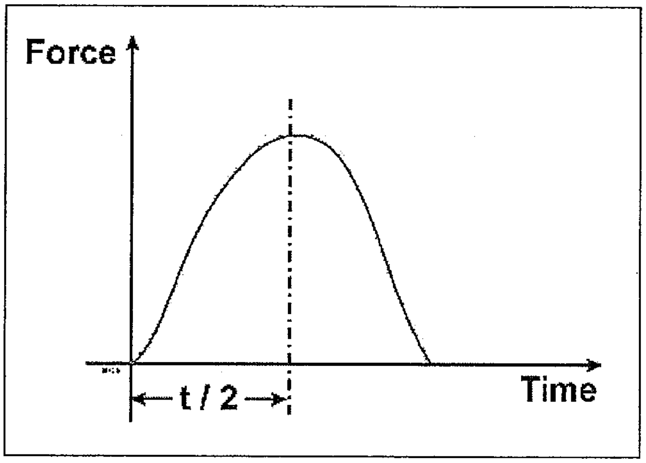


Figure 2. Force versus Time Trace

2.2.2 Controlled Impact Testing

A summary of the conditions for impact sequences 1 through 4 are given below. For all sequences, the impacts occurred at the A-end of the instrumented tank car.

- **Impact Sequence 1:** Empty, instrumented tank car rolling into stationary, loaded three-car anvil string at velocities of 2, 4, 6, and 8 mph. The air and hand brakes were set on the two anvil string cars farthest from impact. The anvil group of cars remained essentially stationary for all but the 8-mph impacts. During the 8-mph tests there was 3 to 5 inches of movement upon impact. The height of the tank car coupler was about 1.5 inches higher than that of the mating stationary cars.

- **Impact Sequence 2:** Loaded, instrumented tank car rolling into loaded stationary three-car anvil string at velocities of 2, 4,6, and 8 mph. The air and hand brakes were set on the two anvil string cars farthest from impact. Movement of the anvil string after impact ranged from about 12 inches at 2 mph to over 40 inches at 8 mph. The heights of the couplers on the tank car and the mating anvil car were within .25 inch of each other.
- **Impact Sequence 3:** Loaded, hopper car rolling into instrumented, loaded stationary tank car at velocities of 2, 4, 6, and 7 mph. The tank car was not coupled with any other cars. The gross weight of the hammer car was 261,764 pounds. The air and hand brakes were set on the tank car. Tank car movement after impact ranged from about 2 feet at 2 mph to about 20 feet at 7 mph. A maximum impact velocity of 7 mph was used in order to limit the maximum longitudinal coupler force (LCF) to around 1.25 million pounds. Again coupler height matched to within 0.25 inch.
- **Impact Sequence 4:** Loaded, hopper car rolling into instrumented, loaded stationary tank car at velocities of 2, 4, 6, and 6.5 mph. This was the same hopper car used in Sequence 3. The tank car was the lead car in a loaded five-car anvil string. The air and hand brakes were set on all cars in the anvil string. Tank car movement after impact ranged from about 2 inches at 2 mph to about 17 inches at 6.5 mph. A maximum impact of velocity of 6.5 mph was used to limit the maximum LCF to around 1.25 million pounds. Again coupler height matched to within .25 inch.

2.2.3 Testing at TTC's Facility for Accelerated Service Testing (FAST)

The High Tonnage Loop (HTL) at FAST is a 2.7-mile closed track consisting of a main loop and a bypass loop (see Figure 3). This track is used primarily for heavy axle load and bridge testing and research. The loaded instrumented tank car was included in the FAST train as it proceeded with its normal operating schedule. Some of the basic parameters of this loop are:

- Each lap includes up to four 5-degree curved sections (Sections 3, 7, 31, or 38) and one 6-degree curve (Section 25).
- During each "main loop" lap, the train travels over three turnouts (Sections 25, 27, and 35). During each "bypass loop" lap, the train travels *through* two turnouts (Sections 27 and 35), over one turnout (Section 23), and over three more turnout frogs in Section 36.
- Normal operating speed is approximately 40 mph.
- There are a number of minor grades included in the FAST loop ranging from 0.4 to 0.9 percent.
- During the test period, the train included 75-78 cars with the travel direction of both clockwise and counter-clockwise (see Table A1 in the attached Appendix)

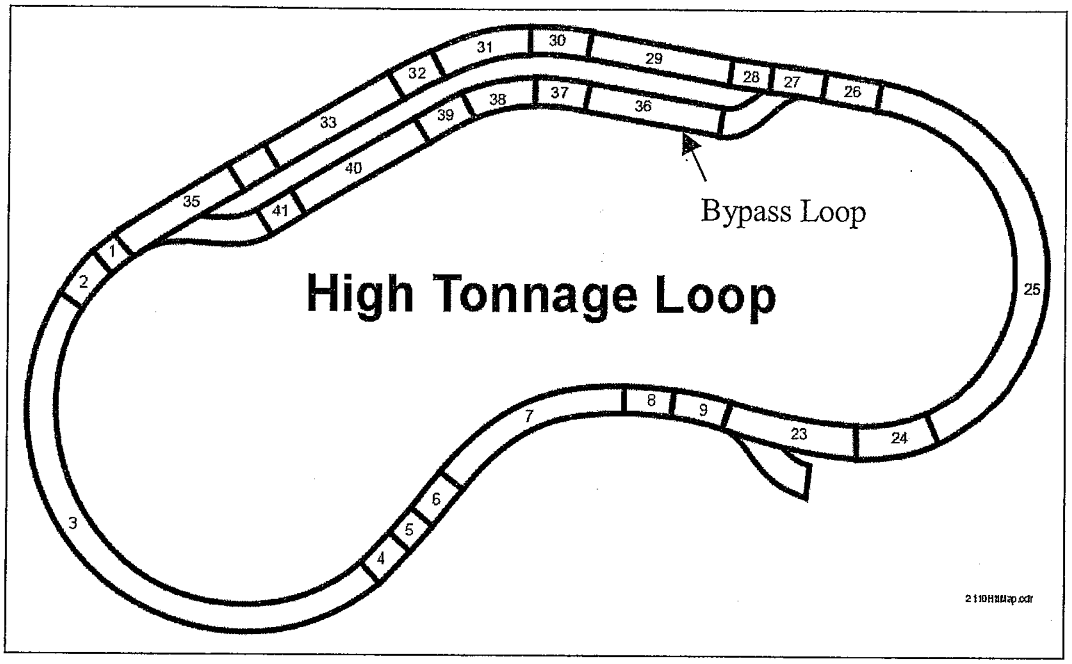


Figure 3. FAST-High Tonnage Loop

The loaded instrumented tank car was allowed to run in the FAST train for 13 nights from March 23 to April 22, 2003. The tank car was near the front of the train for part of the test period, and near the rear of the train for the remainder (Figure 4). Table 3 gives a brief summary of the testing completed. For additional details see Table A1 in the Appendix.

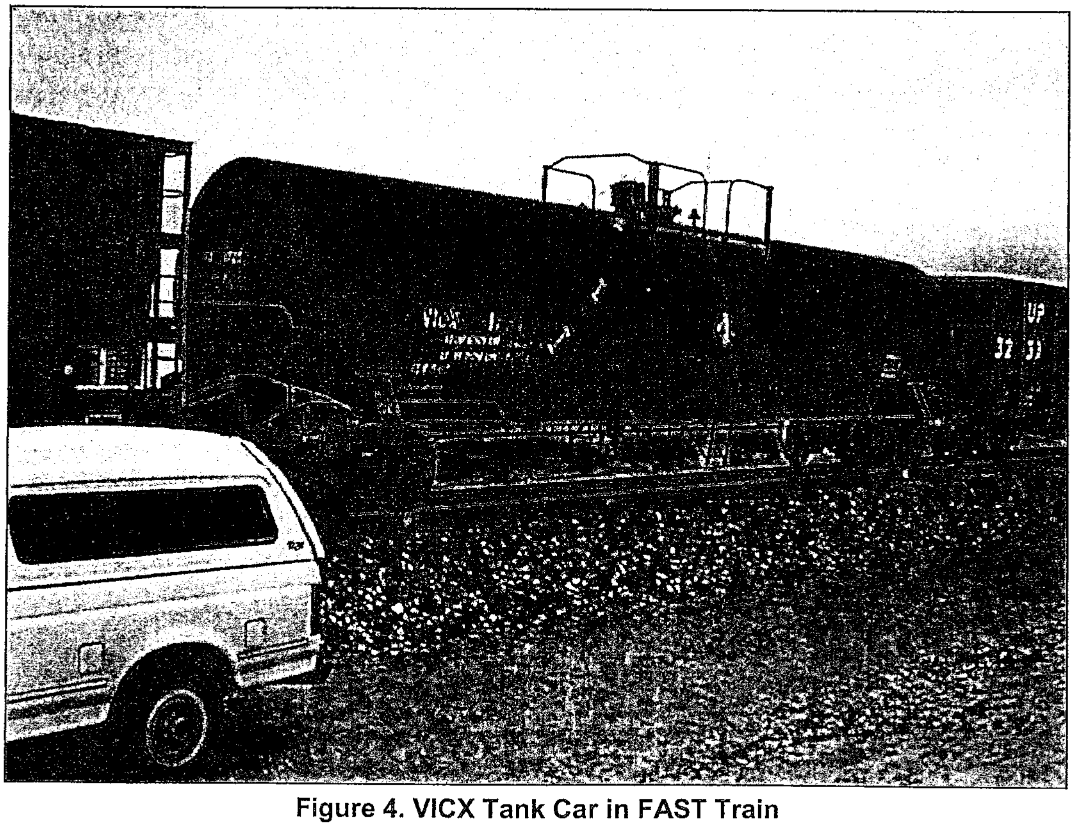


Figure 4. VICX Tank Car in FAST Train

Table 3. Summary of FAST Test

Dates	Laps Completed	Hours of Running	Approximate Miles Traveled
3/23/03 – 3/24/03	129	8.7	398
3/24/03 – 3/25/03	86	6.0	232
3/25/03 – 3/26/03	124	8.6	335
3/26/03 – 3/27/03	134	8.9	362
3/30/03 – 3/31/03	127	8.9	343
3/31/03 – 4/1/03	130	8.8	351
4/7/03 – 4/8/03	135	9.3	365
4/13/03 – 4/14/03	122	8.7	329
4/14/03 – 4/15/03	135	8.8	365
4/15/03 – 4/16/03	129	8.9	348
4/16/03 – 4/17/03	90	6.3	243
4/20/03 – 4/21/03	71	5.0	192
4/21/03 – 4/22/03	130	8.9	351
Totals	1,542	159.8	4,169

2.3 Instrumentation

Originally, 38 single accelerometers and 22 strain gages were installed on the car. The locations of these transducers are shown in Figures 5 through 7. Figure 8 is a photograph of strain gage locations 11, 12, and 13. Figure 9 shows the installation of the data acquisition hardware on the tank car. For each accelerometer location shown, except for numbers 11 and 12, there is one vertical axis and one longitudinal axis accelerometer installed. At locations 11 and 12, only longitudinal accelerometers were installed. The accelerometers used at the center and "impact" end (A-end) of the car had a capacity of ±100 g while those used on the end of the car opposite the impact had a capacity ±50 g. An instrumented coupler was also installed at the impact end of the car to record the LCF.

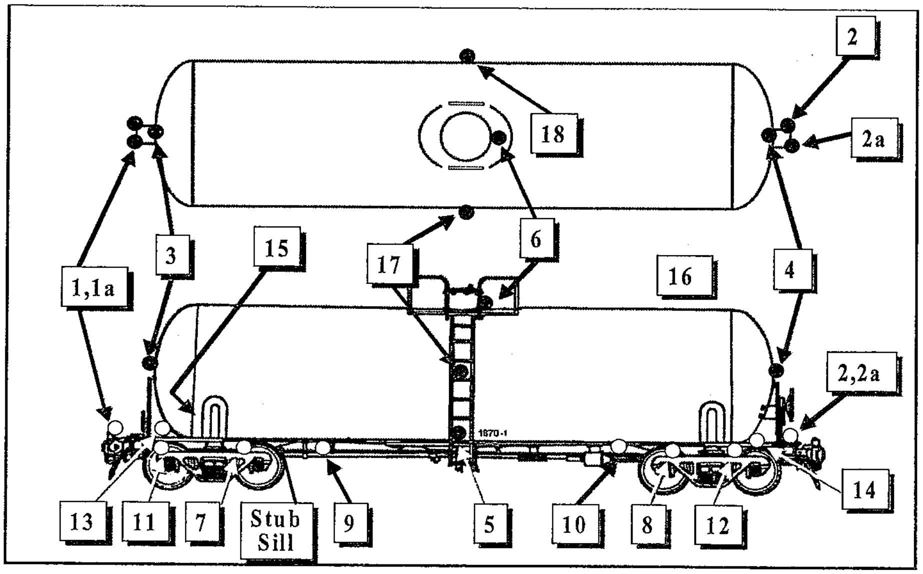


Figure 5. Accelerometer Locations – Overall Layout

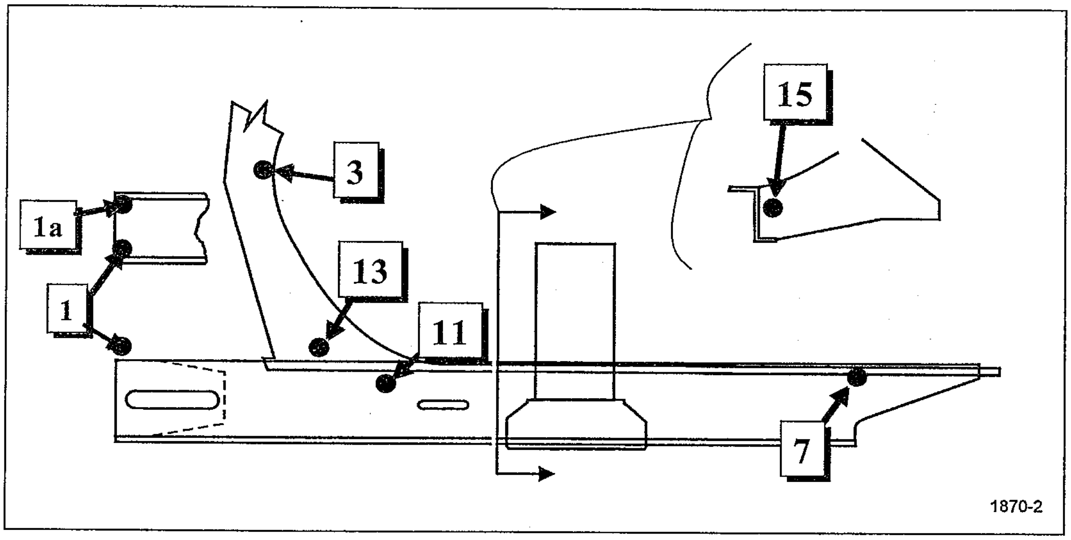


Figure 6. Accelerometer Locations – Details

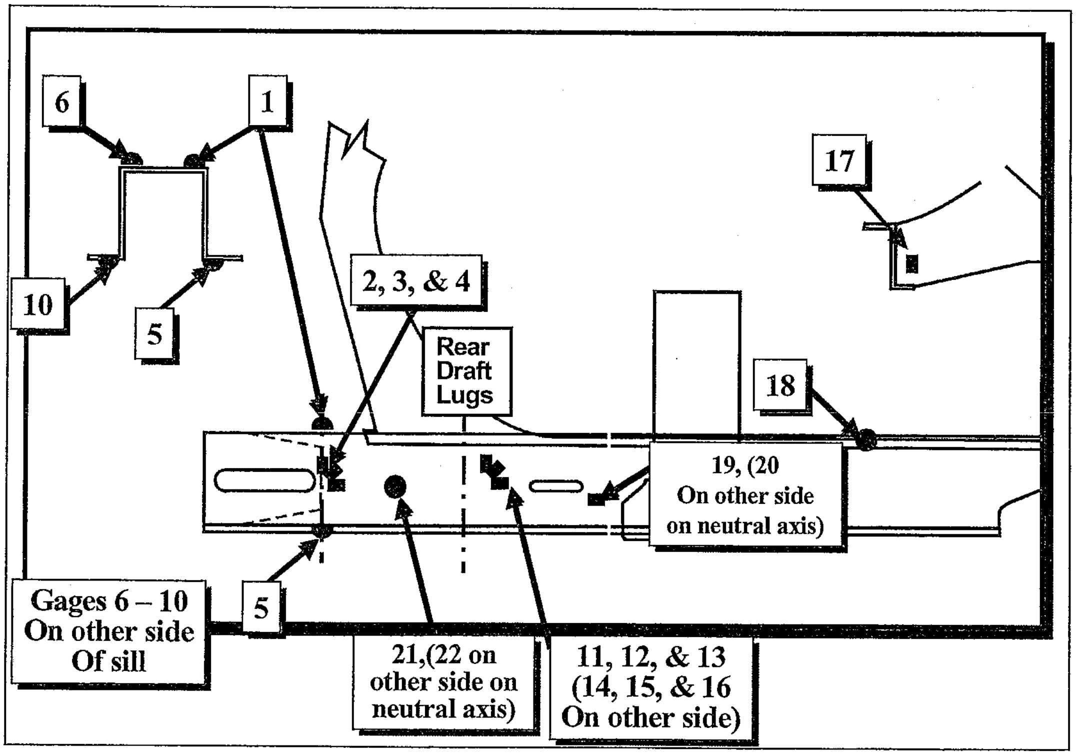


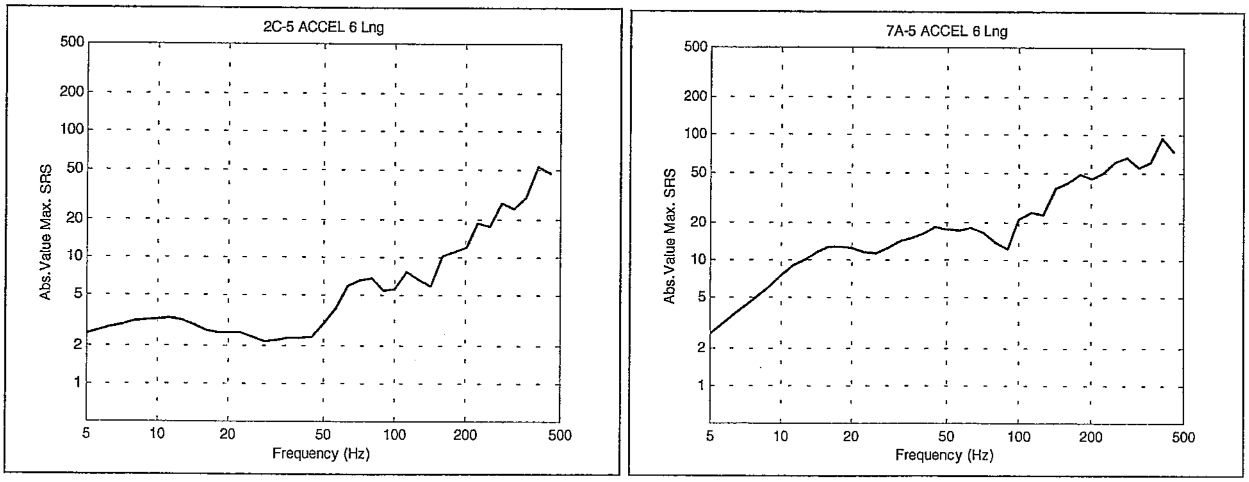
Figure 7. Strain Gage Locations

Where:
Gage 21/22 microstrain is the output from strain gages 21/22, and
Coupler Force is the longitudinal force output from the instrumented coupler.

Since the available instrumented couplers only measure longitudinal force, vertical force must be derived in this manner.

- The data from the transducers listed above was used to evaluate correlations between the following measurements:
  - Peak strain from strain gages 19 and 20 versus peak LCF
  - Peak longitudinal acceleration versus peak LCF
  - Peak vertical acceleration versus peak VCF
  - Maximum longitudinal SRS versus peak LCF
  - Maximum vertical SRS versus peak VCF
  - Average longitudinal SRS values over 5–50 Hz versus peak LCF
  - Average vertical SRS values over 5–50 Hz versus peak VCF
  - Average longitudinal SRS values over 10–100 Hz versus peak LCF
  - Average vertical SRS values over 10–100 Hz versus peak VCF

The correlation of average SRS values and peak LCF and VCF values has proven to be the best one for the estimation of coupler forces using accelerometer output. This is in large part due to the considerable amount of high frequency content in the acceleration versus time traces produced by the impact forces. SRS analysis does not describe the shock itself, but its influence on a set of idealized, single-degree of freedom (SDoF) mechanical systems. To convert acceleration versus time data to a shock response spectrum, the actual acceleration response (acceleration at each time step T) is applied to a number of single degree of freedom systems. Each single degree of freedom system has a unique natural frequency. A maximum response value is obtained for each of these SDOF systems. A shock response spectrum plot is then created when these maximum response values are plotted against frequency. An average SRS value over the frequency range 5 to 50 Hz would just be the average of all of the individual response values between 5 and 50 Hz. Figures 10a and 10b are examples of SRS plots for accelerometer 6 at impact velocities of 2 and 7 mph, respectively.



a.

b.

Figure 10. Examples of SRS Plot for Accelerometer 6

2.4.2 Testing at FAST

Data was recorded from transducers and one instrumented coupler on the VICX 1725 tank car during 13 nights of operation on the track at FAST between March 23 and April 22, 2003. The FAST train operated four nights a week during this time period, but problems with the data acquisition system limited the nights during which data could be recorded. The problems encountered during the first eight nights of testing were as follows:

- Frequent computer shutdown and reboot due to vibration and data throughput limitations. The device that allows the computer to automatically reboot did not provide enough time for a scan disk operation.
- Excessive signal noise and "spikes" due primarily to poor analogue-to-digital card connection.
- Large zero load, electronic offsets in the signal due to a software problem.

Of the 13 nights in which attempts were made to record data, useful information was obtained from 9 nights. For five of these nights, the test car was located six cars from the end of the train. For the remainder of the nights, the test car was located four to eight cars from the last locomotive. Three to eight hours of data were recorded each night.

All data channels were sampled at either 4,096 samples per second (for nine nights) or 2,048 samples per second. The sample rate was reduced by half for four of the nights in an effort to determine if that rate was the cause of problems with the data acquisition computer.

The data was processed using the following steps:

- The full night of data for each channel was inspected to determine if any of the specified thresholds had been exceeded. The Matlab™ signal processing toolbox was used to perform this task. The thresholds were set as follows:
    - Accelerometer 5 longitudinal, accelerometer 6 longitudinal, or accelerometer 18 longitudinal: > 5 g or <-5 g.
    - Strain gages 21/22: >100 microstrain or <-100 microstrain.
    - Instrumented coupler: > 80,000 pounds positive (buff) or < 140,000 pounds negative (draft).

  These values were chosen as a first cut to allow the isolation of the most meaningful data and to somewhat reduce the size of the data analysis task for this short test.
- Data files were created and stored in 45-second increments. Using a Matlab macro, all of the 45-second files that demonstrated values exceeding any of the thresholds were "tagged" for subsequent inspection. Again using a Matlab macro, these files were then concatenated in a way that allowed the data to be combined into one large file. This allowed inspection of all of the data at one time.
- Based primarily on the longitudinal coupler values observed in this set of data, a subset of files was then selected for further, closer examination. The result was that data recorded over the entire night had been reduced to the one to two hours of data that was of the most interest.
- Initially, the data receiving this closer examination was from the following channels: Instrumented Coupler, Strain Gage 21/22, Strain Gage 19, and Strain Gage 20. This reduced

set of data was converted to a format that could be used with computer software developed by nCode International called Fatimas™. During the conversion process, the coupler force and strain gage data was decimated from the original sample rate (either 4,096 or 2,048 samples/second) to 256 samples per second. nCode Fatimas is a fatigue analysis software but also has significant capabilities to process, condition, and evaluate large amounts of data. This software can be used to digitally filter data, remove obvious "spikes," concatenate short files into longer files, and perform mathematical operations using the data from separate files.

- Within Fatimas, the selected strain gage and coupler force files were subjected to spike removal if required and filtered with a 30 Hz low pass filter. The strain gage and coupler force data was then used in the following sequence to compute longitudinal and vertical coupler force:

$$\text{Calculated VCF (kip)} = -0.16 \times (\text{Gage 21/22 Microstrain} + 0.5 \times \text{Coupler Force})$$

$$\text{Calculated LCF (kip)} = -1.24 \times (\text{Gages 19 and 20 Microstrain} - 1.36 \times \text{Calculated VCF})$$

Where:
Gage 21/22 Microstrain is the output from Strain Gages 21/22,
Coupler Force is the output from the instrumented coupler (in thousands of pounds or "kips"), and
Gages 19 and 20 Microstrain is the average of the output from Gages 19 and 20.

Positive LCF values are compressive and positive VCF values are upward. These relationships were established using the data collected during the static load calibration tests conducted in September of 2000 (prior to the initial impact testing).

- Finally, acceleration versus time data collected during the nights of April 14-15, April 15-16, and April 20-21 was inspected. This set of data was chosen based on the magnitude of the coupler forces recorded during these time periods. Only the data from Accelerometers 18 longitudinal, 18 vertical, 6 longitudinal, and 6 vertical were inspected. Shock response spectrum analysis was performed for a total of nine events where either compressive or tensile coupler forces of over 150,000 pounds were measured. The average SRS response over frequencies of 5-50 Hz and 10-100 Hz were then compared to peak LCF values recorded during the same event.

2.5 Summary of Results

2.5.1 Controlled Vertical Force Test

2.5.1.1 Strain gage response

- Strain gages 8 and 21-22 were not the most responsive to vertical force input, but they were the most responsive gages that were least affected by longitudinal force input. The sensitivity of gage 8 was approximately 0.00431 microstrain per pound of vertical force. The sensitivity of gages 21-22 was approximately 0.00633 microstrain per pound of vertical force (See Plot A1 in the Appendix).
- Strain response for all gages was essentially linear with increasing vertical force.
- The rate at which load was applied made little significant difference in the relationship between strain and applied peak load for a particular gage.

- Standard deviation values were calculated based on the three repetitions at each test condition. These values indicated that the repeatability of the response of all strain gages was essentially equivalent.

2.5.1.2 Accelerometer response

- There was no detectable output from any of the accelerometers until a peak load of at least 13,000-15,000 pounds was applied.
- At a pulse duration of 2 seconds, a peak force amplitude of at least 20,000 pounds was required to generate any detectible acceleration response. Plots A2 and A3 in the Appendix show estimated linear relationships between peak acceleration and vertical force amplitude for vertical accelerometers 1 and 1A. Using these plots, the peak vertical force can be roughly estimated:

  From accelerometer 1: –8,354.3 × (peak accel.) + 11,977 for a 0.5-second pulse duration– 11,162 × (peak accel.) + 11,940 for a 1.0-second pulse duration

  From accelerometer 1A: –12,984 × (peak accel.) + 10,894 for a 0.5-second pulse duration–29,583 × (peak accel.) + 7,433.8 for a 1.0-second pulse duration.

  As an example, at a force pulse duration of 0.5 second, a peak 0.5 g output from accelerometer 1 would predict a peak vertical force of about 16,200 pounds while a similar output value from accelerometer 1A would yield a peak vertical force of 17,400 pounds. If the same 0.5 g output came during an event of about 1.0 second in duration, the accelerometer 1 relationship would yield a peak vertical force of about 17,500 pounds while the accelerometer 1A relationship would result in an estimate of about 22,200 pounds.
- It should be emphasized that due to the scatter of this data, these are only rough estimations. At a pulse duration of 2 seconds, a peak force amplitude of at least 20,000 pounds was required to generate any detectable acceleration response.
- Responses were recorded for both longitudinal and vertical accelerometers. The most responsive vertical accelerometers were at the 1 and 1A positions while the most responsive longitudinal accelerometer was at the 3 position.

2.5.2 Controlled Impact Tests

2.5.2.1 Peak coupler forces versus impact velocity

Plot A6 in the Appendix shows two very significant relationships between impact velocity and peak LCF. For all loaded car impacts (Sequences 2 through 4), the peak LCF versus impact velocity relationship is essentially horizontal for impact velocities between 2 and 4 mph. Peak LCF only varies between about 350,000 and 500,000 pounds for impact events in this velocity range. As impact velocities increase to 6 and 8 mph, however, there is suddenly a very steep slope with peak LCF values increasing significantly. This is likely an indication that the draft gear is performing as designed. At velocities up to about 5 mph, there is movement within the draft gear, and the friction wedges and internal springs produce the required reaction forces. At velocities above 5 mph, however, the draft gear has likely reached its deflection capacity resulting in a sudden rise in the force transmitted from the gear to the car structure. The data indicates that for this loaded car, impact velocity could be used to estimate peak LCF in the following manner:

- For velocities from 2-5 mph, peak LCF = 350,000 to 500,000 pounds
- For velocities above 5 mph, peak LCF = 440,000×(velocity – 5) + 440,000

The last 440,000 value in this equation is the point on the y (force) axis at which the function intersects the 5-mph x value.

Plot 6 also shows that the peak LCF versus impact velocity relationship for Sequence 1 (empty car) again is significantly different from the loaded car relationships. The Sequence 1 data indicates a more constant relationship between velocity and peak LCF with no significant change in slope between 5 and 6 mph. This could indicate that the characteristics of the draft gear changed between the Sequence 1 and Sequence 2 impacts, or that due to the lower kinetic energy levels during Sequence 1, the draft gear never reached its deflection limits.

Plots A7-A10 in the Appendix show that throughout all of the impact sequences, there is a relatively good relationship between measured peak LCF and calculated peak VCF. The weakest correlation was observed from the data recorded during Impact Sequence 3 (single car-to-single car). Generally, the peak VCF can be estimated by using the following function:

$$\text{Peak VCF} = (0.11 \text{ to } 0.12)\times(\text{Peak LCF})$$

In all impact cases, the peak VCF was in the "upward" (away from track) direction.

Tables 4-7 give a summary of the recorded peak LCF and calculated peak VCF values for all four impact sequences. These tables illustrate that the coupler forces at a given impact velocity were about 30 to 40 percent greater during the "loaded car" impacts (Sequences 2-4) than during the "empty car" tests. They also reveal that Sequence 4 generally produced the highest coupler forces per mph of impact velocity.

Table 4. Peak LCF and VCF for Impact Sequence 1

Velocity at Impact (mph)	Measured Peak LCF (lbs)	Calculated Peak VCF (lbs)
2.5	374,743	51,320
2.0	254,972	38,060
3.0	242,145	34,790
4.5	444,059	52,900
5.0	541,853	70,230
3.8	593,849	63,700
5.9	618,556	55,920
6.1	582,814	59,960
6.2	808,052	98,490
8.0	1051,530	116,680
7.8	970,455	105,310
7.9	1,003,544	126,950

Table 5. Peak LCF and VCF for Impact Sequence 2

Velocity at Impact (mph)	Measured Peak LCF (lbs)	Calculated Peak VCF (lbs)
3.0	469,000	44,600
2.9	495,000	53,500
2.6	500,000	50,600
2.4	445,500	39,600
2.4	408,000	52,500
3.3	479,600	36,800
4.2	495,000	58,200
4.1	442,000	55,340
4.1	485,700	44,810
4.2	404,400	44,700
6.1	1,10,8000	118,080
6.1	1,05,7000	115,040
6.1	1,05,0000	113,790
7.4	1,346,600	149,400
7.2	1,27,5900	142,600
7.5	1,374,600	149,400

Table 6. Peak LCF and VCF for Impact Sequence 3

Velocity at Impact (mph)	Measured Peak LCF (lbs)	Calculated Peak VCF (lbs)
3.0	338,880	46,300
2.8	408,110	52,000
2.7	419,870	53,900
2.4	420,070	71,000
2.2	377,970	32,200
2.3	373,140	64,600
4.2	380,720	59,000
4.1	396,580	57,000
4.2	350,260	71,700
4.2	344,510	54,700
5.1	405,620	44,400
6.0	836,660	133,000
6.0	843,660	85,000
6.1	793,490	72,000
7.1	1,242,740	137,800
7.1	1,175,090	141,700
7.1	1,168,440	127,100

Table 7. Peak LCF and VCF for Impact Sequence 4

Velocity at Impact (mph)	Measured Peak LCF (lbs)	Calculated Peak VCF (lbs)
2.4	399,520	399,000
2.2	369,360	379,000
2.2	418,040	451,000
2.2	392,030	485,000
4.1	529,760	699,000
4.0	396,480	521,000
4.1	415,790	527,000
5.0	443,980	619,000
6.0	1,134,080	132,400
6.1	1,111,210	128,400
6.0	1,091,080	128,600
6.4	1,235,730	155,400
6.9	1,333,100	159,900
5.8	1,023,790	122,300
6.3	1,185,110	144,600

2.5.2.2 Strain gage response

Strain gages at locations 15, 16, 19, and 20 proved to be the most consistent and most sensitive indicators of peak LCF. Of these four gages, the output of gage 20 proved to be the most consistent and sensitive.

It is worth noting, however, that the relationship between peak LCF and maximum strain from gage 20 was not a continuous linear relationship during Impact Sequence 1. Plot A11 in the Appendix shows that whether the strain versus peak LCF relationship is treated as a continuous or discontinuous function, there is an obvious change in that relationship at coupler forces above about 600,000 pounds. Still, the relationship between peak strain and peak LCF at strain gage location 19 remains relatively consistent as peak LCF reaches maximum levels.

The fact that there was a significant difference between the strain response of gages at similar locations on either side of the sill (gage 19 versus gage 20) may indicate that as the peak coupler forces reached levels above 600,000 pounds the longitudinal forces into the rear draft lugs were not the same on one side of the sill as the other. This could be due to slight misalignment of the coupler and draft gear, or manufacturing tolerances locating the rear draft lugs. A contributing factor could also be fact that the point of application of the force is offset from the center of the side plate of the sill. This could introduce out-of-plane, localized stresses on the plate surface that are difficult to predict. Plot A11 in the Appendix shows that the strain versus peak LCF relationships for gages 20 and 19 actually diverge significantly at peak forces above about 600,000 pounds. One way to combat these effects could be to use an ***average*** of the outputs from gages 19 and 20 to predict or calculate longitudinal coupler force. A set of points created by averaging the output from gages 19 and 20 is also shown on Plot A11.

Even though the data from gages 19 and 20 recorded during the loaded car impacts (Sequences 2 thru 4) did not show the tendency to diverge at larger LCF values, averaging the output from these two gages still provided the best correlation between strain and peak LCF.

2.5.2.3 Accelerometer response

Accelerometers 18, 9, 6, and 5 provided the best correlation between peak longitudinal acceleration and peak LCF. Examples of these relationships are shown in Plots A12 and A13 in the Appendix. This trend was discovered as a result of the analysis of the Sequence 1 impact data. In all cases for Impact Sequence 1, discontinuous linear relationships appeared to provide the best fit for the data. As an example, for accelerometer 18, when output values were between 0 and about -2.5 g, the peak LCF could be estimated as:

$$-183{,}590 \times \text{peak acceleration}$$

However, for accelerations greater than -2.5 g, the peak LCF could be estimated as:

$$-20{,}561 \times (\text{peak acceleration}) + 430{,}000$$

Even though the relationships above could be estimated using peak acceleration versus coupler force data from impact sequence 1, further analysis demonstrated that a significantly better correlation between acceleration response and peak coupler force values could be obtained if calculated SRS values rather than peak acceleration values were used. As a result, for the remaining impact tests, emphasis was placed on the SRS versus coupler force relationships.

SRS calculations were performed on the Impact Sequence 1 output from the following longitudinal accelerometers: 1, 1A, 2, 2A, 5, 6, 8, 9, 11, 12, 13, 14, and 18. Shock response values were calculated for natural frequencies ranging from 5 to 500 Hz. The result was an SRS plot of response versus frequency for each accelerometer and each impact (see Figure 10 for examples).

Relationships were studied relating peak LCF with the following values from the impact sequence 1 SRS data:

- **Peak** SRS value over the 5-500 Hz range versus peak LCF.
- The **average** SRS value over the 5-500 Hz range versus peak LCF.
- The **average** SRS value over a restricted frequency range of 5-50.4 Hz versus peak LCF.
- The **average** SRS value over a restricted frequency range of 10-100.8 Hz versus peak LCF.

The last two relationships were studied because the response vs. frequency plots were generally more linear within these frequency ranges. Attempts were made to apply continuous as well as discontinuous function relationships, but again, it appeared that the discontinuous linear functions provide the best correlation of SRS response to peak LCF.

The output from accelerometer locations 1A, 2A, 5, 6, 18, 9, and 12 recorded during impact Sequence 1 provide credible correlation between SRS response and peak LCF. The best correlation is generally provided by locations 12, 6, and 18. Examples are shown in Plots A14 and A15 in the Appendix. As an example, using the average SRS response from accelerometer 6 over the 10-100.8 Hz range peak LCF could be estimated as follows:

$$\text{LCF} = 231{,}620 \times (\text{average SRS response}) \text{ for average response values from 0 to 2.4, or}$$
$$\text{LCF} = 30{,}097 \times (\text{average response}) + 460{,}000 \text{ for response values greater than 2.4}$$

Plot A17 in the Appendix shows that there is a very distinct difference in the SRS versus LCF relationships between Sequence 1 (empty car) and Sequences 2 through 4 (loaded case). This difference could be due to the condition of the draft gear or to the significant change in mass of the car. The factors contributing to this difference are not fully understood at this point. It is therefore important to know the state of as many of the contributing factors as possible. Since car mass could be one of these important contributing factors, it remains important to be able to determine the mass of the car during an impact. It is also important to recognize that a discontinuous or "dual" function appears to be the best approximation for the SRS versus peak LCF data from Sequence 1. There is one linear function that fits the data fairly well at coupler forces below about 550,000 pounds. It is at these impacts that the draft gear is still effective and has not "bottomed." However, there is a different linear function at coupler forces greater than 550,000 pounds. At coupler forces higher than 550,000 pounds, the draft gear does apparently go through its full range of travel resulting in a distinctly different transfer function.

The data shows that for these impact conditions, the SRS versus peak LCF relationship may be represented reasonably well by a simple linear function of the form:

$$\text{Peak LCF} = \text{m} \times (\text{Average SRS Response}) + \text{b}$$

Where:
A is the slope, and
B is the intercept constant.

Plots A18-A21 of the Appendix and Table 8 below summarize some proposed linear SRS versus peak LCF relationships for a loaded, instrumented tank car during three different impact conditions (Impact Sequences 2 through 4). Plot A21 also illustrates, however, that when all of the loaded tank car impact data is considered, the SRS versus peak LCF relationship might be best approximated by more than one function. For this car/draft gear combination, the change in relationship or function generally occurred at peak LCF values of about 400,000 to 500,000 pounds and again at about 1.0 to 1.1 million pounds; indicating the possibility of three functions to completely define the SRS versus peak LCF relationship.

Table 8. Estimated Linear Relationships, SRS Response versus Peak LCF – Accelerometer Number 6

Impact Seq.	Freq. over which SRS Values Averaged	Function Slope (m)	Function Intercept (b)	Coefficient of Determination (R^2)
2	5-50 Hz	97,046	125,834	.925
3	5-50 Hz	136,612	13,476	.894
4	5-50 Hz	128,634	40,716	.926
2, 3, and 4	5-50 Hz	110,904	101,369	.882
2	10-100 Hz	74,905	109,071	.904
3	10-100 Hz	96,763	-3,486	.840
4	10-100 Hz	91,009	40,896	.880
2, 3, and 4	10-100 Hz	83,731	70,821	.865

The results of linear regression analysis of the SRS data produced from the output of accelerometer 6 during Impact Sequences 2, 3, and 4 are shown in Plots A18 through A21 of the Appendix. Plots A18 through A20 show the results if the data from each impact sequence is considered separately, and Plot A21 shows the results if the data from all three sequences is considered together. Each plot contains a scatter band (bounded by the dashed lines) illustrating the range of peak LCF values that could be expected to be calculated from a given SRS value with a 95 percent confidence level. Table 9 lists a sample of calculated peak LCF values using given SRS values of 4 g and 10 g for the 5-50 Hz data, and 6 g and 14 g for the 10-100 Hz data.

The information contained in Tables 8 and 9 show the following significant results:

- The Coefficient of Determination data in Table 8 indicates that a linear approximation is a better fit for the SRS data averaged over 5 to 50 Hz than that averaged over 10 to 100 Hz. This would also imply that the bands of scatter on each side of the best-fit, mean line are somewhat smaller for the 5 to 50 Hz data than for the 10 to 100 Hz data.
- For any measured SRS value, the estimated or calculated peak LCF value should fall within the ranges shown in the last column of Table 9 with a 95 percent confidence level. These ranges of peak LCF values could be significant, ranging from about ±45 to 50 percent at the lower LCF values to ±20 to 25 percent at the higher LCF values.
- Considering the range of estimated LCF values that are calculated for a given SRS value, the data from all impact sequences yield similar results. The implication is that, other than payload condition, knowledge of the details of an impact situation may not be required for this method of estimating peak LCF.

Table 9. Sample of Predicted Peak LCF Values using SRS Data – Accelerometer Number 6

Impact Sequence	Frequency over which SRS Values Averaged	SRS Value used to Calculate Peak LCF	Range of Calculated LCF Values (lbs.)
2	5-50 Hz	4	272,260 to 755,684
3	5-50 Hz	4	306,747 to 813,098
4	5-50 Hz	4	304,787 to 805,718
2, 3, & 4	5-50 Hz	4	285,276 to 804,719
2	5-50 Hz	10	843,304 to 1,349,246
3	5-50 Hz	10	1,102,023 to 1,657,160
4	5-50 Hz	10	1,070,675 to 1,583,438
2, 3, & 4	5-50 Hz	10	1,164,740 to 1,699,919
2	10–100 Hz	6	283,604 to 833,938
3	10–100 Hz	6	264,251 to 889,944
4	10–100 Hz	6	266,713 to 907,193
2, 3, & 4	10–100 Hz	6	295,743 to 851,355
2	10–100 Hz	14	872,452 to 1,443,030
3	10–100 Hz	14	1,016,915 to 1,685,504
4	10–100 Hz	14	991,449 to 1,638,609
2, 3, & 4	10–100 Hz	14	960,783 to 1,525,771

As shown in Plot A22 in the Appendix, there is considerable scatter in the peak vertical acceleration versus peak VCF data. As a result, even though there is a general trend of increasing peak vertical acceleration with increasing peak VCF, it is difficult to identify a function that satisfactorily defines a relationship between the two parameters from the data currently available.

Shock response calculations were performed on the output from the following vertical accelerometers: 1, 1A, 2, 2A, 5, 6, 14, and 18. Shock response values were calculated for natural frequencies ranging from 5 to 500 Hz. The result was an SRS plot of response versus frequency for each accelerometer and each impact. Relationships were studied relating peak VCF with the following values from the SRS data:

- **Peak** SRS value over the 5-500 HZ range versus peak VCF.
- The **average** SRS value over the 5-500 HZ range versus peak VCF.
- The **average** SRS value over a restricted frequency range of 5-50.4 HZ versus peak VCF.
- The **average** SRS value over a restricted frequency range of 10-100.8 HZ versus peak VCF.

The last two relationships were studied because the response vs. frequency plots were generally more linear within these frequency ranges.

The last two types of relationships studied provided the best correlation between SRS response and peak VCF. Plots A23 through A26 in the Appendix indicate that there are also some fairly well-defined trends relating SRS data from vertical accelerometer 6 to peak vertical coupler forces (VCF). The SRS versus peak VCF relationships for accelerometer 5 are similar. As shown in Table 10, however, these relationships tend to be somewhat less defined than those established for the longitudinal coupler force response. As a result, for a given SRS value generated using data from either accelerometer 5 or 6, the predicted peak VCF would have a range of possible values larger than for the similar peak LCF predictions.

Table 10. Estimated Linear Relationships, SRS Response vs. Peak VCF – Accelerometer 6

Impact Sequence	Frequency over which SRS Values Averaged	Function Slope (m)	Function Intercept (b)	Coefficient of Determination (R^2)
2	5-50 Hz	5,542	20,235	.930
3	5-50 Hz	5,782	36,821	.753
4	5-50 Hz	9,997	15,087	.918
2, 3, and 4	5-50 Hz	5,905	32,661	.732
2	10-100 Hz	4,282	12,651	.901
3	10-100 Hz	4,420	31,070	.761
4	10-100 Hz	7,152	5,761	.919
2, 3, and 4	10-100 Hz	4,535	25,031	.741

Engineers at the Volpe National Transportation Center performed additional analysis of the acceleration versus time data. A power spectral density (PSD) analysis was performed on each tank car acceleration history to determine the dominant frequencies in the response of the tank car structure. Accelerations in both the vertical and longitudinal directions, with the tank empty as well as filled, were examined. The results of this analysis indicated that for an empty tank, the dominant excited frequencies for the tank structure were 0 Hz (rigid body motion) in the longitudinal axis and 13 Hz in the vertical direction. A vertical axis frequency of 100 Hz, likely excited by the stick-slip action of the draft gear, was also prominent in the empty car data collected during events when the stick-slip coupler forces were observed. PSD results from the "full tank" tests exhibit dominant peaks at 0 Hz in the longitudinal direction and at both 5 Hz and 23 Hz in the vertical direction.[1][2]

2.5.3 Testing at FAST

2.5.3.1 Coupler Forces

Table A1 in the Appendix summarizes the test conditions and resulting coupler force measurements (LCF from coupler and VCF calculated) during the FAST test. In general terms, when the car was near the locomotives (near the front of the train), the LCF values were primarily tensile and varied from near 0 to 170,00-250,000 pounds. The mean value was about 60,000-70,000 pounds. The calculated VCF values were similar in character and varied from about 20,000-40,000 pounds upward to 6,000-13,000 pounds downward (negative values). Figure 11 shows typical measured LCF (top plot) and calculated LCF (lower plot) versus time data for this car location. This data was recorded on the night of April 15/16 over a time period of approximately 45 minutes. Figure 12 shows the measured LCF and calculated VCF values for the same time period as the data in Figure 11. This plot demonstrates the relationship between LCF and calculated VCF for this operating environment. Output from Accelerometers 6L, 6V, 18L, and 18V was insignificant during this time period. This 45-minute segment is indicative of the data recorded for the entire night with the car near the front of the train.

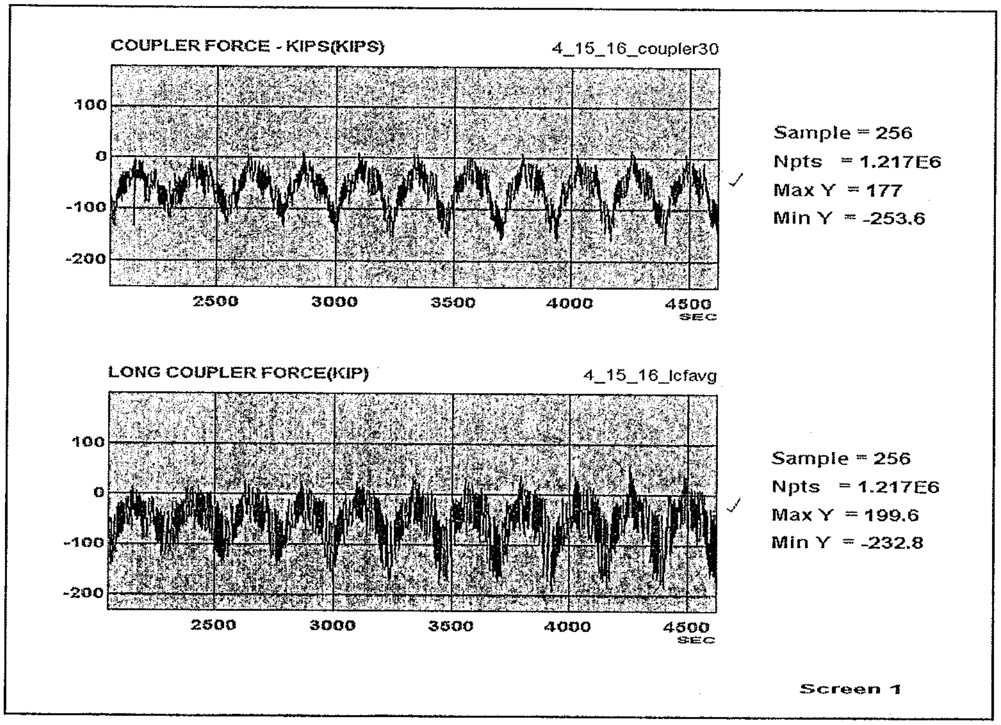


**Figure 11. Measured (top) and Calculated LCF Versus Time, April 15/16, 2003
Test Car near Front of Train**

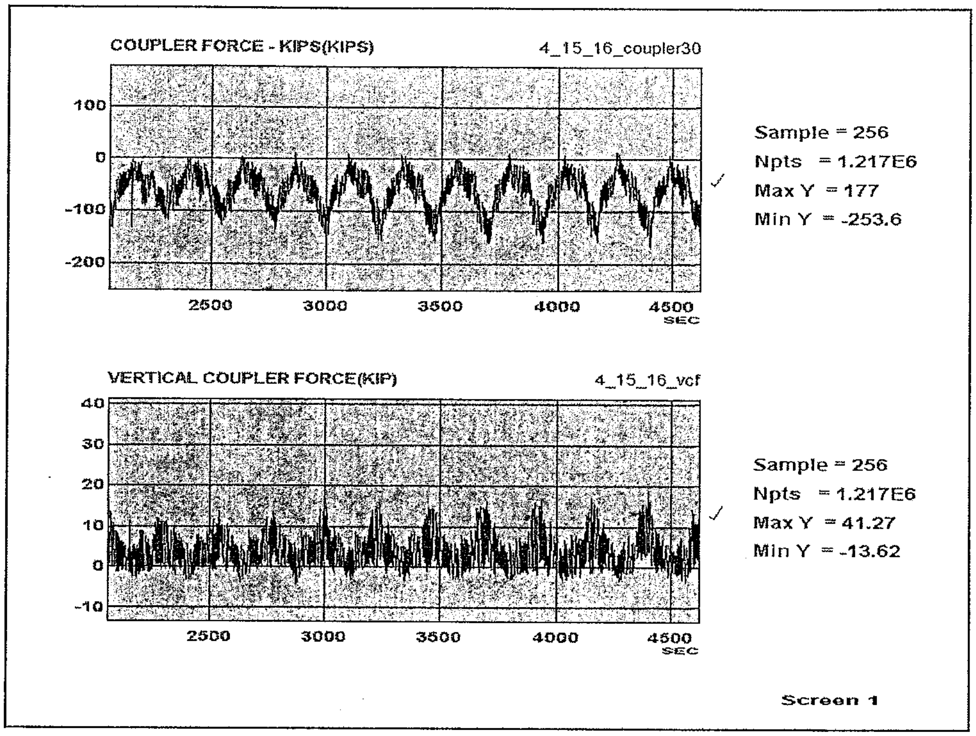


Figure 12. Measured LCF (top) and Calculated VCF Versus Time, April 15/16, 2003, Test Car near Front of Train

By contrast, when the test car was near the end of the train, there was enough "slack action" to produce numerous events characterized by short duration buff and draft LCF. As shown in Table A1 in the Appendix the values of the measured LCF were in order of magnitude from 160,000 to 263,000-pound compression to 150,000- to 270,000-pound tension. This is illustrated in Figures 13 through 15. Figure 13 shows about 45 minutes of measured and calculated LCF data from the night of April 14/15, 2003. Figures 14 and 15 show a 41-second segment from the same time period.

2.5.3.2 Accelerometer Response

Tables A2 and A3 in the Appendix and Figures 16 and 17 show some of the data from accelerometers 6L and 18L recorded during the night of April 14/15, 2003. This acceleration data was processed for the nine most significant LCF events recorded during the night. The peak acceleration values were less than 7 g and SRS values were generally in the 2-3 g range.

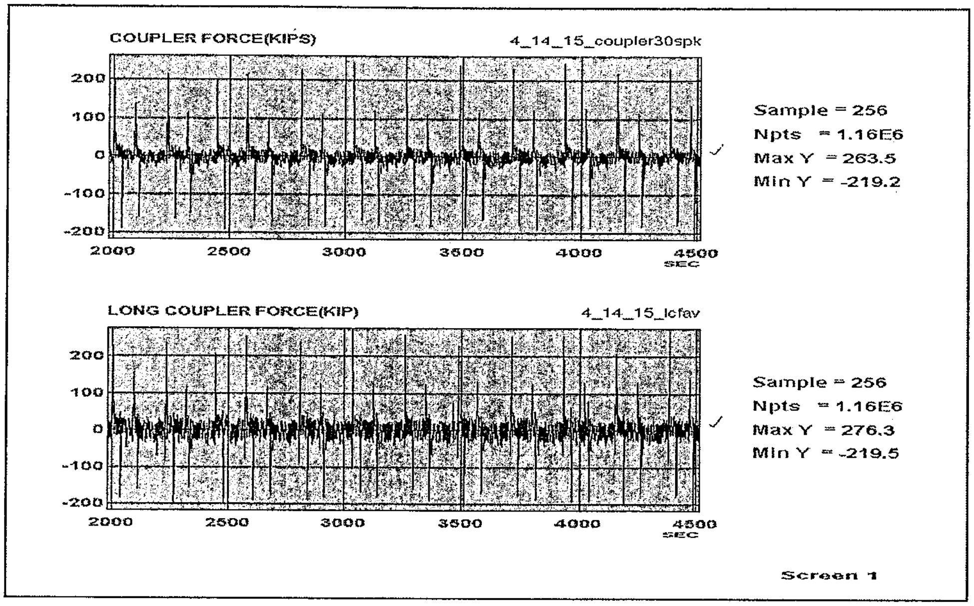


Figure 13. Measured (top) and Calculated LCF Versus Time, April 14/15, 2003, Test Car Near Rear of Train

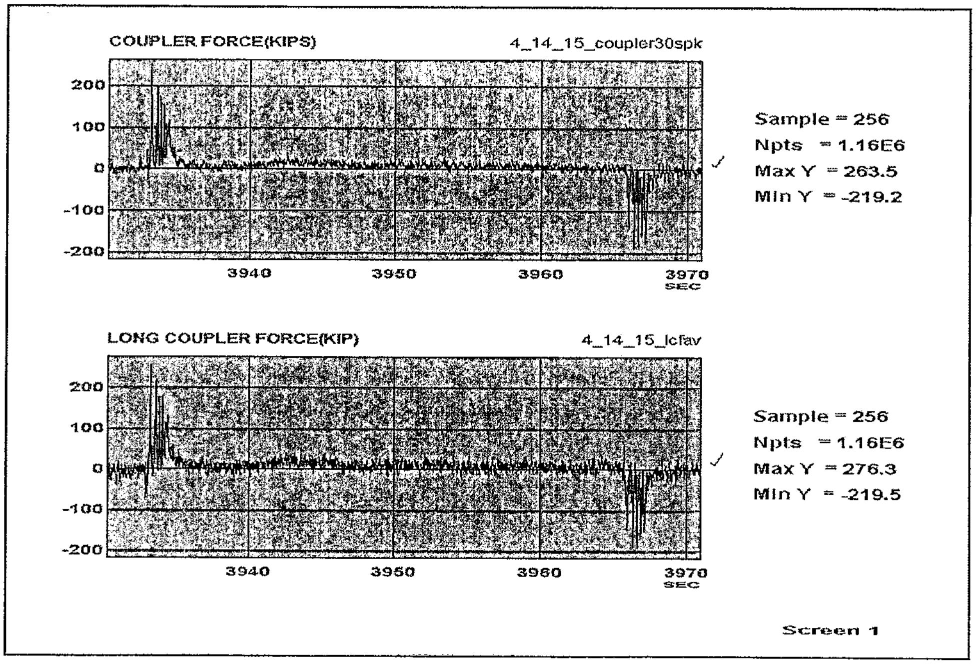


Figure 14. Measured (top) and Calculated LCF Versus Time During a 41-Second Time Period, April 14/15, 2003, Test Car Near Rear of Train

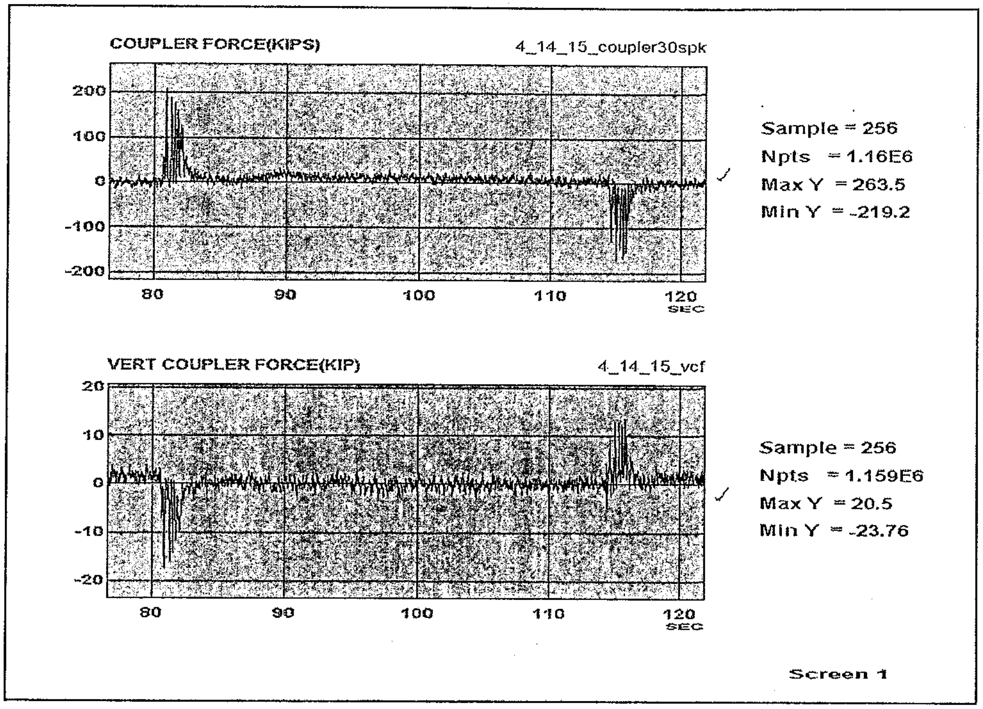


Figure 15. Measured LCF (top) and Calculated VCF Versus Time During a 41-Second Time Period, April 14/15, 2003, Test Car Near Rear of Train

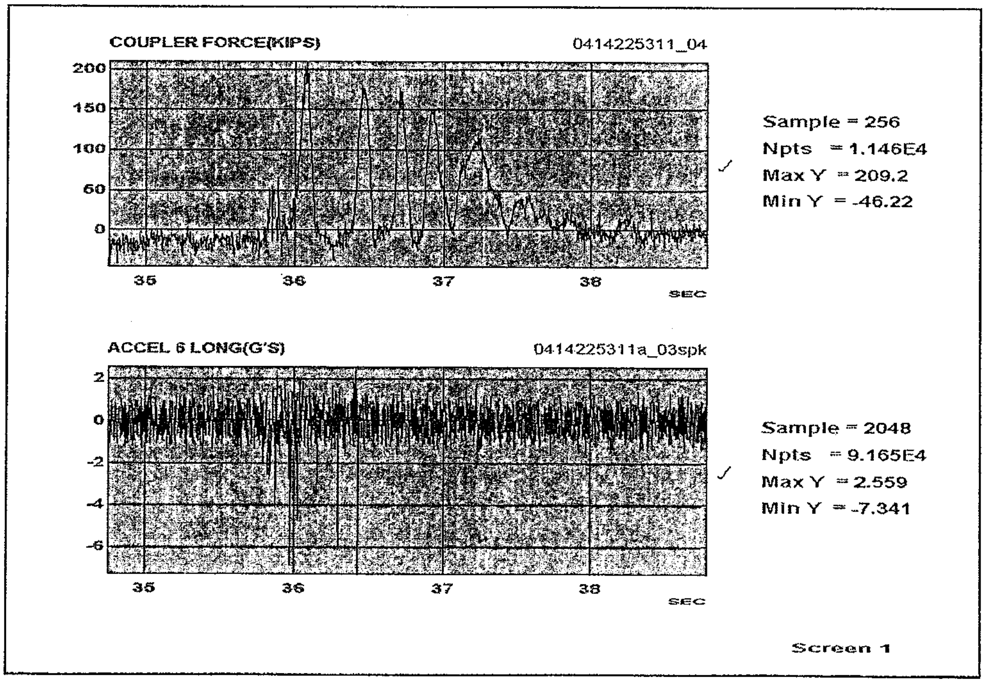


Figure 16. Measured LCF and Associated Longitudinal Acceleration at Location 6, April 14/15, 2003

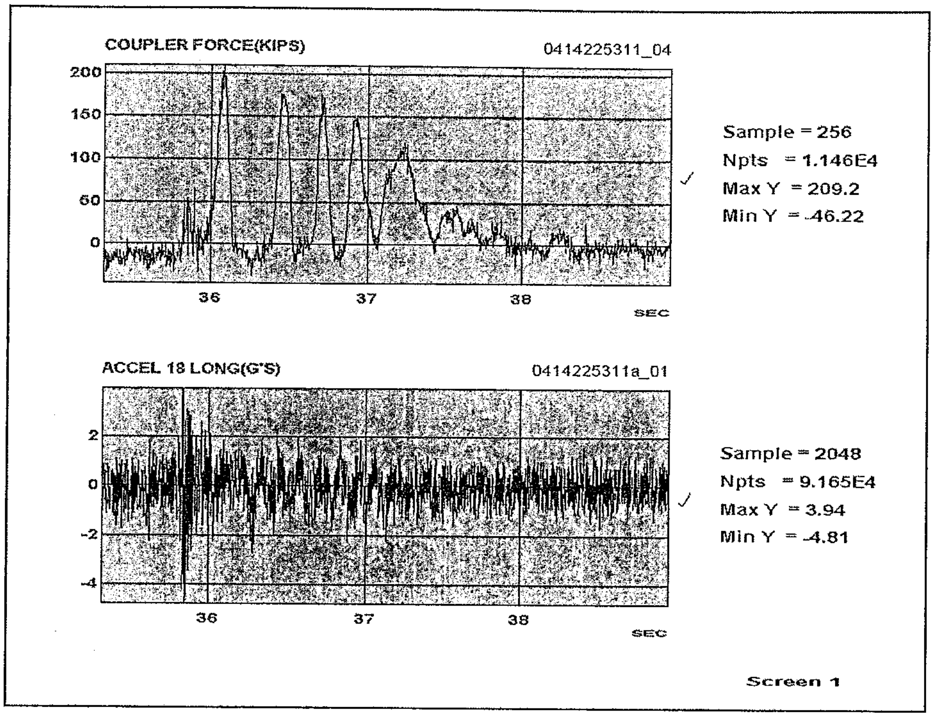


Figure 17. Measured LCF and Associated Longitudinal Acceleration at Location 18, April 14/15, 2003

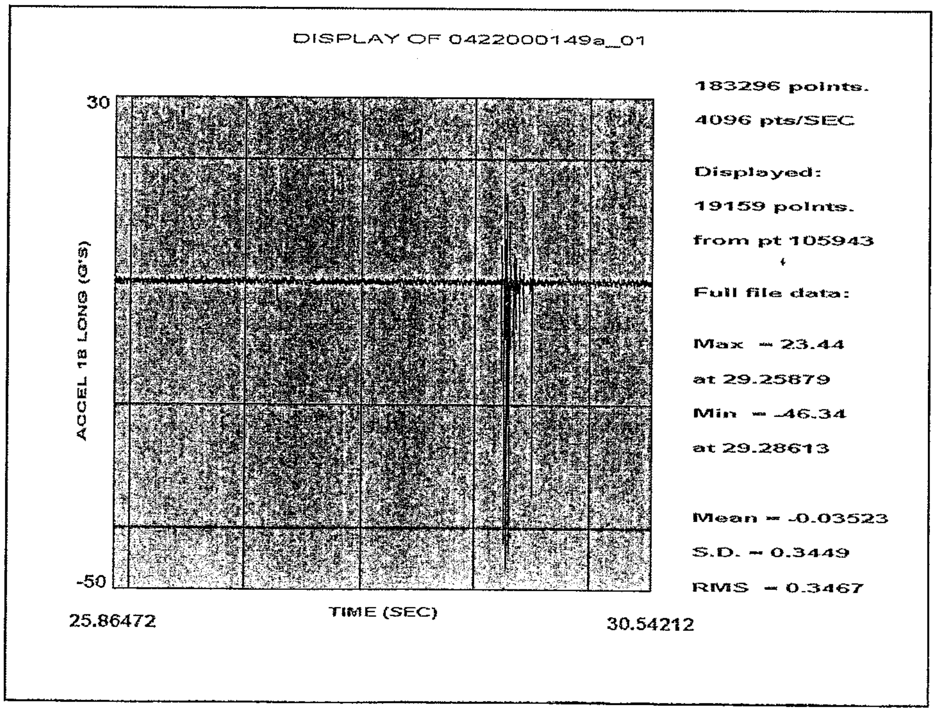


Figure 18. Typical Accelerometer Data Recorded April 20 –22, 2003

Plots A28 and A29 in the Appendix are plots of average SRS value versus measured peak LCF for the same events mentioned previously. There seemed to be little correlation between peak LCF and average SRS values at this coupler relatively low (less than 300,000 pounds) force level. It must be recognized, however, that all of the LCF values in this small comparison were of the same general order of magnitude.

During the first four to five nights of testing there were several problems with the data acquisition system including premature computer shutdown, and data with considerable noise, spikes, and zero offsets. Much of this poor quality data was not processed. Most of the problems were eventually solved and the result was significantly better data quality during the last five nights of testing. The problem of spikes in the acceleration data, however, was never totally solved. It is felt that this problem was due to amplifier connections that became intermittent during train action impacts. The peak acceleration values indicated by these "spikes" are not realistic or consistent with data recorded and illustrated in Figure 18 during previous nights when lower coupler force events occurred.

2.5.3.3 Strain gage response

Figures 19 through 22 are cross plots of recorded LCF values versus those calculated using the data from strain gages 19 and 20. These plots cover time spans of from 1.25 to 2.34 hours (representing over 1 million data points) and demonstrate that the correlation is close to 1-to-1 with a relatively narrow band of scatter. This is especially true of the data recorded during the last three to four nights of testing. It was during this time period that the data quality was at its best. It is possible that the band of scatter could be reduced in width at higher LCF values (above 300,000 pounds), or if additional filtering was used.

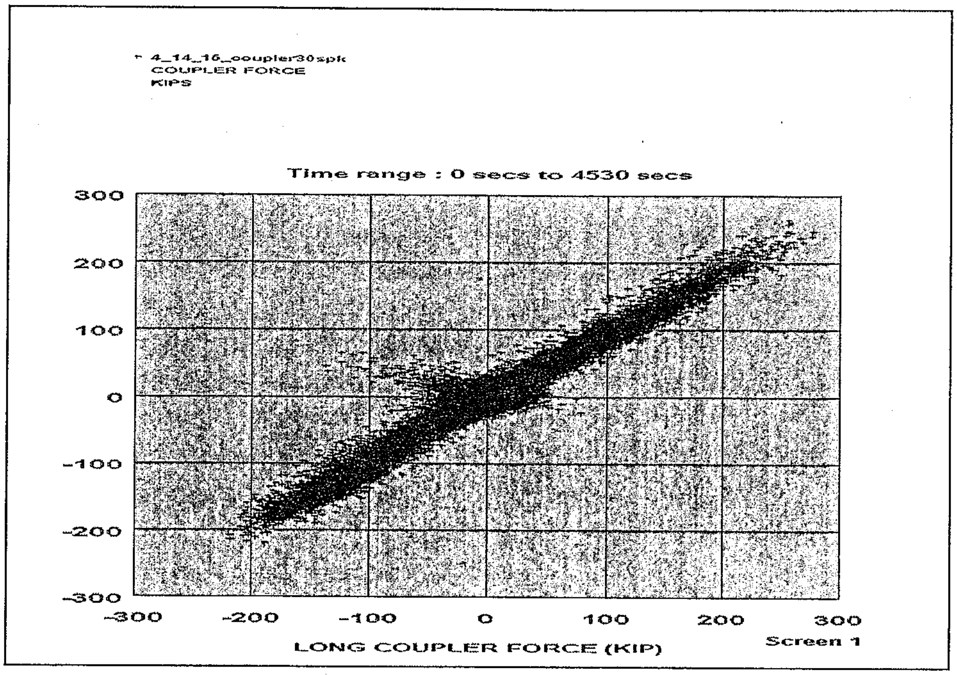


Figure 19. Cross Plot of Calculated LCF (y-axis) versus Measured LCF, April 14-15, 2003

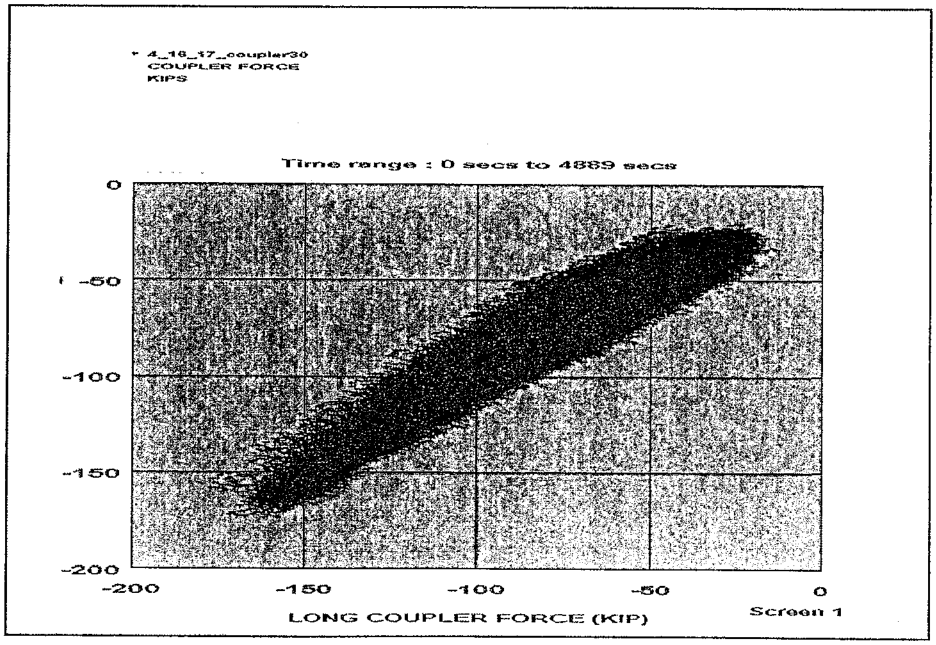


Figure 20. Cross Plot of Calculated LCF (y-axis) versus Measured LCF, April 16-17, 2003

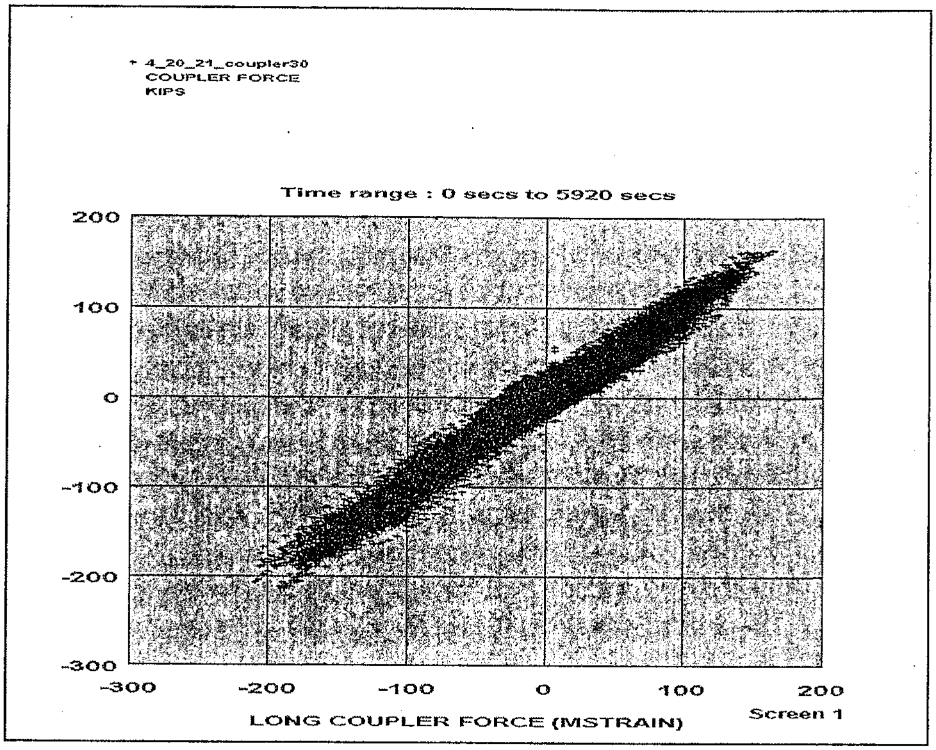


Figure 21. Cross Plot of Calculated LCF (y-axis) Versus Measured LCF, April 20-21, 2003

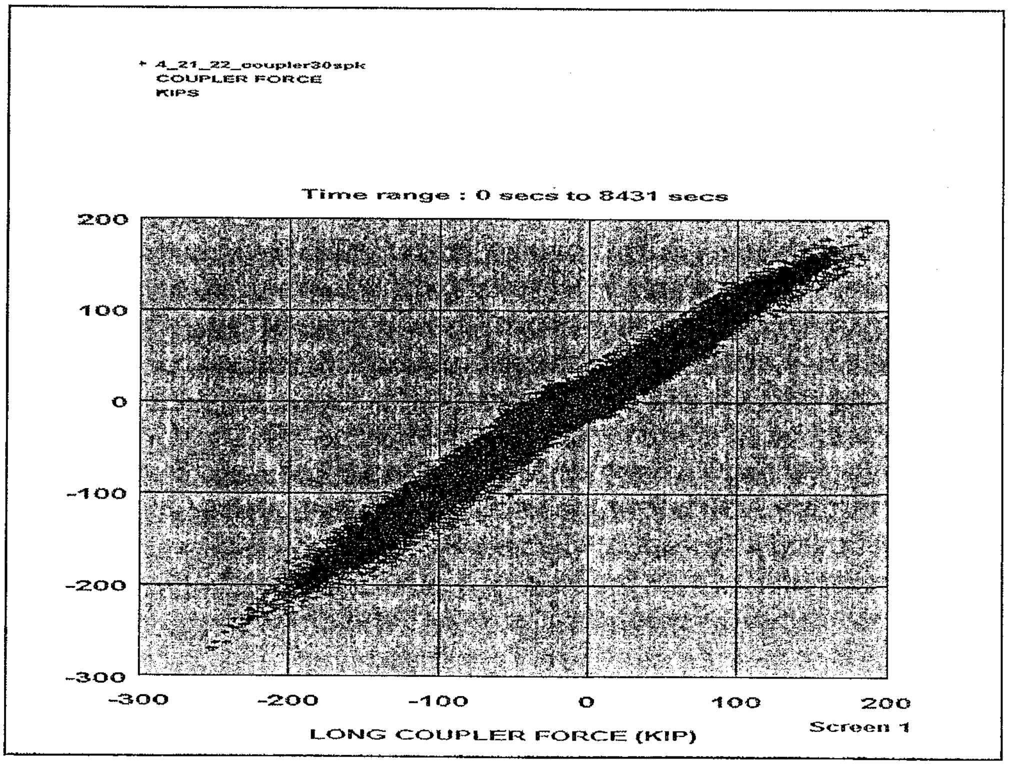


Figure 22. Cross Plot of Calculated LCF (y-axis) versus Measured LCF, April 21-22, 2003

2.6 Conclusions

2.6.1 Controlled Vertical Force Test

Phase I testing measuring accelerometer response resulting from controlled, low magnitude, vertical force pulses applied to the end of the stub sill revealed that such acceleration responses **(in the form of peak acceleration values)** could not effectively be used in an estimation of peak VCF resulting from such low magnitude inputs. Plots A4 and A5 in the Appendix illustrate two problems with this method. In both plots, T/2 represents one-half of the time period of the vertical force pulse. The first area of concern is that as the rate of force input decreased (T/2 increased), accelerometer response (in terms of the resulting peak vertical acceleration) became less sensitive to changes in magnitude of the maximum amplitude of the vertical force pulse. This is illustrated by observing the difference in the slopes of the curves estimated for the T/2 = 0.25 and T/2 = 0.5 tests in Plot A5. The second and more serious problem with this method is that there could be different peak force versus peak acceleration curves developed depending on the duration of the vertical force pulse. As a result, if all that is known is the amplitude of the acceleration, two or more peak force values could be surmised. As an example using the data in Plot A4, if a peak acceleration value of 0.38 g had been recorded, the calculated peak vertical coupler force could be estimated at from 14,000 to 20,000 pounds depending on the rate at which the load was applied. These problems should effectively eliminate this method as a way to calculate in-train VCF at this time.

2.6.2 Impact Test

The data from these tests provides the most accurate alternative to instrumented coupler s for predicting peak LCF and the best option for predicting VCF. The strain versus peak LCF and VCF relationships do not appear to be significantly affected by impact severity or draft gear action. The variation of strain response for a given, measured peak LCF appears to be significantly smaller than the variation of SRS response. If strain gages are used to indicate vertical coupler forces, it is recommended they be placed in locations where they will be sensitive to those vertical forces but essentially unaffected by longitudinal coupler forces.

As Plots A14 through A21 in the Appendix show, it is possible to use Shock Response Spectrum (SRS) data to estimate peak longitudinal coupler forces (LCF) that occur as a result of car-to-car impacts. This method shows the most promise for the purposes of indicating the severity of moderate to severe impacts (impact environment characterization) using accelerometer response. For the purposes of such impact environment characterization, the range or scatter of SRS response for a given, peak LCF and some changes in SRS versus coupler force relationships as impact severity increases may not be unacceptable limitations. The longitudinal accelerometer at location No. 6 in Figure 5 (top surface of the tank shell near the longitudinal center line) has thus far proven to provide the best data for such predictions. Conversely test data has shown that the use of unfiltered (as recorded) peak accelerometer output (either positive or negative) cannot be used to reliably predict peak LCF during an impact event. Peak acceleration values that result from acceleration vs. time data filtered at either 50 or 100 HZ have also proven to be a relatively poor predictor of peak coupler force resulting from impacts.

The data collected from Impact Sequences 1 through 4 indicates that SRS response cannot, at this time, be used very effectively to estimate peak VCF or LCF values for the purposes of performing crack growth, fatigue, or damage tolerance analysis. The reasons for this are as follows:

- Even for the best SRS versus peak LCF relationships, there is enough "scatter" in the data (regardless of the regression function used) that the resulting range of peak LCF values that might be predicted with a given SRS value is too broad to be effectively used in an accurate crack growth or damage tolerance analysis.
- The change of the SRS versus peak LCF relationship as impact forces increase (for a particular type of impact) is most likely due to draft gear design or condition. It must be recognized that among different draft gear designs or even among draft gear of the same design but different ages there can be a wide variation in force versus deflection performance. If this is the case, the effects on the SRS versus peak LCF relationship cannot be generalized in a way that can be applied to all possible draft gear/car combinations.

Since testing thus far has only involved one car/draft gear combination, the overall form of the peak LCF versus SRS relationship is only known for that one combination. At this time it must be assumed that the form of the LCF versus SRS relationship will be significantly different for any other car/draft gear combination. These factors again prevent any type of practical generalization or expansion of the relationships established thus far to cover all significant car/draft gear designs.

2.6.3 Testing at FAST

Analysis of the data revealed that at peak LCF values less than 300,000 lb., the output from Strain Gages 20 and 19 could be used to make estimates of longitudinal coupler force as measured by the instrumented coupler. This is illustrated by Figures 11, 13 and 14, and 19 through 12. The response versus time traces in Figures 11, 13, and 14 illustrate the similar nature of the data from the instrumented coupler to that calculated using strain values from Gages 19 and 20. Figures 19 through 22 on the other hand show the similar data in a cross plot format and illustrates the accuracy and scatter of the LCF values calculated using strain gage output versus those measured by the instrumented coupler.

The data collected during this test confirmed that accelerometer response in the form of shock response spectrum values does not correlate well with either vertical or longitudinal peak coupler force at peak LCF values below 200,000 pounds.

Plots A30 and A32 in the appendix illustrate that at this coupler force level there seemed to be little correlation between peak LCF and SRS values averaged over frequency ranges of either 5 to 50 Hz or 10 to 100 Hz.

3.0 RECOMMENDATIONS

Conduct extended over the road trials to prove that: 1) strain gage response can be used to accurately predict longitudinal and vertical coupler forces during uncontrolled, long-term service, and 2) accelerometer response in the form of Shock Response Spectrum values can be used to effectively monitor the level of longitudinal and vertical coupler forces resulting from severe yard impacts. This could be accomplished within a Phase 2A by installing a reduced set of transducers on a single stub sill tank car that would then be subjected to standard over-the-road conditions for 10,000 to 13,000 miles. It is anticipated that this mileage can be accumulated in 6 to 8 weeks of testing. If the data collected during this trial test continue to suggest that these two methods of predicting coupler forces are valid and useful, three more cars — each of a different design— should be similarly instrumented and placed in similar extended service. This last step would be required to prove that the concept has true universal application.

It is recommended that the following transducers be installed on the stub sill/tank structure:

- Instrumented coupler at each end of car.
- Strain gages at locations 19 and 20 on A-end of car.
- Strain gages at locations 19 and 20 on B-end of car.
- Strain gages at location 21/22 on A-end of car.
- Strain gages at location 21/22 on B-end of car.
- 100 g vertical and longitudinal accelerometers at location 6.
- 100 g vertical and longitudinal accelerometers at location 5.
- 100 g vertical and longitudinal accelerometers at location 18 (used as backup).

In addition, there should be a set of strain gages applied to one of the bolsters to record data on bolster loads that can be compared with similar data collected in the stub sill tank car research project DOT/FRA/ORD/95-11, often referred to as FEEST II, [3] conducted in 1995. As the coupler force data from the proposed Phase 2A test is evaluated and compared with that recorded during the FEEST II test, it will be useful to also compare bolster load history as an indication of relative route severity.

Before on-track testing begins the output of all strain gages should be re-calibrated against known loads, repeating the quasi-static process used before Phase I testing began.

The recorded data during over-the-road testing should be processed in a manner similar to that used for the FAST test of Phase I. Thresholds should be set to control the recording of acceleration data and that data should only be recorded for the time that the values exceed the limits. The acceleration versus time data for each event should be converted to SRS response values averaged over 5-50 Hz by software within the data acquisition system. As a result, the data downloaded for each significant acceleration event would be an SRS value averaged over a range of 5-50 Hz and a peak coupler force value. Based on the Volpe analysis, accelerometer data should be recorded at about 2,000 samples per second.[1][2]

Strain gage and coupler force data should be recorded continuously while car velocity is over 1.0 mph. This data can also be recorded at 2,000 samples per second, but then decimated to 256 Hz to save onboard file space. This data should then pass through a 30-Hz digital filter before being processed. The filtered strain gage data should be processed using software on the data acquisition computer so that the information available for download is in the form of calculated vertical and longitudinal coupler forces versus time.

If the data recorded during this trial test continues to confirm an acceptable level of accuracy for the correlation of SRS response versus measured peak coupler force and coupler force calculated form strain data versus measured peak coupler force, a Phase 2B should be planned. In this phase, similar transducer/data acquisition systems would be installed on three more stub sill tank cars of three different contemporary designs. These three cars would also be subjected to 10,000 to 13,000 miles of over-the-road testing as a final confirmation of the system effectiveness and the usefulness of the concept using cars of designs deferent from that of the Phase 2A car.

References

1. Lyons, Matthew; Riddell, William, and Koch, Kevin. "Analysis of Accelerations Measured During Full-Scale Tank Car Impact Tests," Report No. DOT/FRA/RDV-to be published, U. S. Department of Transportation, Federal Railroad Administration, May, 2003.
2. Lyons, Matthew; Riddell, William and Koch, Kevin. "Full Scale Tank Car Impact Tests," American Society of Mechanical Engineers (ASME) Report IMECE2003-44062, November 2003.
3. Cogburn, L. "Stub Sill Tank Car Research Project Results of a 15,000-mile Over-the-Road Test," Report No. FRA/ORD/95-11, September 1995.

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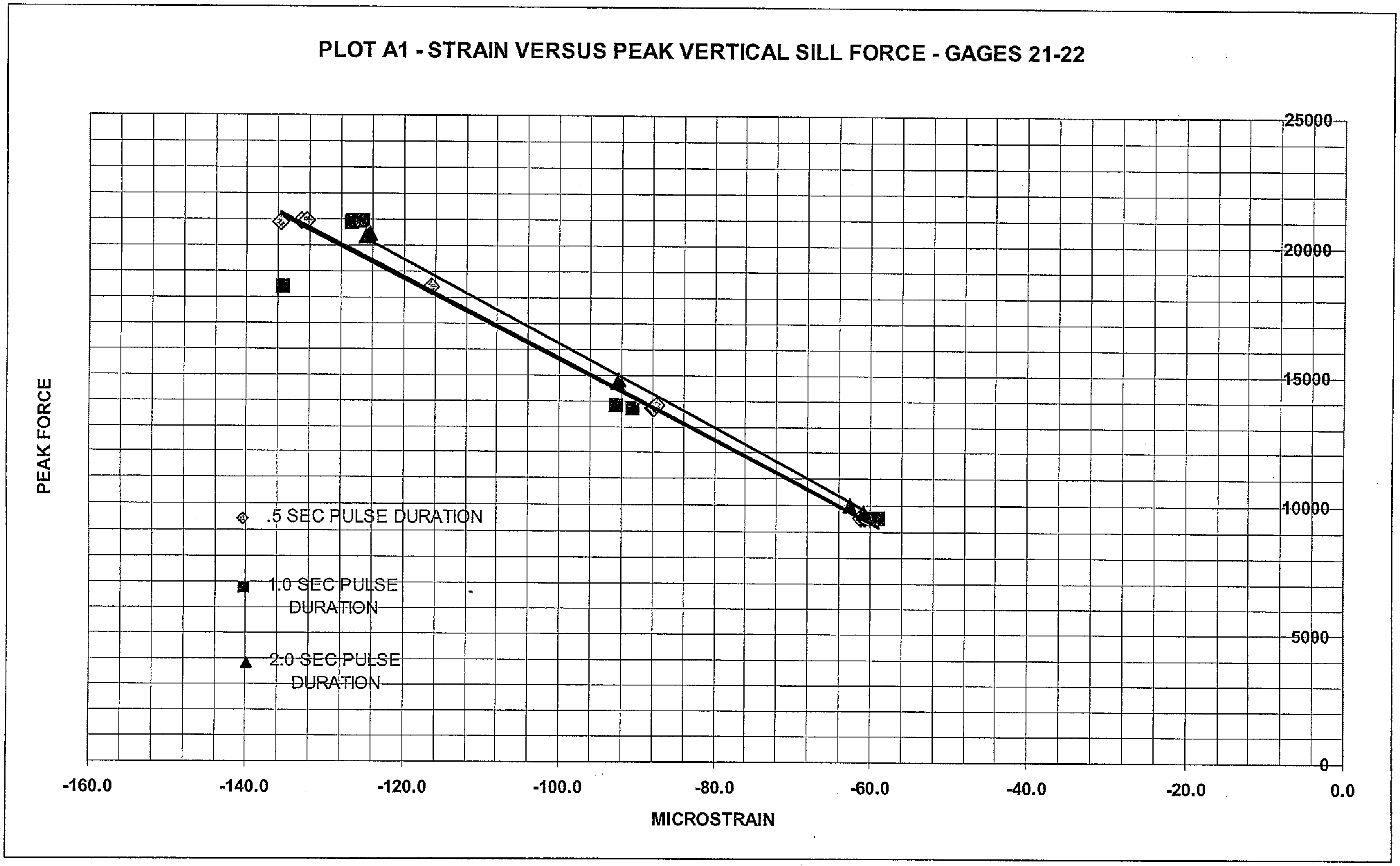
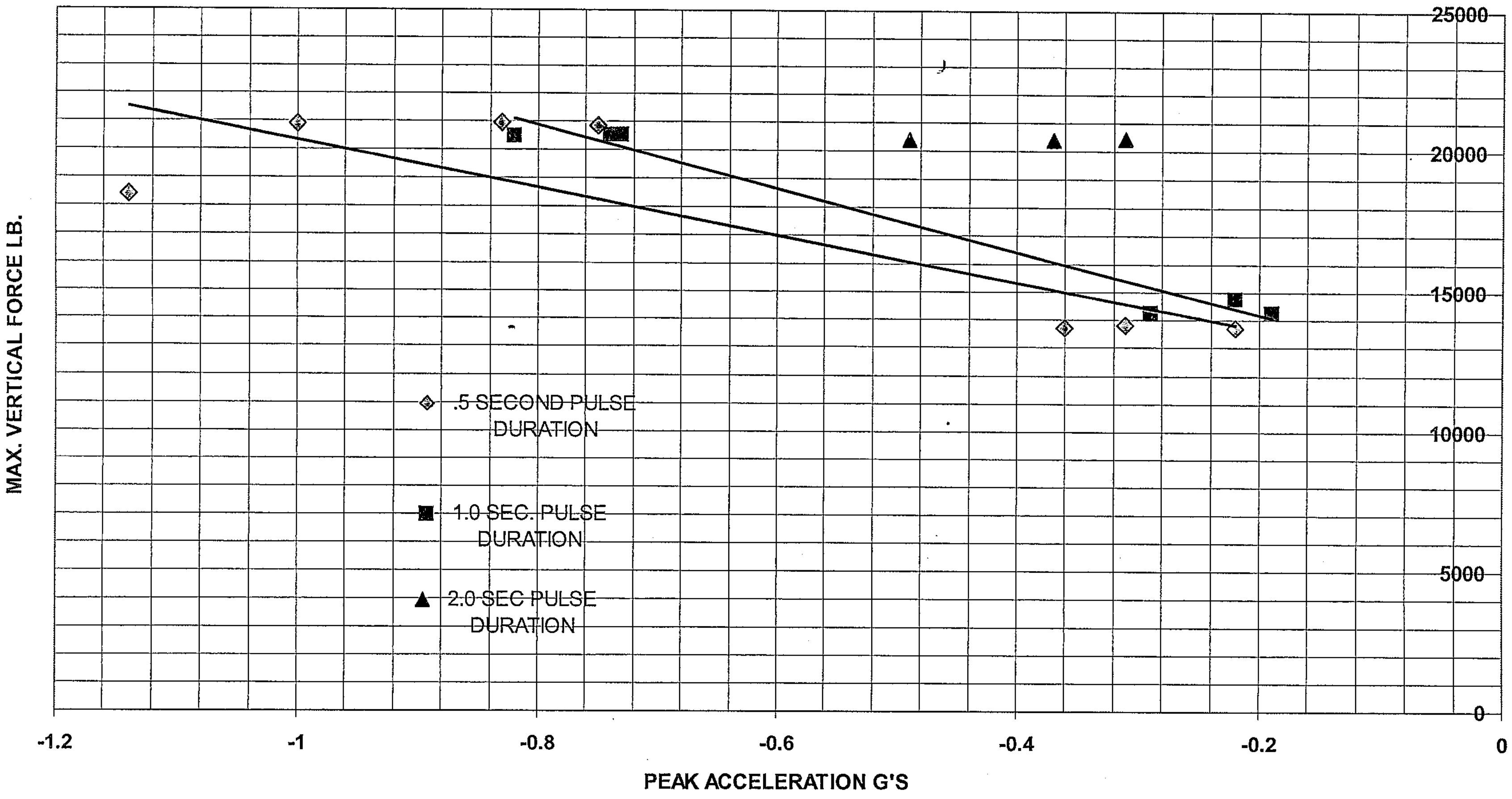
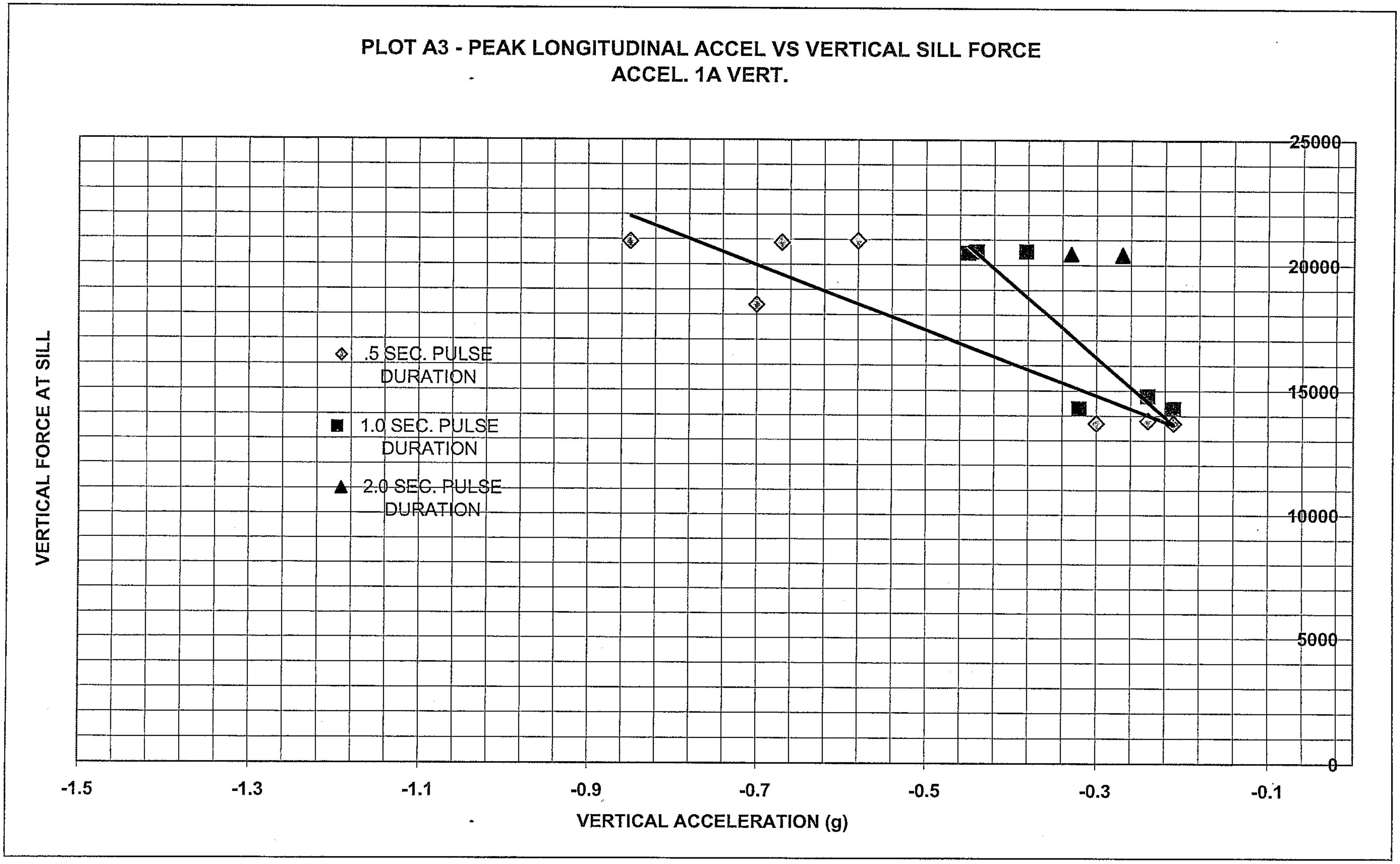
APPENDIX

Plots A1 through A22

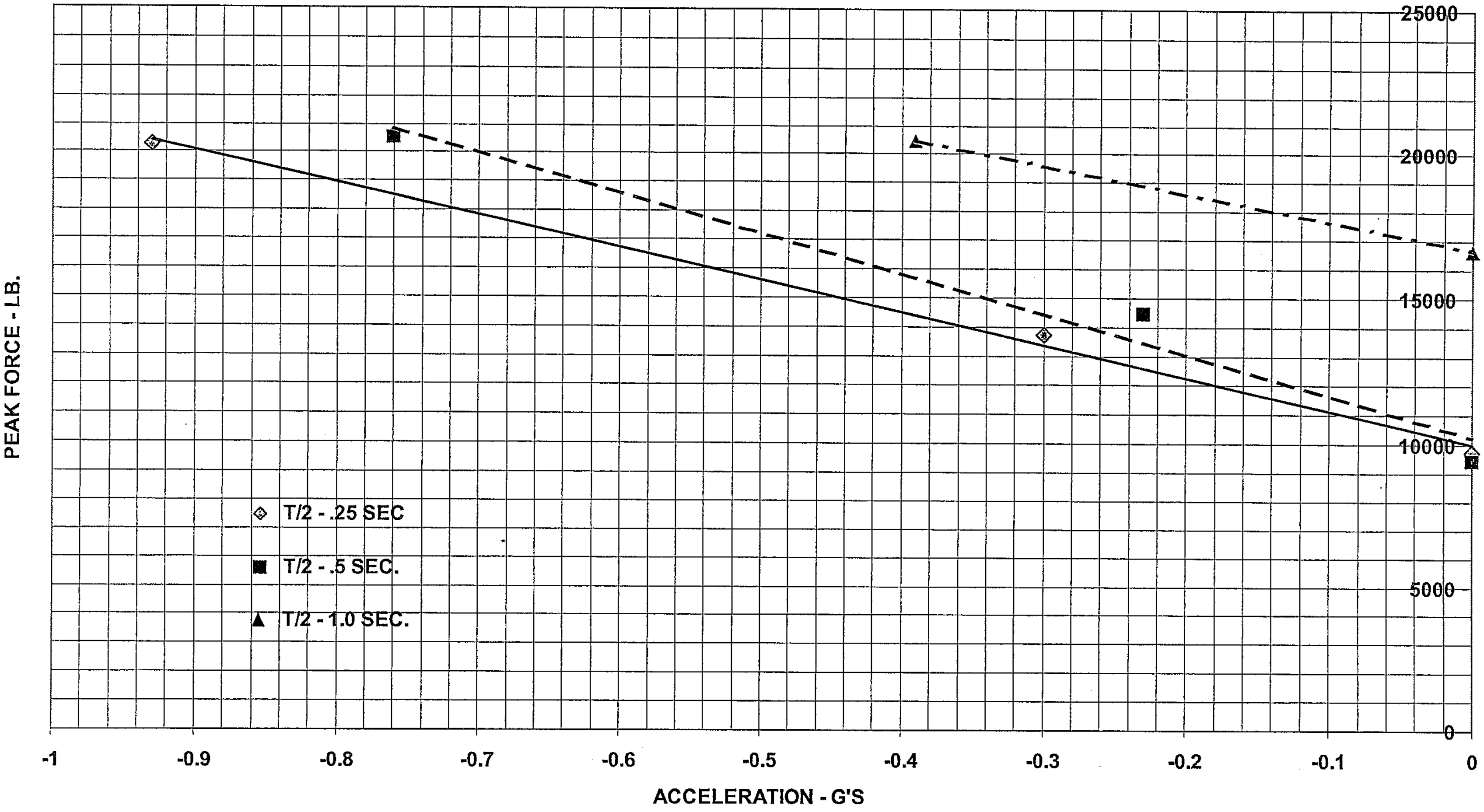

PLOT A1 - STRAIN VERSUS PEAK VERTICAL SILL FORCE - GAGES 21-22
PEAK FORCE
MICROSTRAIN
25000
20000
15000
10000
5000
0
-160.0
-140.0
-120.0
-100.0
-80.0
-60.0
-40.0
-20.0
0.0
.5 SEC PULSE DURATION
1.0 SEC PULSE DURATION
2.0 SEC PULSE DURATION

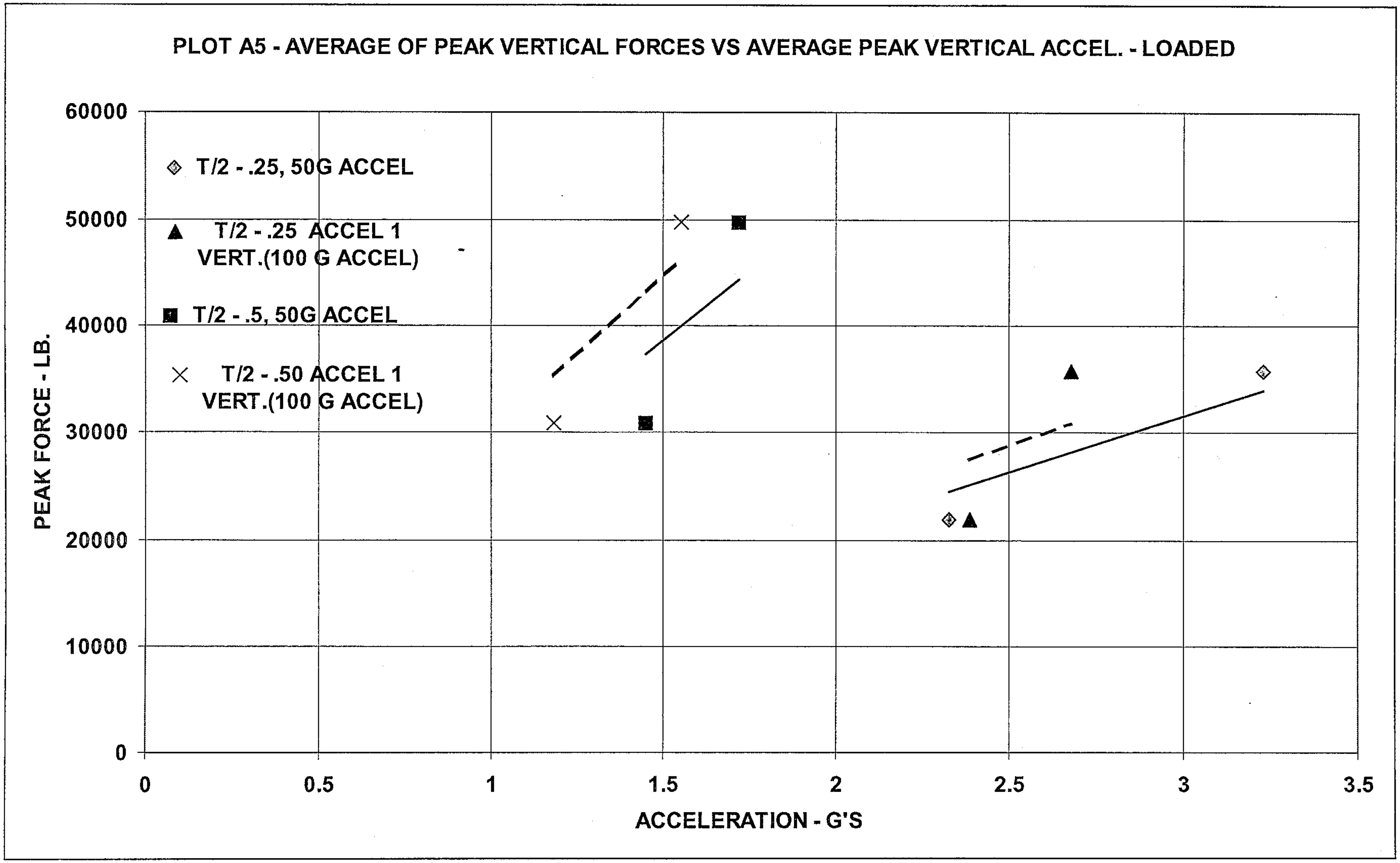
PLOT A2 - PEAK VERTICAL ACCELERATION VS MAX. VERTICAL SILL FORCE
ACCEL. 1 VERT.



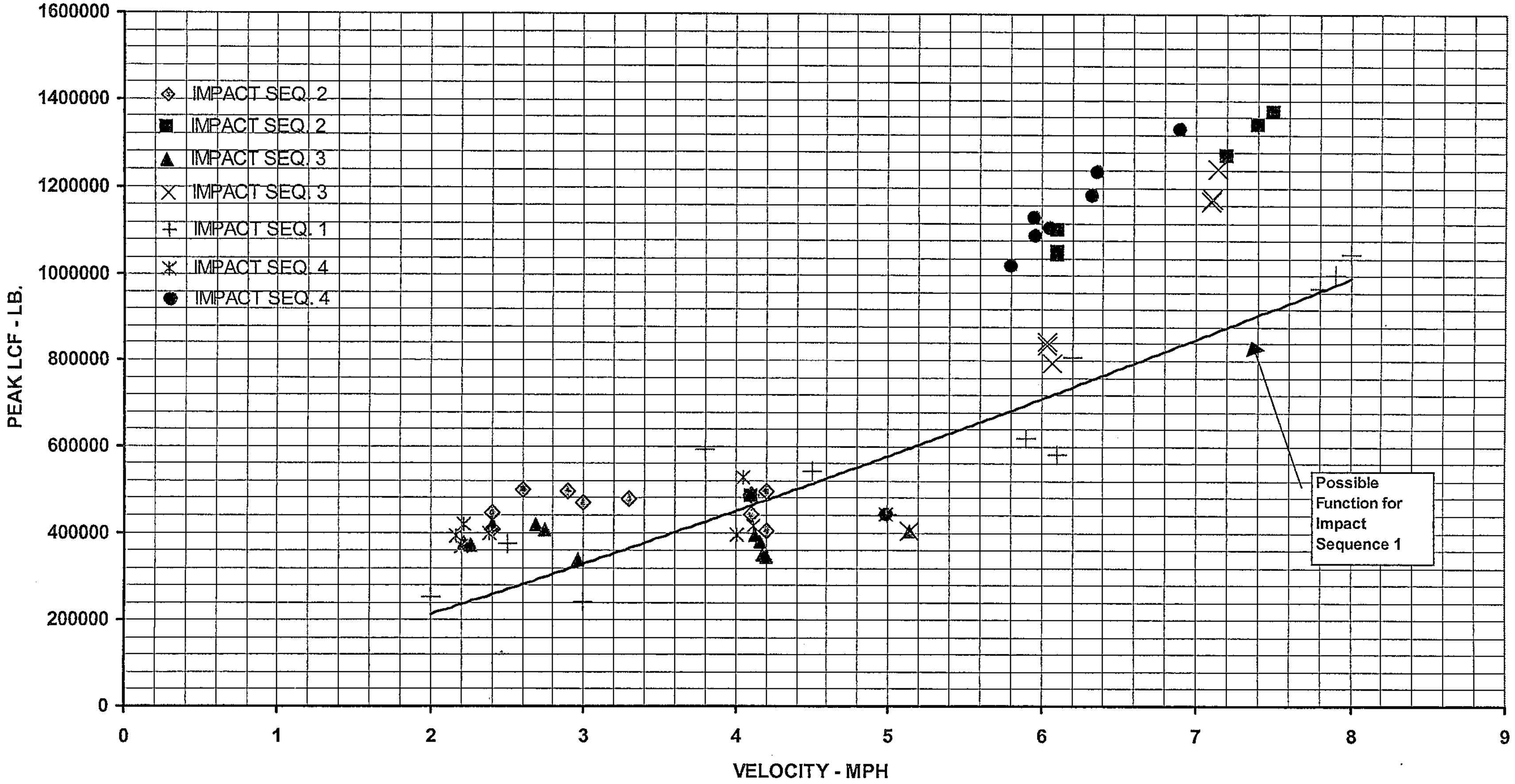

PLOT A3 - PEAK LONGITUDINAL ACCEL VS VERTICAL SILL FORCE
ACCEL. 1A VERT.
VERTICAL FORCE AT SILL
25000
20000
15000
10000
5000
0
◇ .5 SEC. PULSE DURATION
■ 1.0 SEC. PULSE DURATION
▲ 2.0 SEC. PULSE DURATION
-1.5
-1.3
-1.1
-0.9
-0.7
-0.5
-0.3
-0.1
VERTICAL ACCELERATION (g)

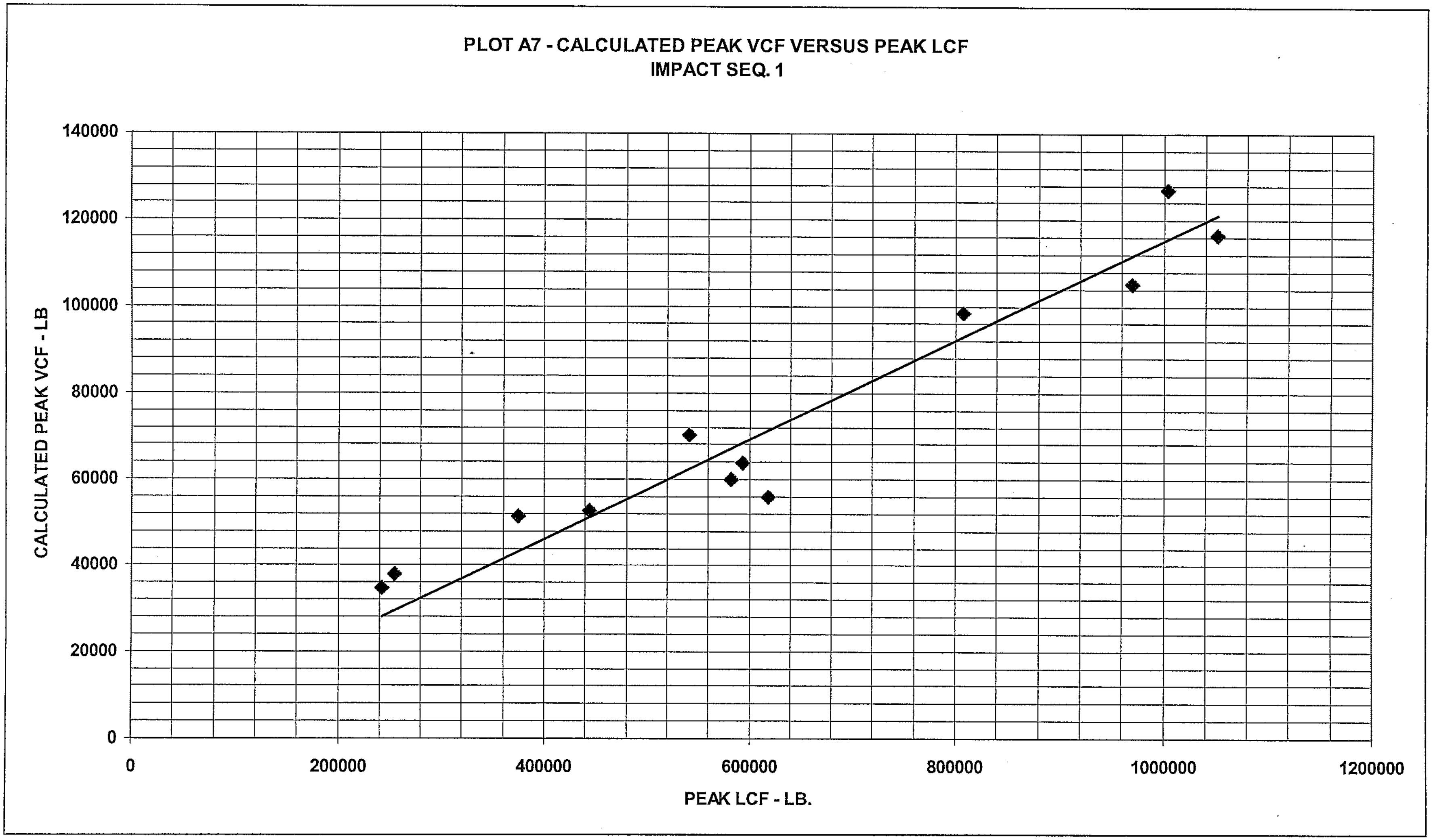
PLOT A4 AVERAGE OF PEAK VERTICAL FORCES VS AVERAGE PEAK VERT. ACCEL. #1 EMPTY CAR

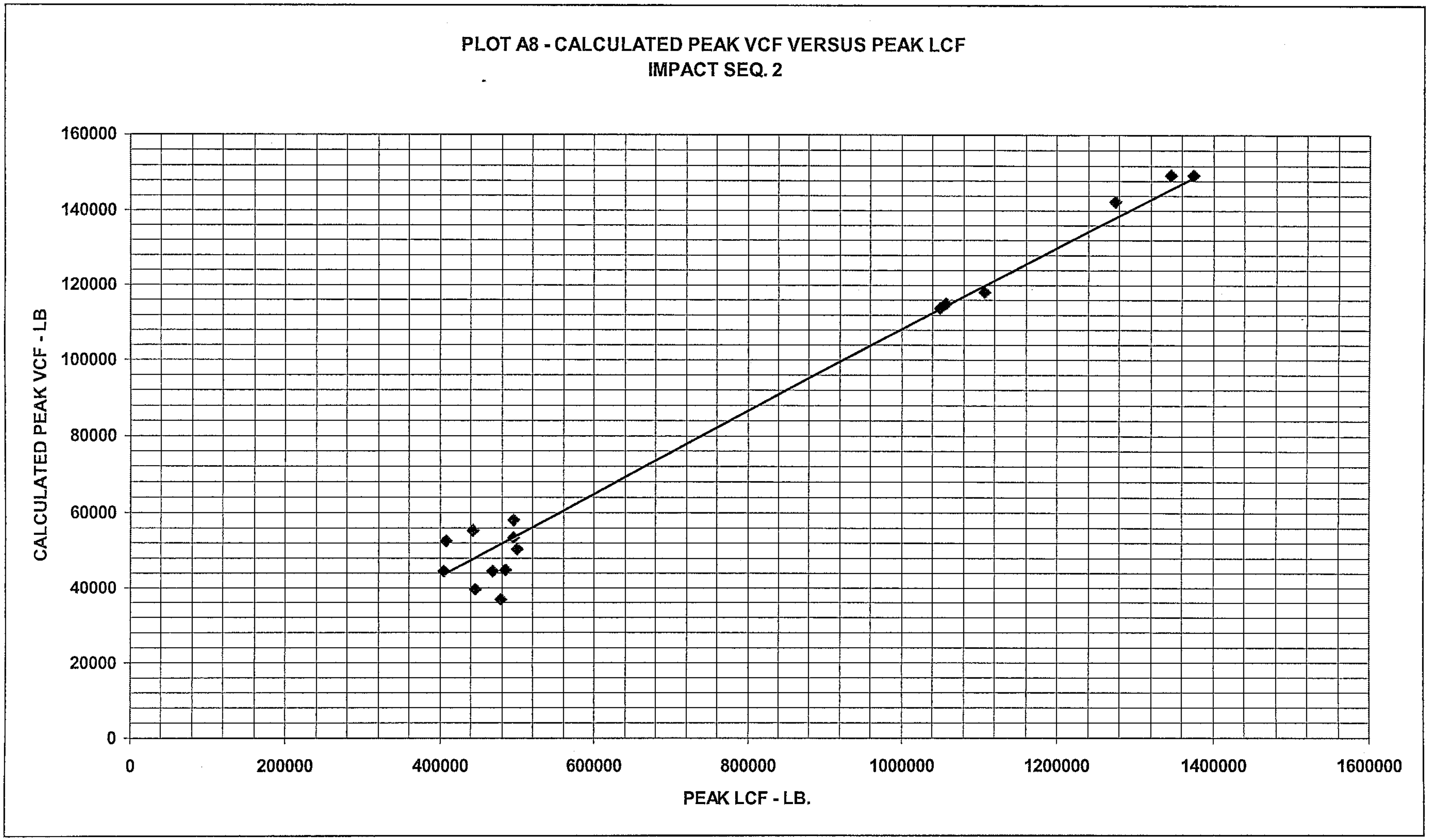



PLOT A5 - AVERAGE OF PEAK VERTICAL FORCES VS AVERAGE PEAK VERTICAL ACCEL. - LOADED
◈ T/2 - .25, 50G ACCEL
▲ T/2 - .25 ACCEL 1 VERT.(100 G ACCEL)
■ T/2 - .5, 50G ACCEL
× T/2 - .50 ACCEL 1 VERT.(100 G ACCEL)
PEAK FORCE - LB.
60000
50000
40000
30000
20000
10000
0
ACCELERATION - G'S
0
0.5
1
1.5
2
2.5
3
3.5

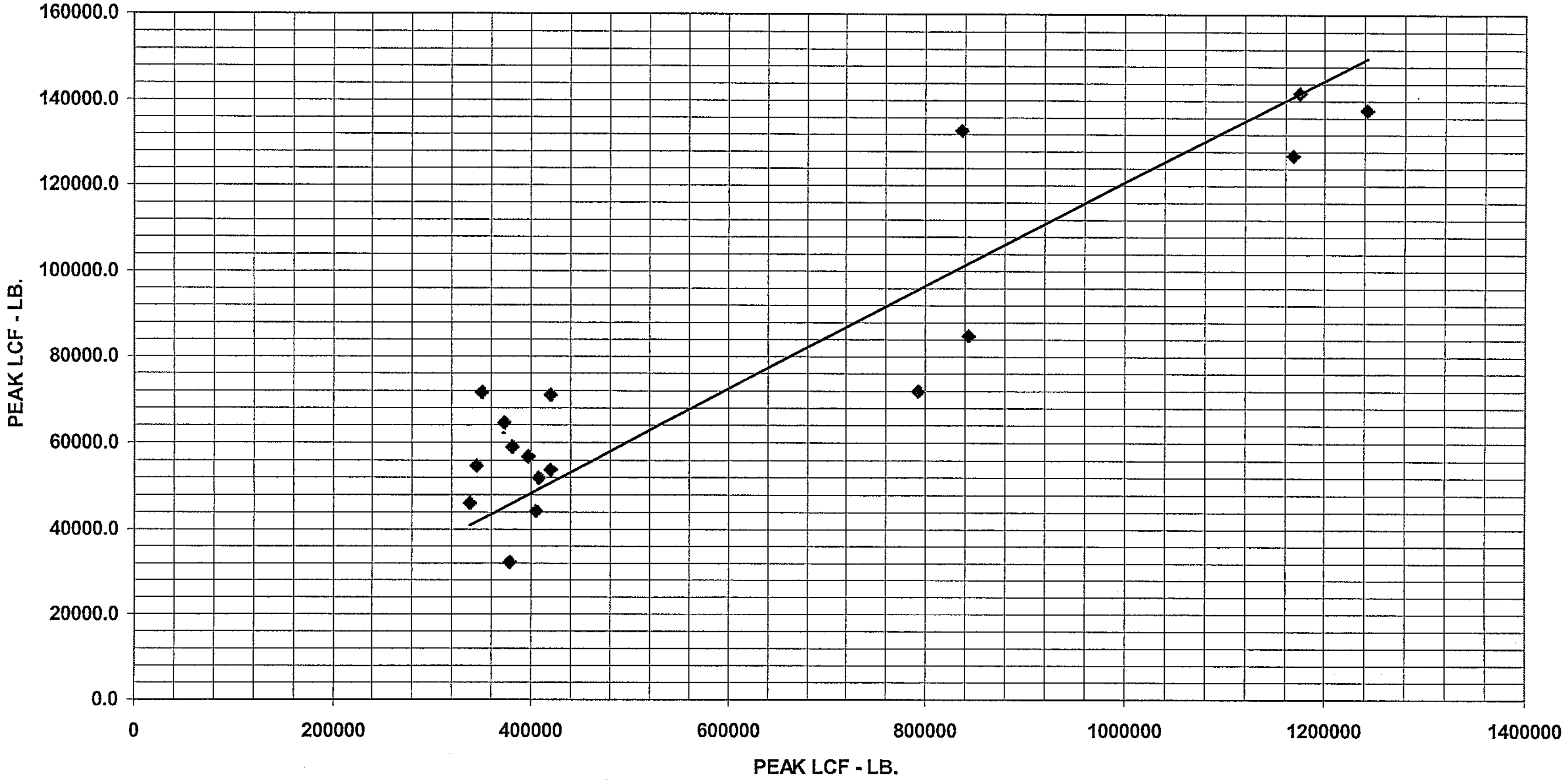
PLOT A6 - PEAK LCF VERSUS IMPACT VELOCITY - ALL IMPACTS

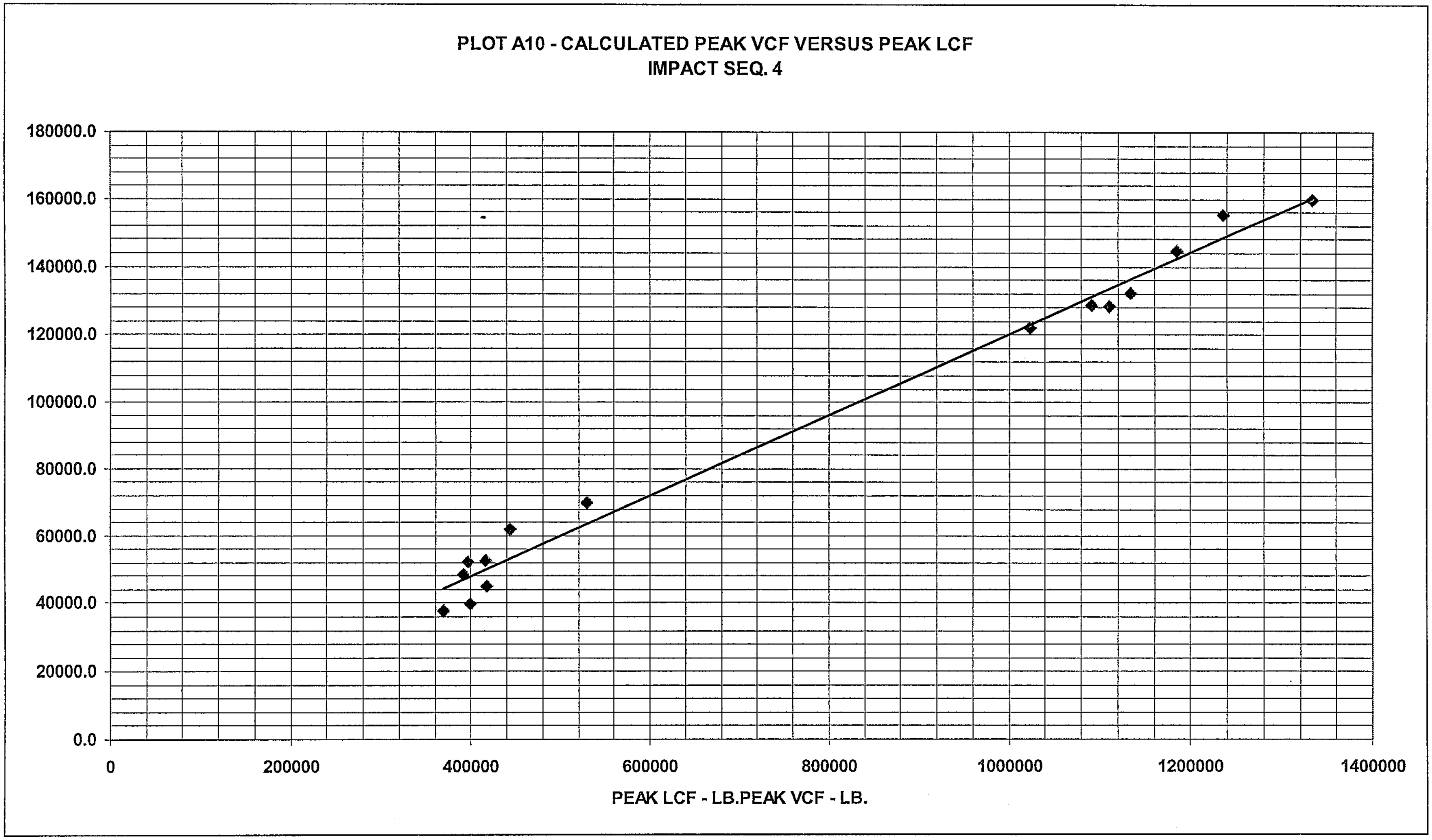



PLOT A7 - CALCULATED PEAK VCF VERSUS PEAK LCF
IMPACT SEQ. 1
CALCULATED PEAK VCF - LB
140000
120000
100000
80000
60000
40000
20000
0
0
200000
400000
600000
800000
1000000
1200000
PEAK LCF - LB.

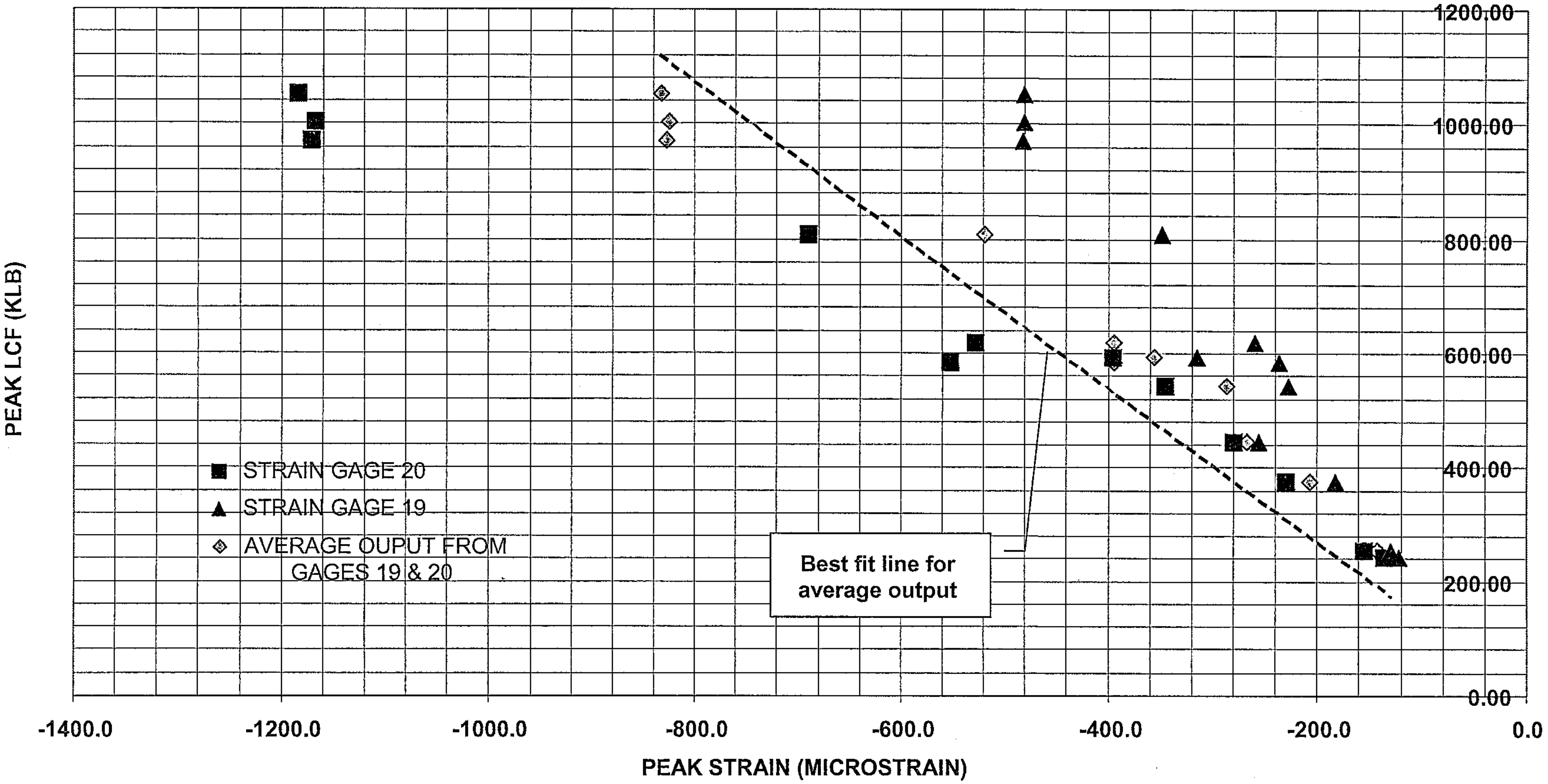

PLOT A8 - CALCULATED PEAK VCF VERSUS PEAK LCF
IMPACT SEQ. 2
CALCULATED PEAK VCF - LB
160000
140000
120000
100000
80000
60000
40000
20000
0
0
200000
400000
600000
800000
1000000
1200000
1400000
1600000
PEAK LCF - LB.

PLOT A9 - CALCULATED PEAK VCF VERSUS PEAK LCF
IMPACT SEQ. 3

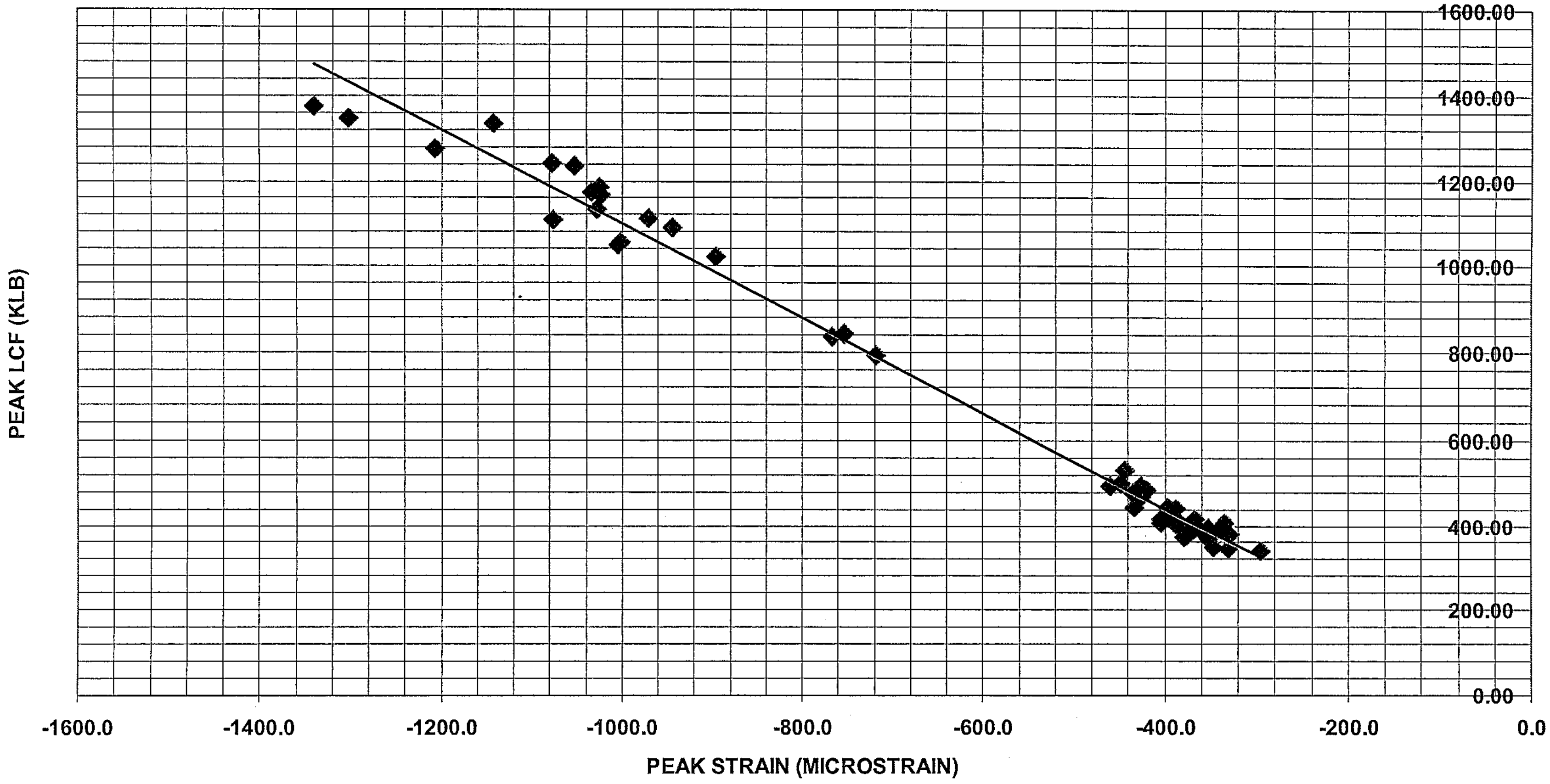


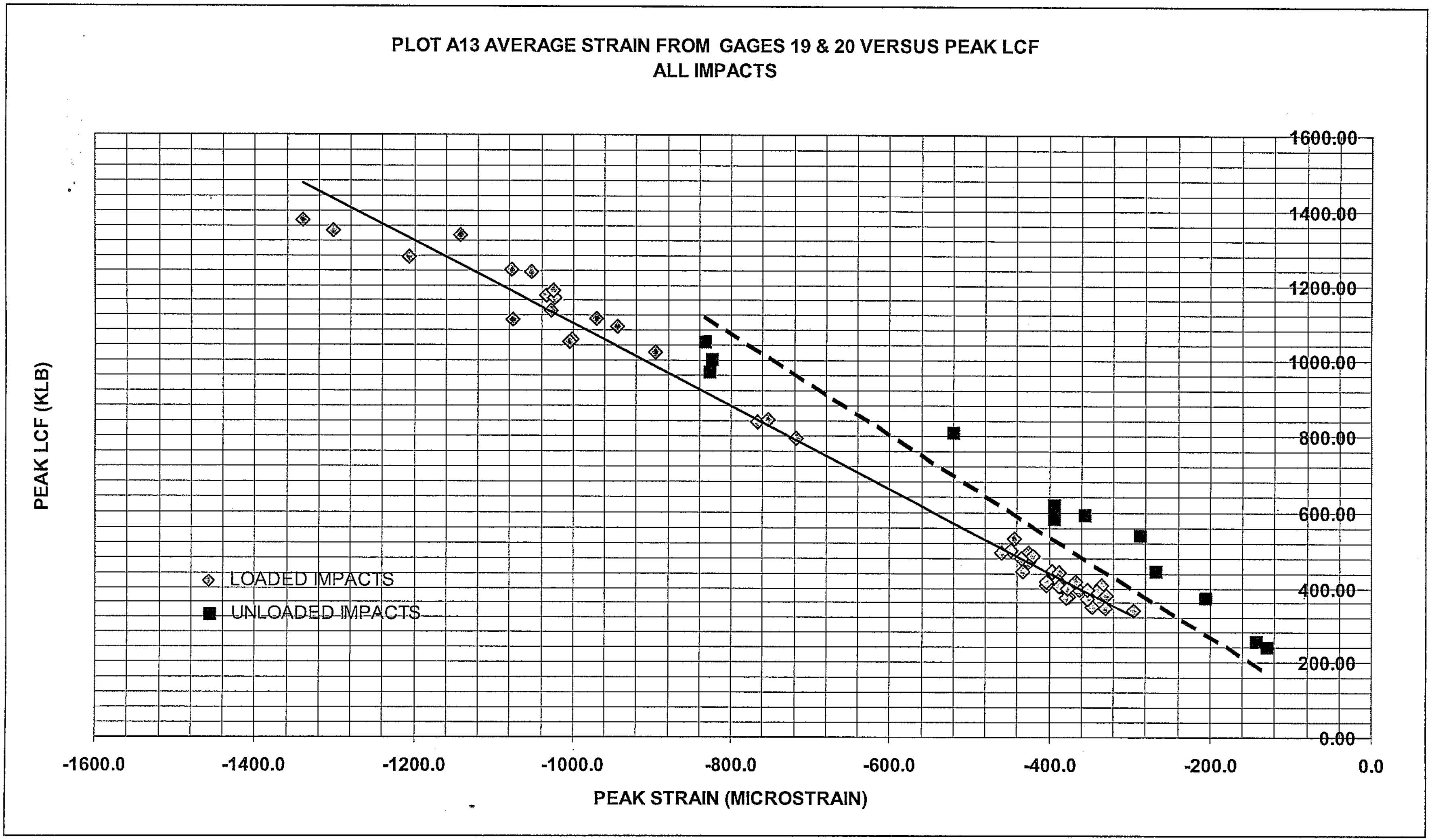

PLOT A10 - CALCULATED PEAK VCF VERSUS PEAK LCF
IMPACT SEQ. 4
180000.0
160000.0
140000.0
120000.0
100000.0
80000.0
60000.0
40000.0
20000.0
0.0
0
200000
400000
600000
800000
1000000
1200000
1400000
PEAK LCF - LB.PEAK VCF - LB.

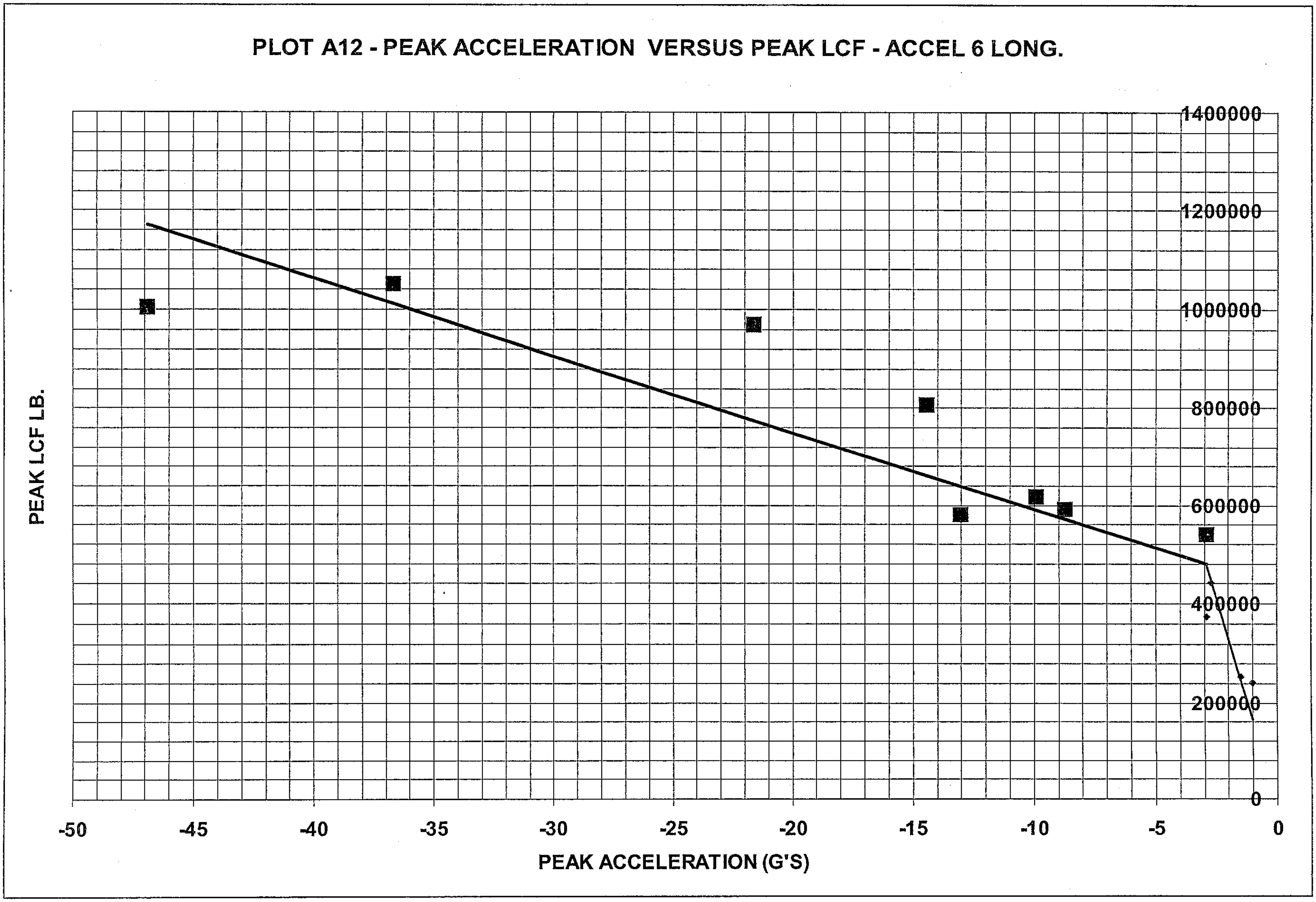
PLOT A11 - STRAIN FROM GAGES 19 & 20 VERSUS PEAK LCF
IMPACT SEQUENCE 1

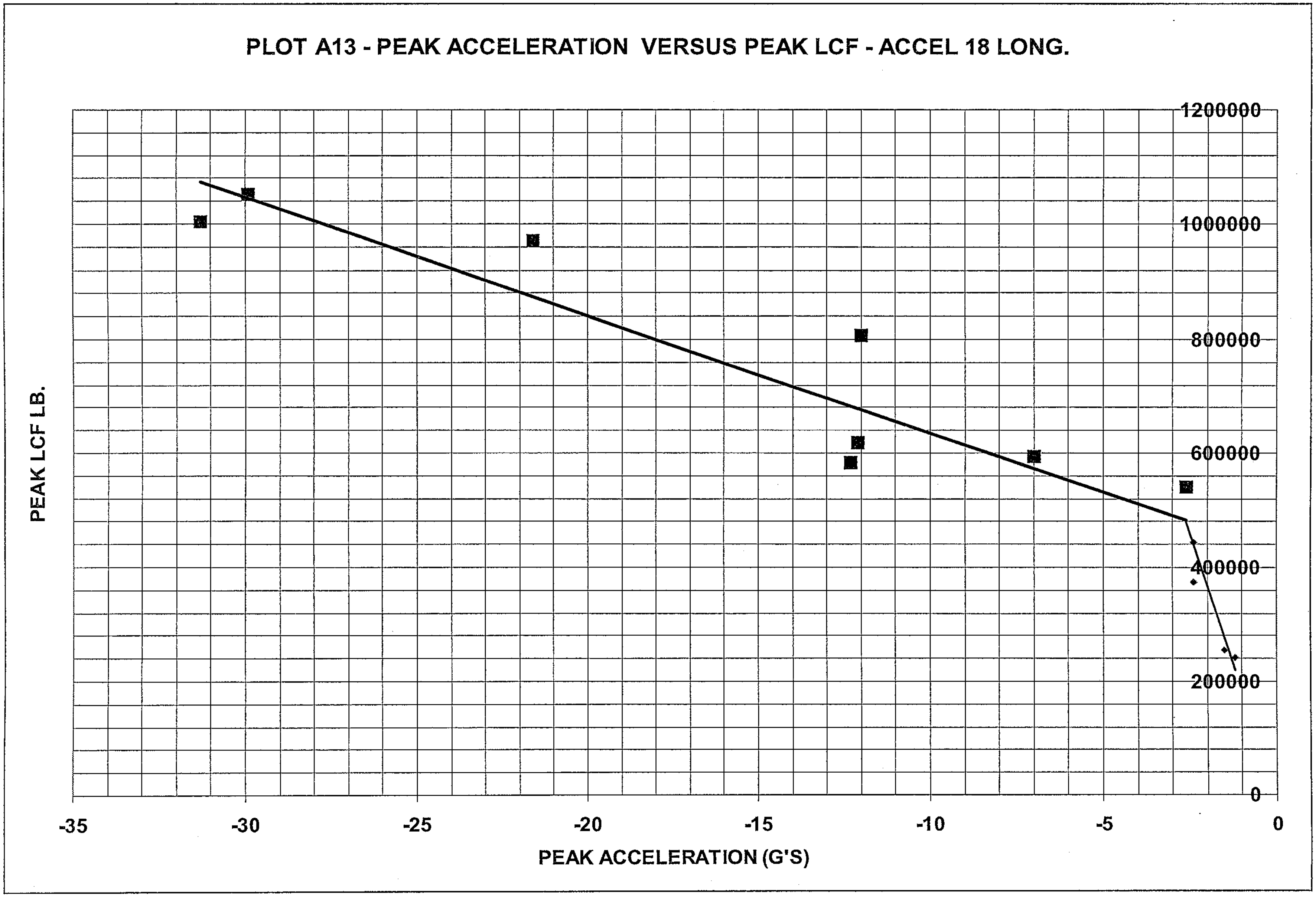


PLOT A12 AVERAGE STRAIN FROM GAGES 19 & 20 VERSUS PEAK LCF
ALL LOADED IMPACTS

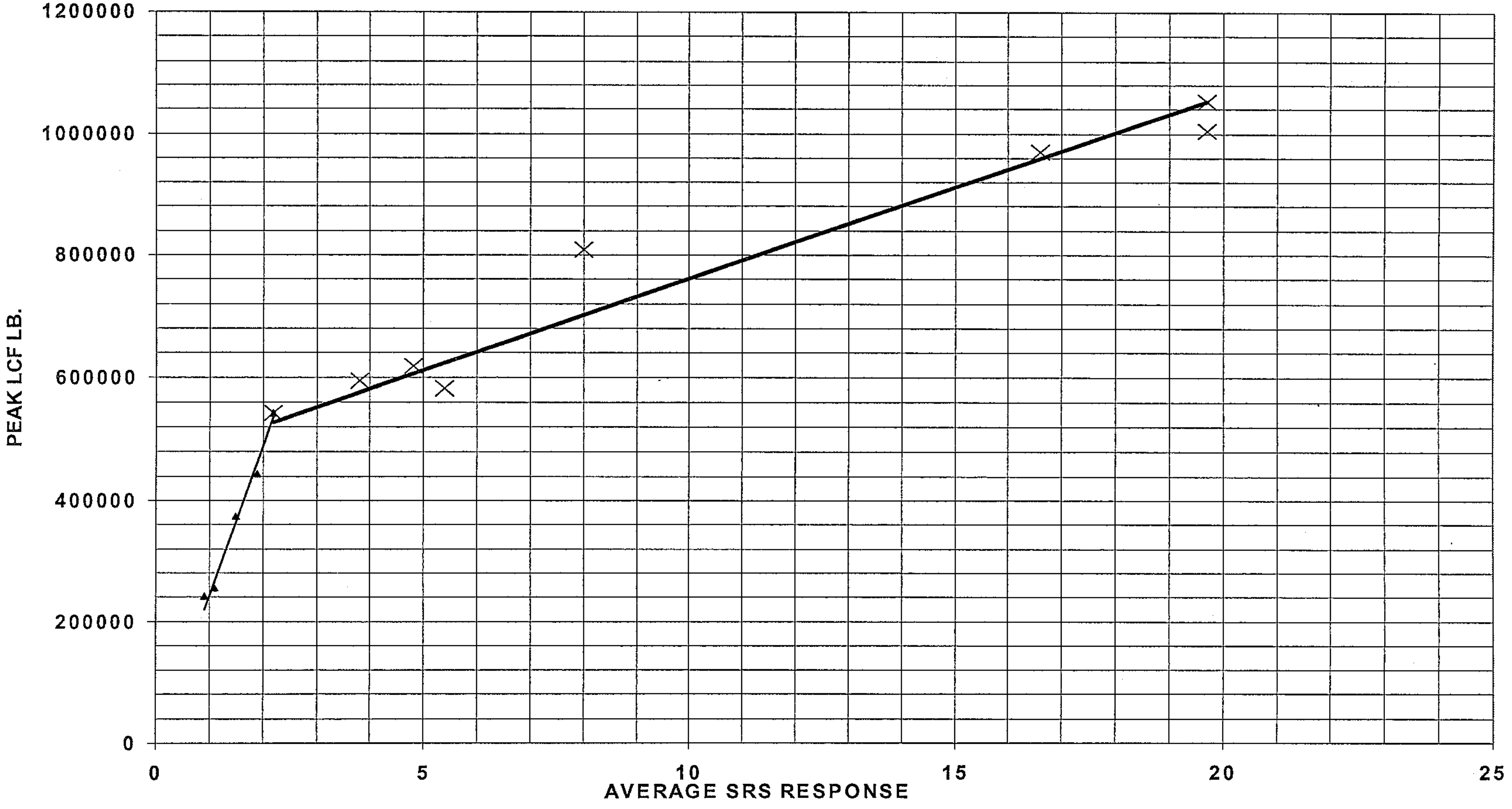



PLOT A13 AVERAGE STRAIN FROM GAGES 19 & 20 VERSUS PEAK LCF
ALL IMPACTS
PEAK LCF (KLB)
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
-1600.0
-1400.0
-1200.0
-1000.0
-800.0
-600.0
-400.0
-200.0
0.0
PEAK STRAIN (MICROSTRAIN)
◇ LOADED IMPACTS
■ UNLOADED IMPACTS

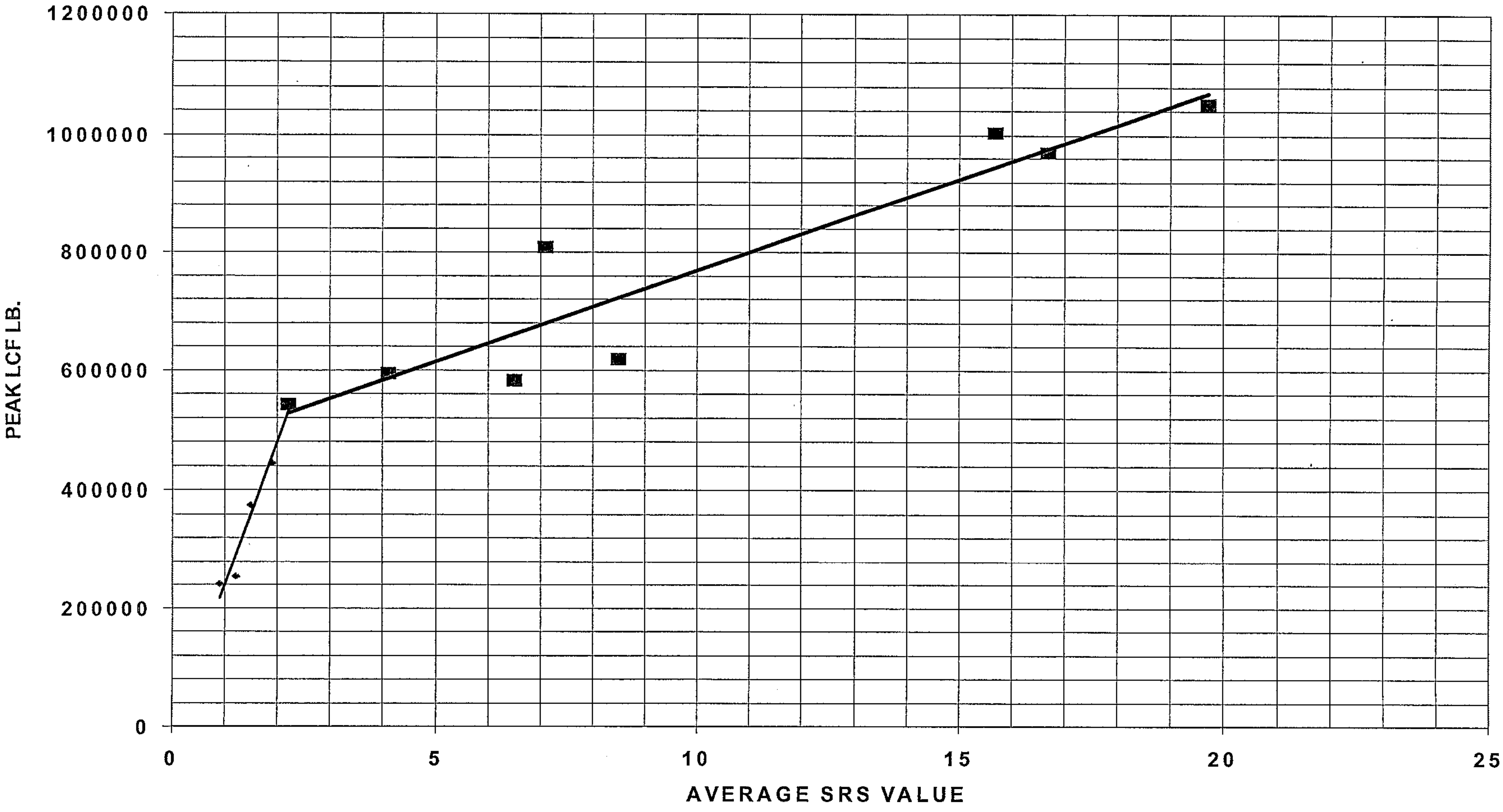

PLOT A12 - PEAK ACCELERATION VERSUS PEAK LCF - ACCEL 6 LONG.
PEAK LCF LB.
1400000
1200000
1000000
800000
600000
400000
200000
0
-50
-45
-40
-35
-30
-25
-20
-15
-10
-5
0
PEAK ACCELERATION (G'S)


PLOT A13 - PEAK ACCELERATION VERSUS PEAK LCF - ACCEL 18 LONG.
1200000
1000000
800000
600000
400000
200000
0
PEAK LCF LB.
-35
-30
-25
-20
-15
-10
-5
0
PEAK ACCELERATION (G'S)

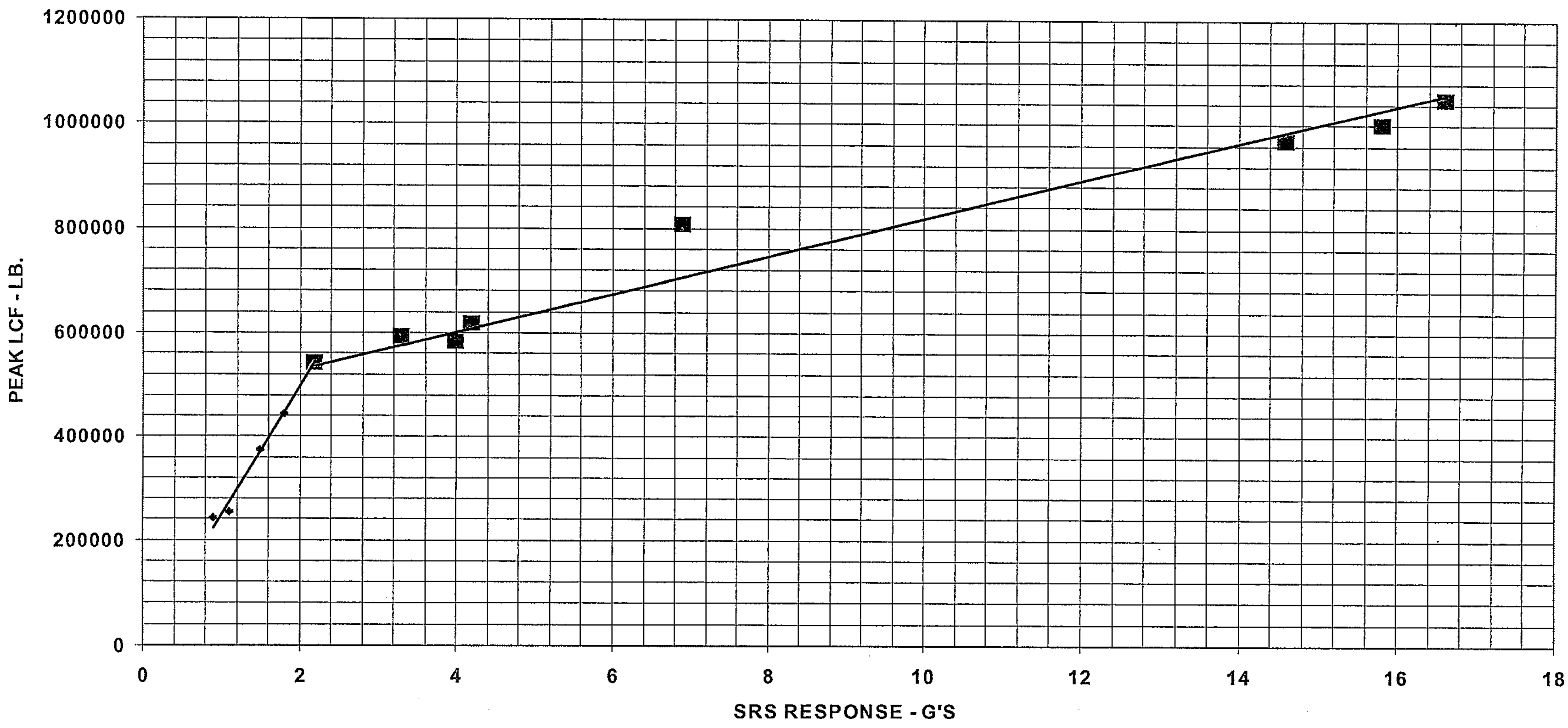
PLOT A14 - AVERAGE SRS RESPONSE, 10 - 100.8 HZ VS PEAK LCF
ACCEL. 6 LONGITUDINAL

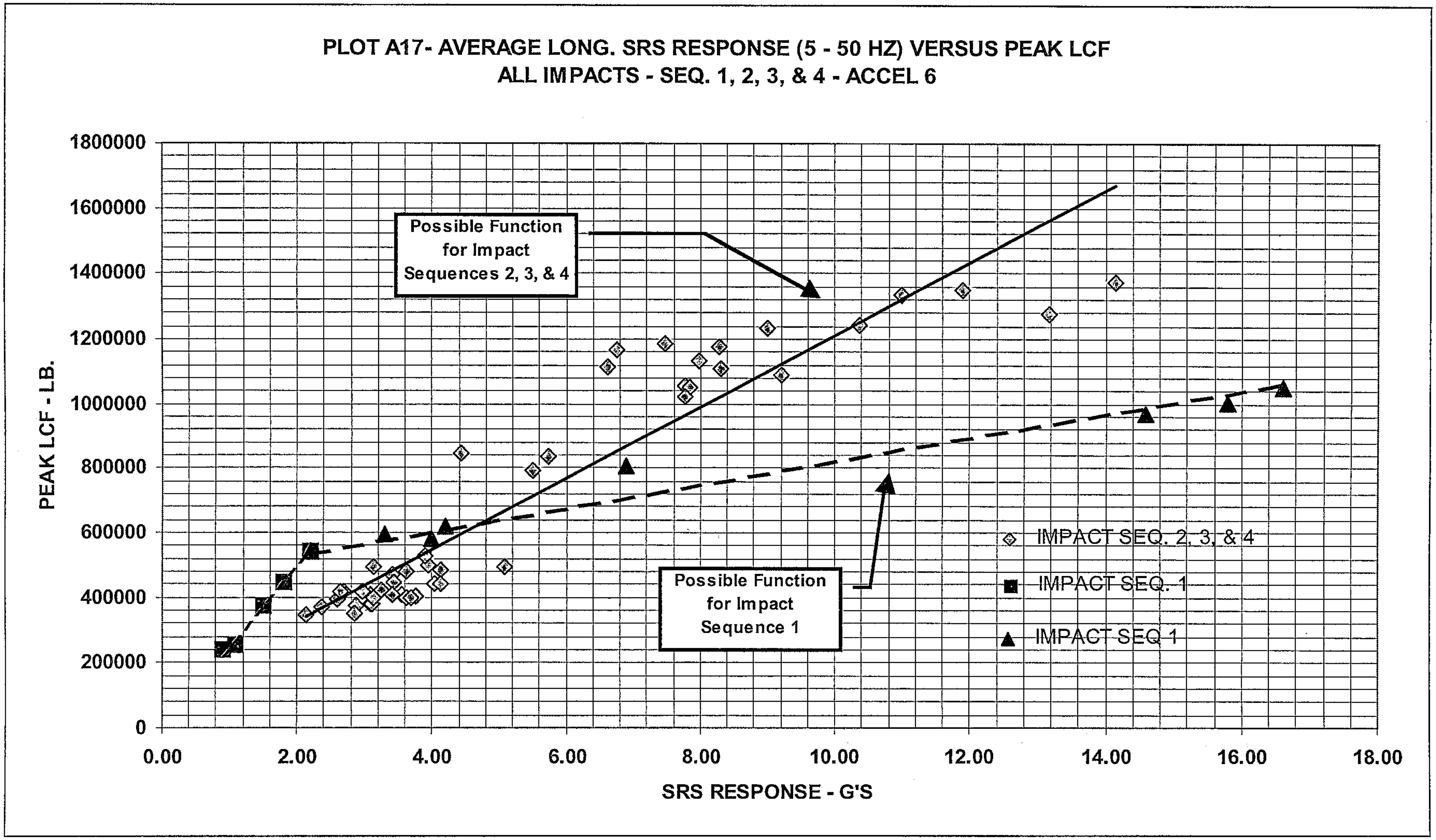


PLOT A15 - AVERAGE SRS RESPONSE, 10 -100.8 HZ VS PEAK LCF - ACCEL 18 LONG.

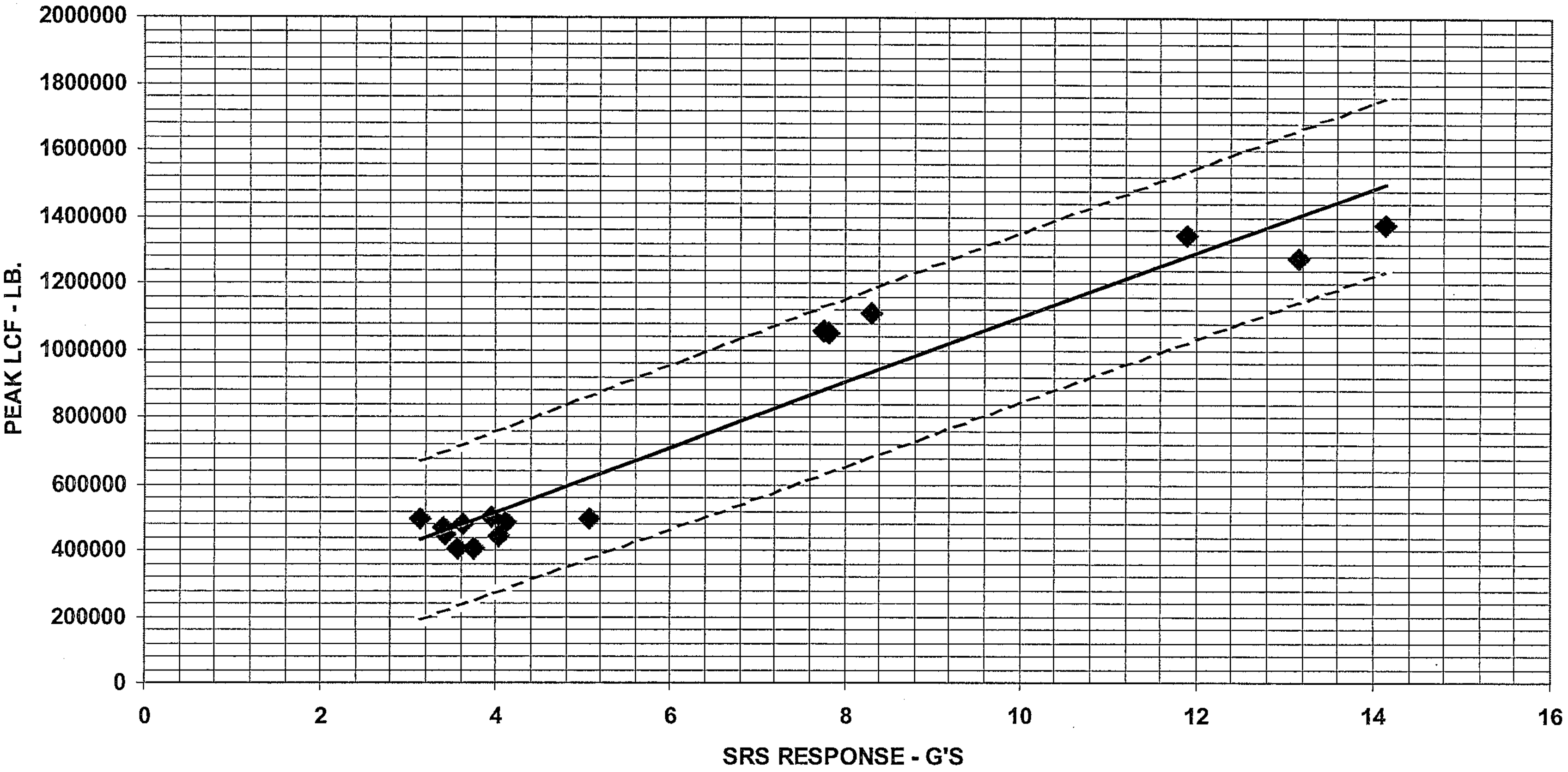


PLOT A16 - AVERAGE LONGITUDINAL SRS RESPONSE (5 - 50 HZ) VERSUS PEAK LCF
ACCEL. 6, IMPACT SEQ, 1

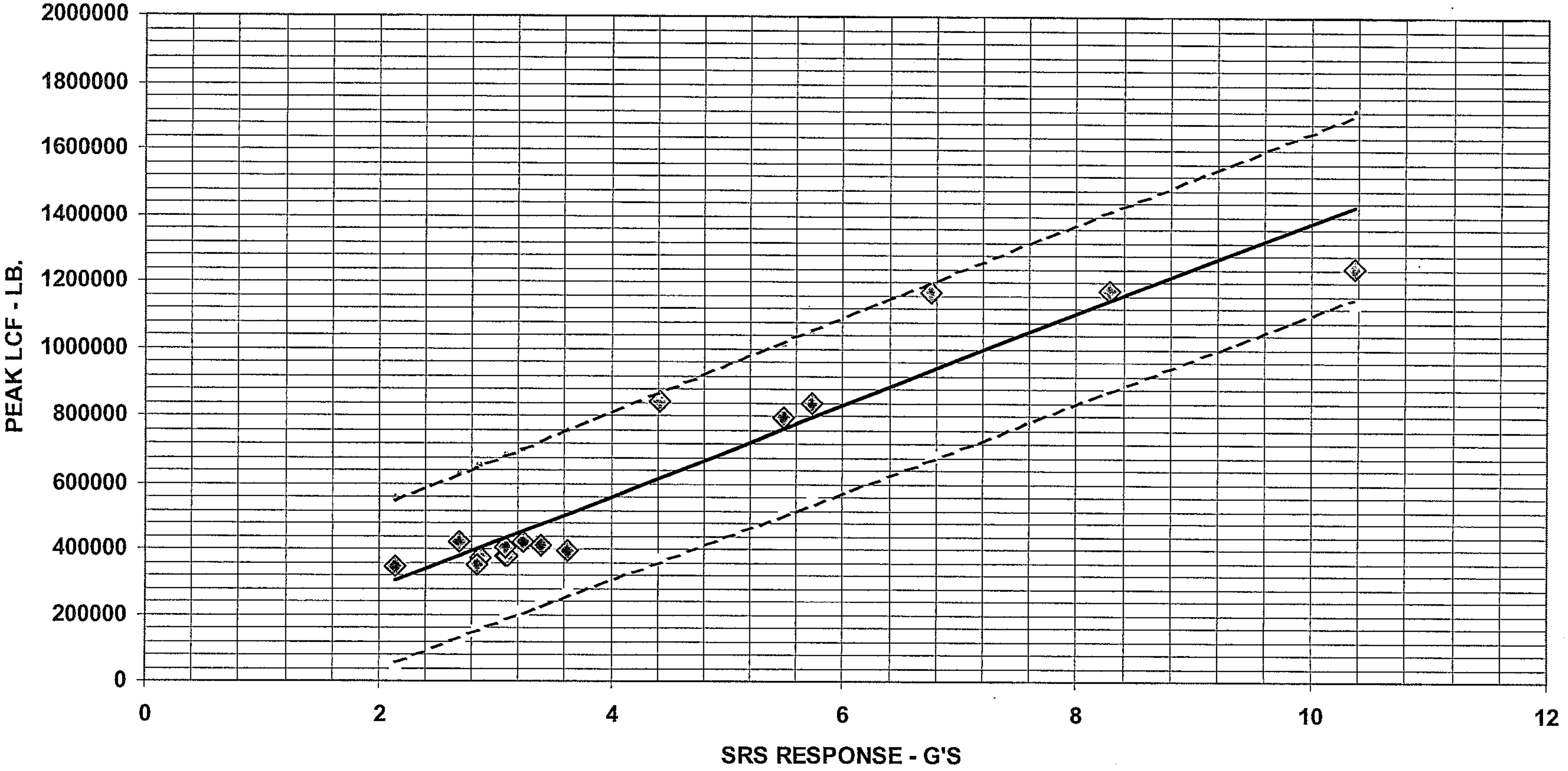


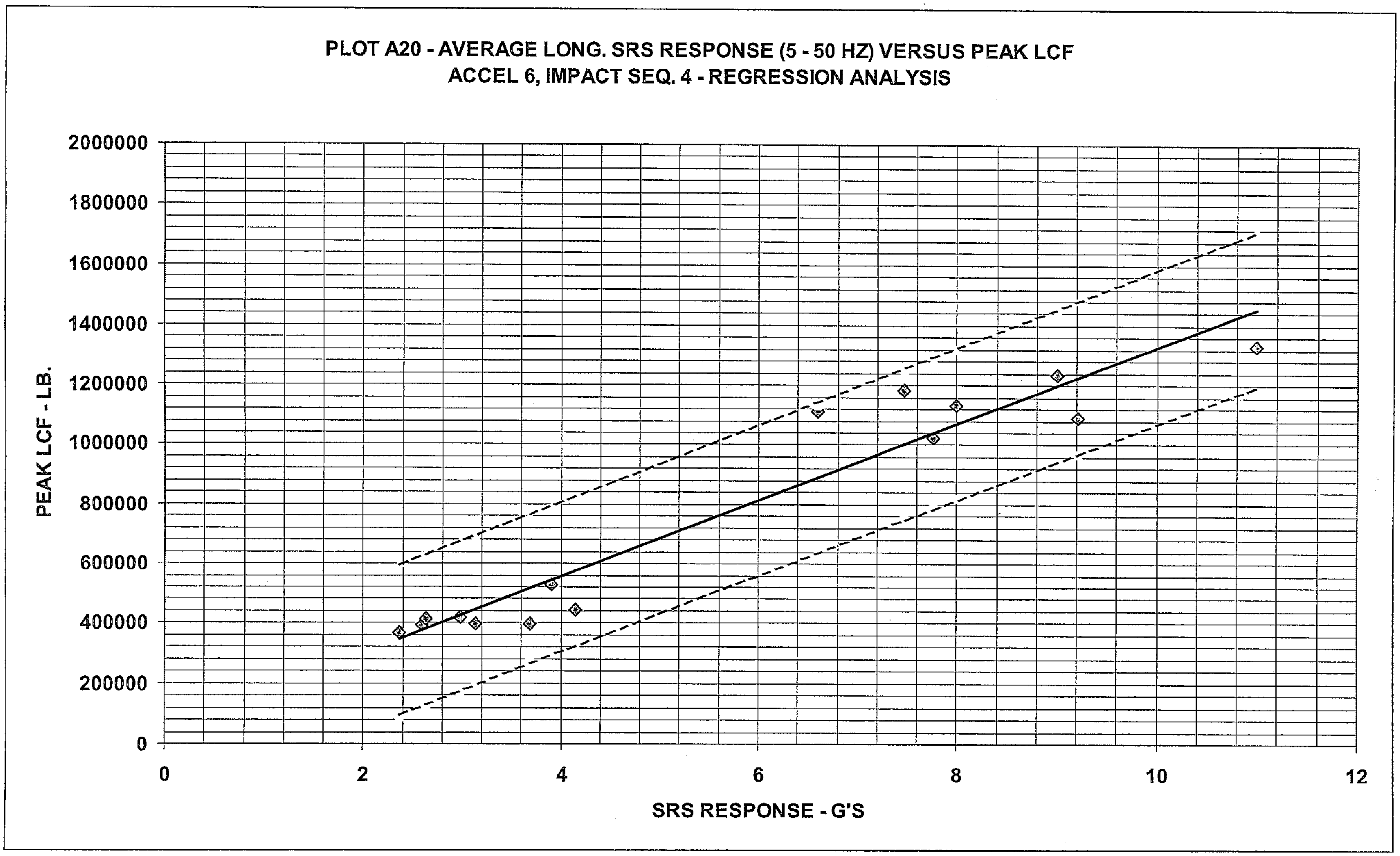

PLOT A17- AVERAGE LONG. SRS RESPONSE (5 - 50 HZ) VERSUS PEAK LCF
ALL IMPACTS - SEQ. 1, 2, 3, & 4 - ACCEL 6
PEAK LCF - LB.
1800000
1600000
1400000
1200000
1000000
800000
600000
400000
200000
0
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
SRS RESPONSE - G'S
Possible Function for Impact Sequences 2, 3, & 4
Possible Function for Impact Sequence 1
◇ IMPACT SEQ. 2, 3, & 4
■ IMPACT SEQ. 1
▲ IMPACT SEQ 1

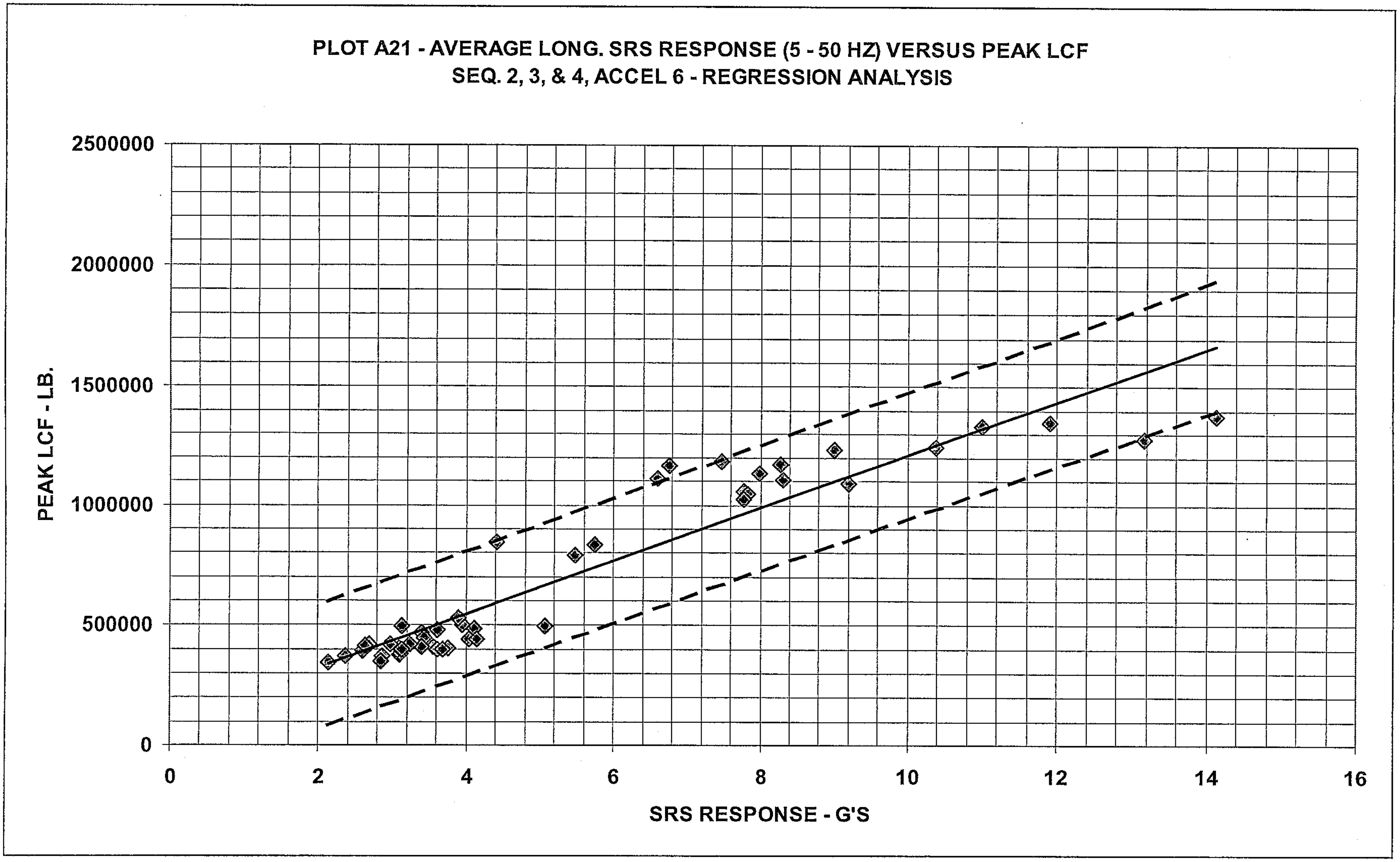
PLOT A18 - AVERAGE LONG. SRS RESPONSE (5 -50 HZ) VERSUS PEAK LCF ACCEL 6, IMPACT SEQ. 2 - REGRESSION ANALYSIS

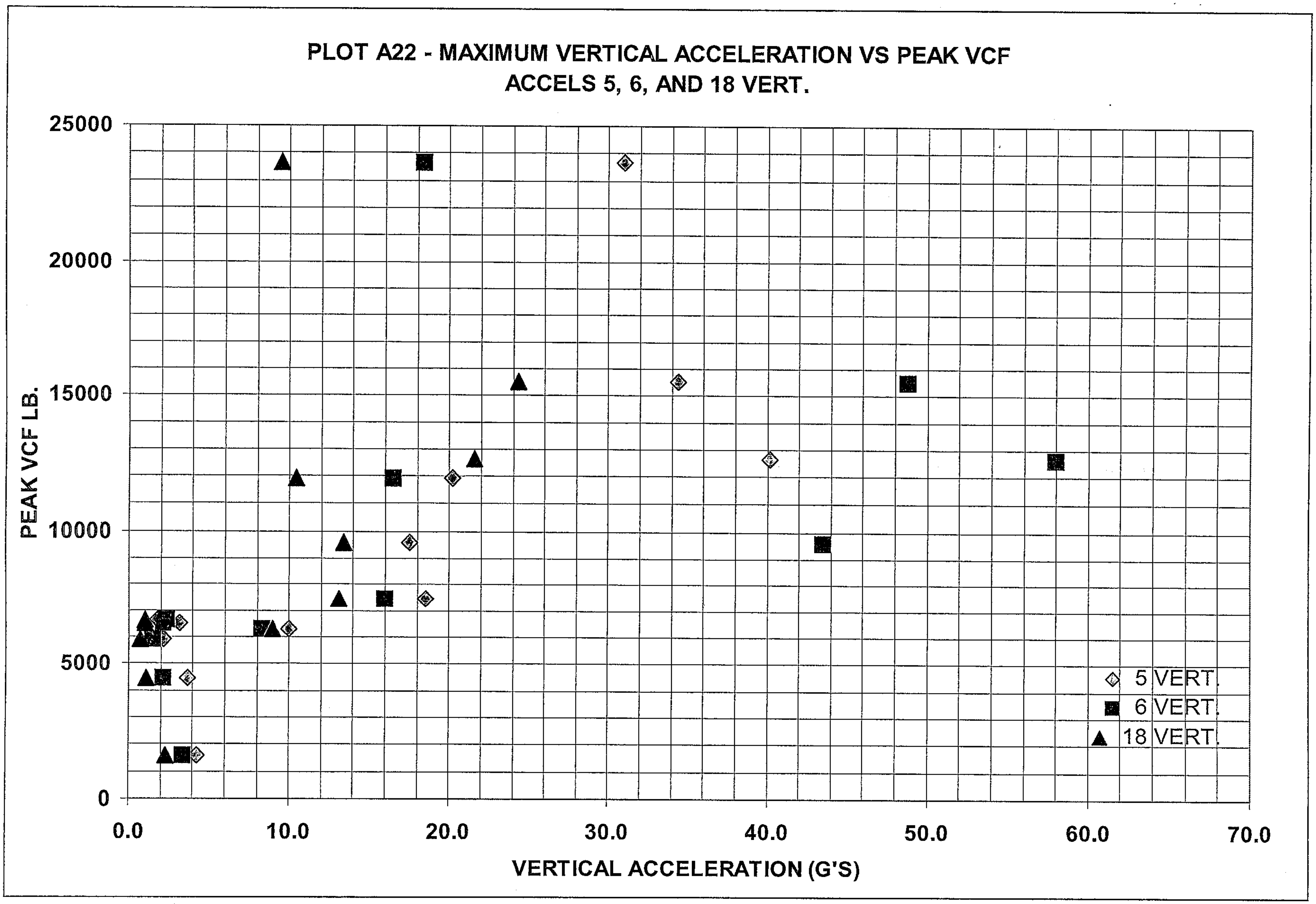


PLOT A19 - AVERAGE LONG. SRS RESPONSE (5 - 50 HZ) VERSUS PEAK LCF ACCEL. 6, IMPACT SEQ. 3 - REGRESSION ANALYSIS

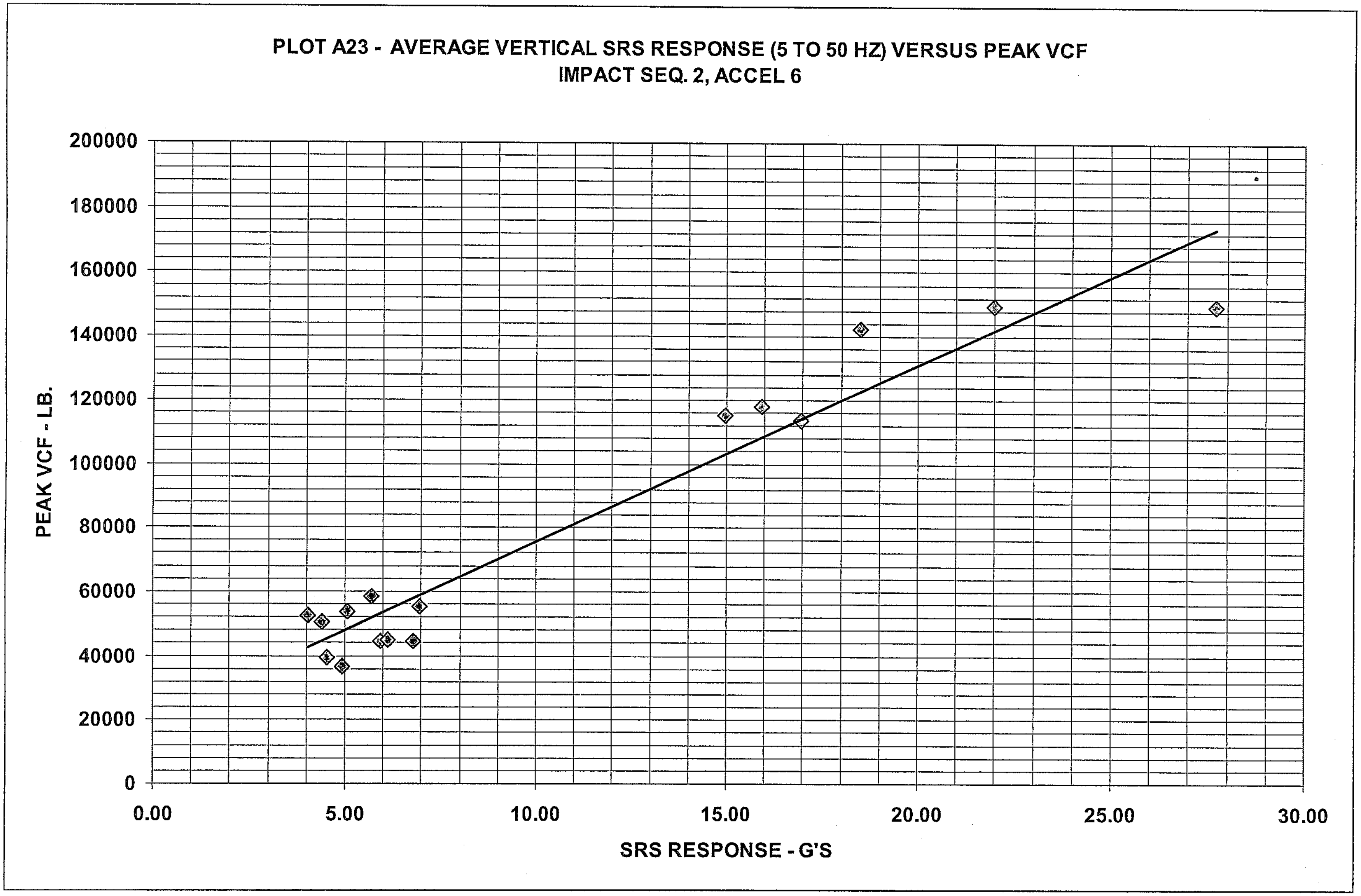



PLOT A20 - AVERAGE LONG. SRS RESPONSE (5 - 50 HZ) VERSUS PEAK LCF
ACCEL 6, IMPACT SEQ. 4 - REGRESSION ANALYSIS
2000000
1800000
1600000
1400000
1200000
1000000
800000
600000
400000
200000
0
PEAK LCF - LB.
0
2
4
6
8
10
12
SRS RESPONSE - G'S

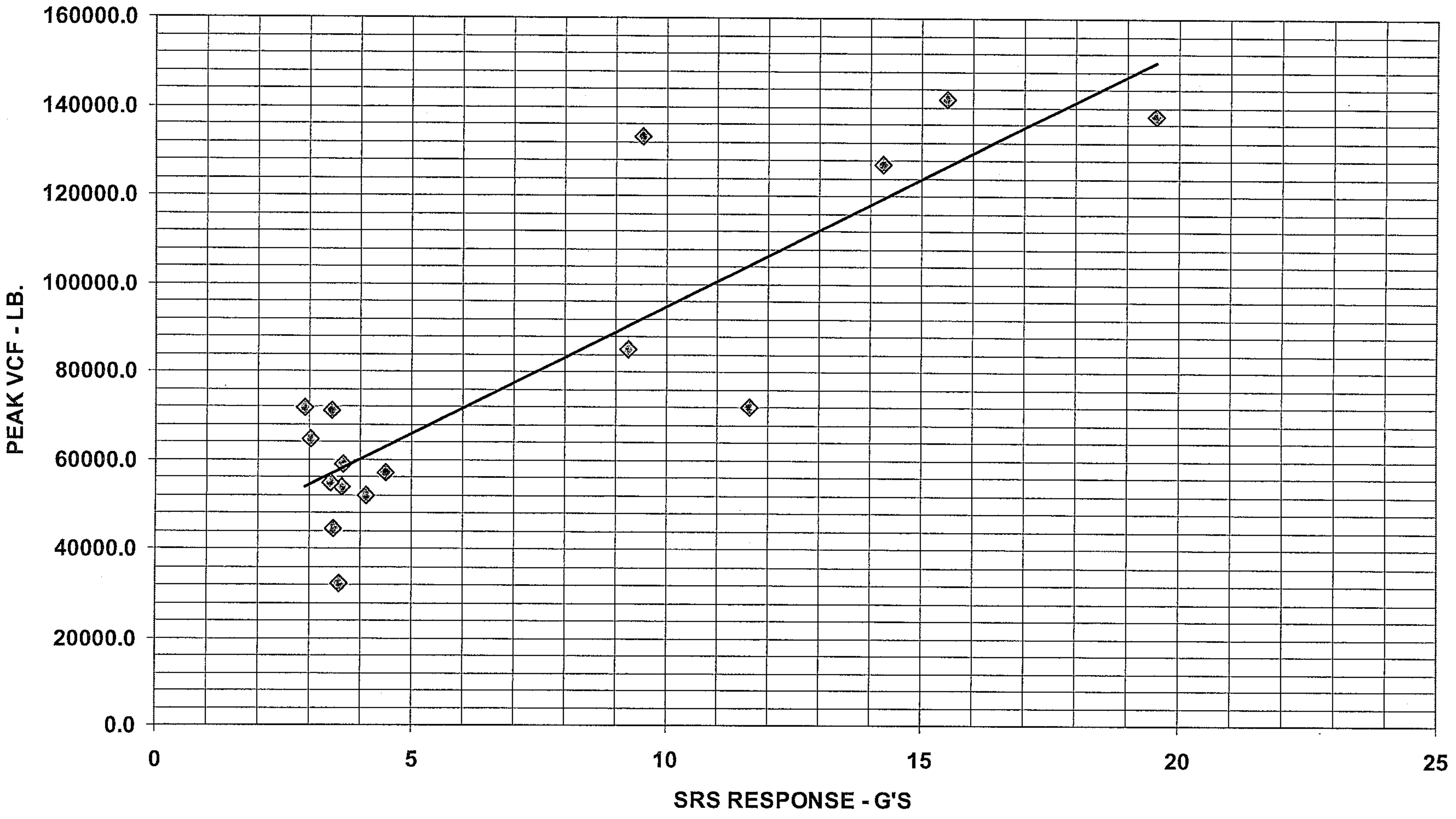

PLOT A21 - AVERAGE LONG. SRS RESPONSE (5 - 50 HZ) VERSUS PEAK LCF
SEQ. 2, 3, & 4, ACCEL 6 - REGRESSION ANALYSIS
PEAK LCF - LB.
2500000
2000000
1500000
1000000
500000
0
0
2
4
6
8
10
12
14
16
SRS RESPONSE - G'S

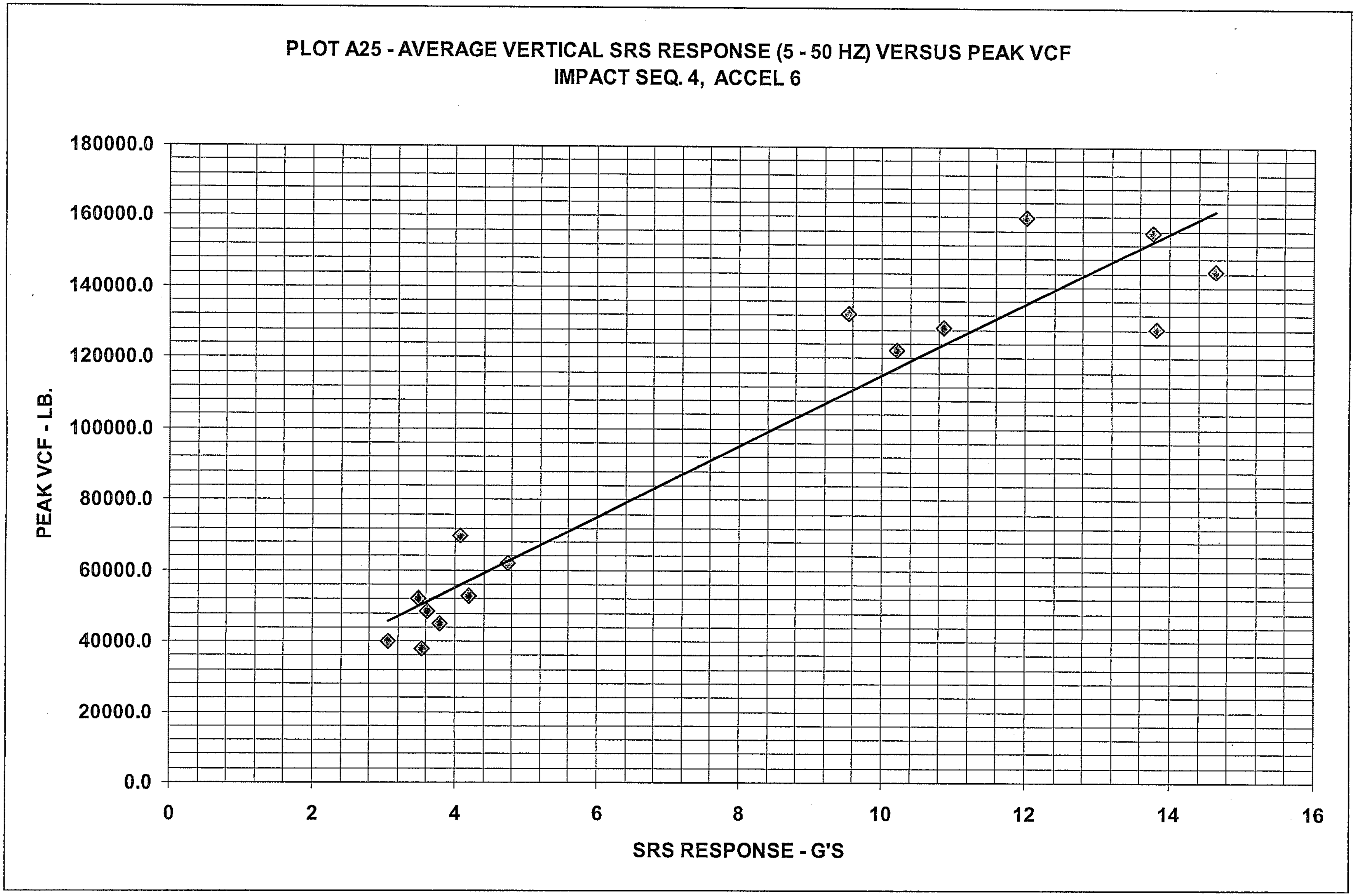


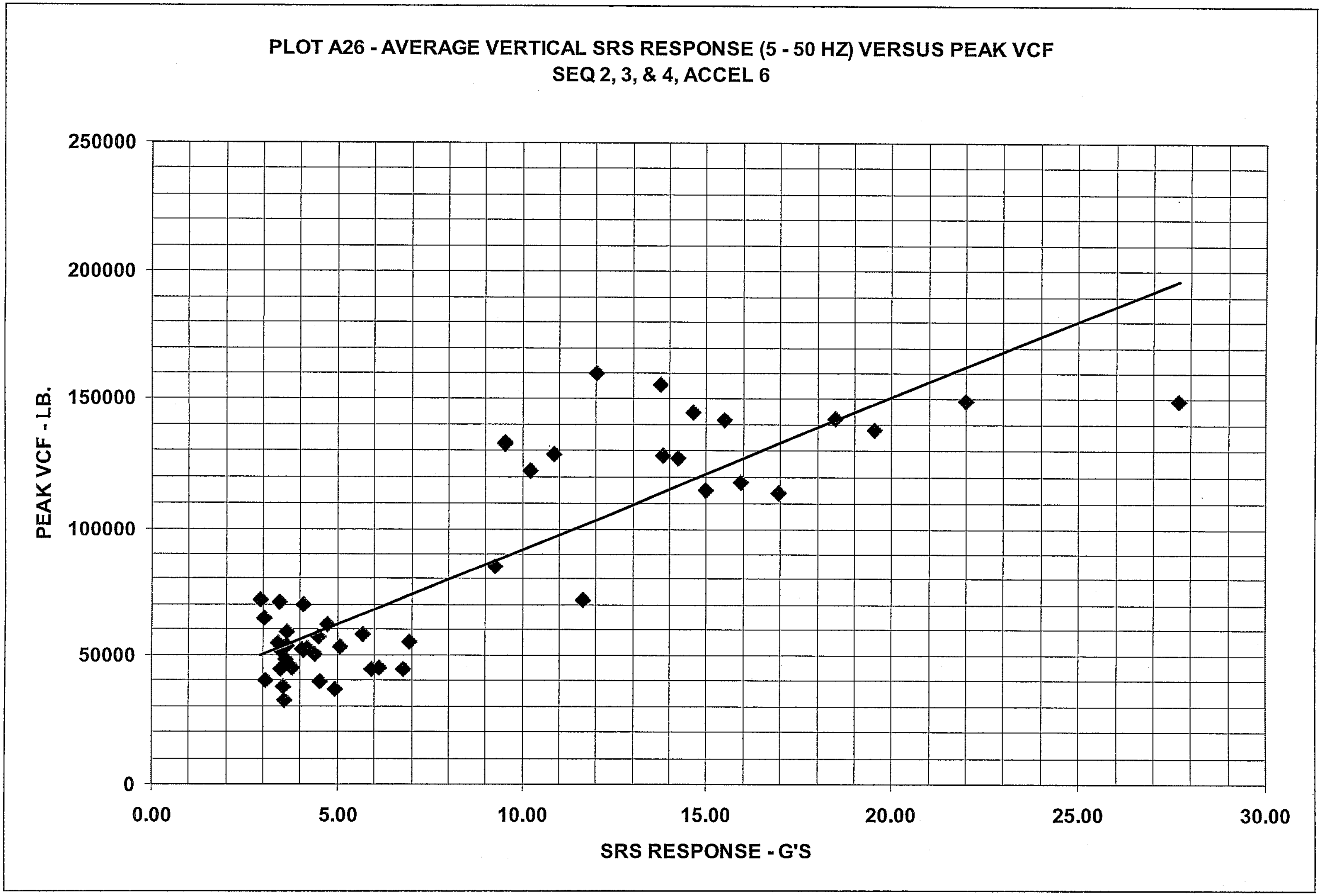
PLOT A22 - MAXIMUM VERTICAL ACCELERATION VS PEAK VCF
ACCELS 5, 6, AND 18 VERT.


PLOT A23 - AVERAGE VERTICAL SRS RESPONSE (5 TO 50 HZ) VERSUS PEAK VCF
IMPACT SEQ. 2, ACCEL 6
PEAK VCF - LB.
200000
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
0.00
5.00
10.00
15.00
20.00
25.00
30.00
SRS RESPONSE - G'S

PLOT A24 - AVERAGE VERTICAL SRS RESPONSE (5 - 50 HZ) VERSUS PEAK VCF
IMPACT SEQ. 3, ACCEL 6

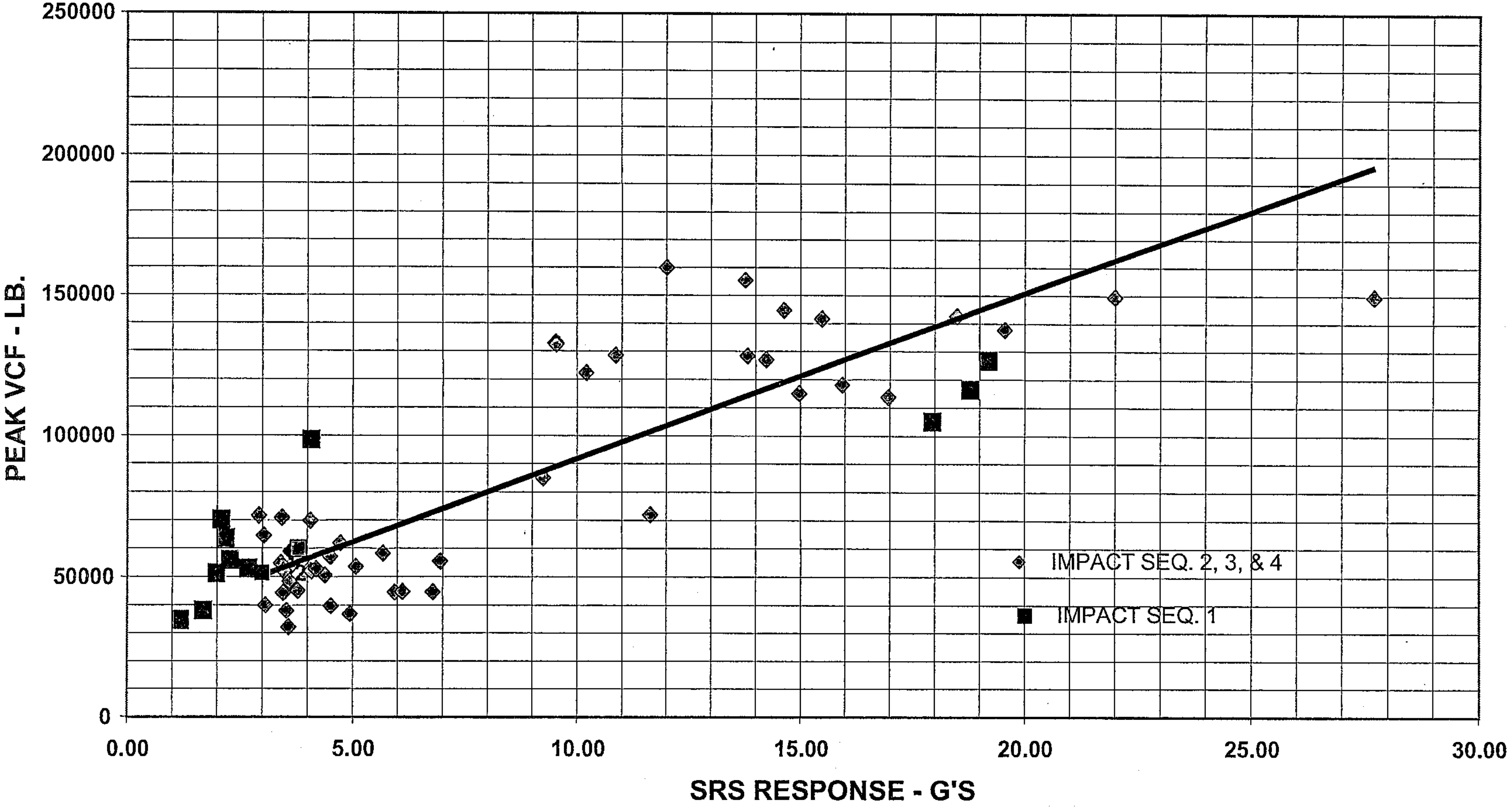



PLOT A25 - AVERAGE VERTICAL SRS RESPONSE (5 - 50 HZ) VERSUS PEAK VCF
IMPACT SEQ. 4, ACCEL 6
PEAK VCF - LB.
180000.0
160000.0
140000.0
120000.0
100000.0
80000.0
60000.0
40000.0
20000.0
0.0
0
2
4
6
8
10
12
14
16
SRS RESPONSE - G'S

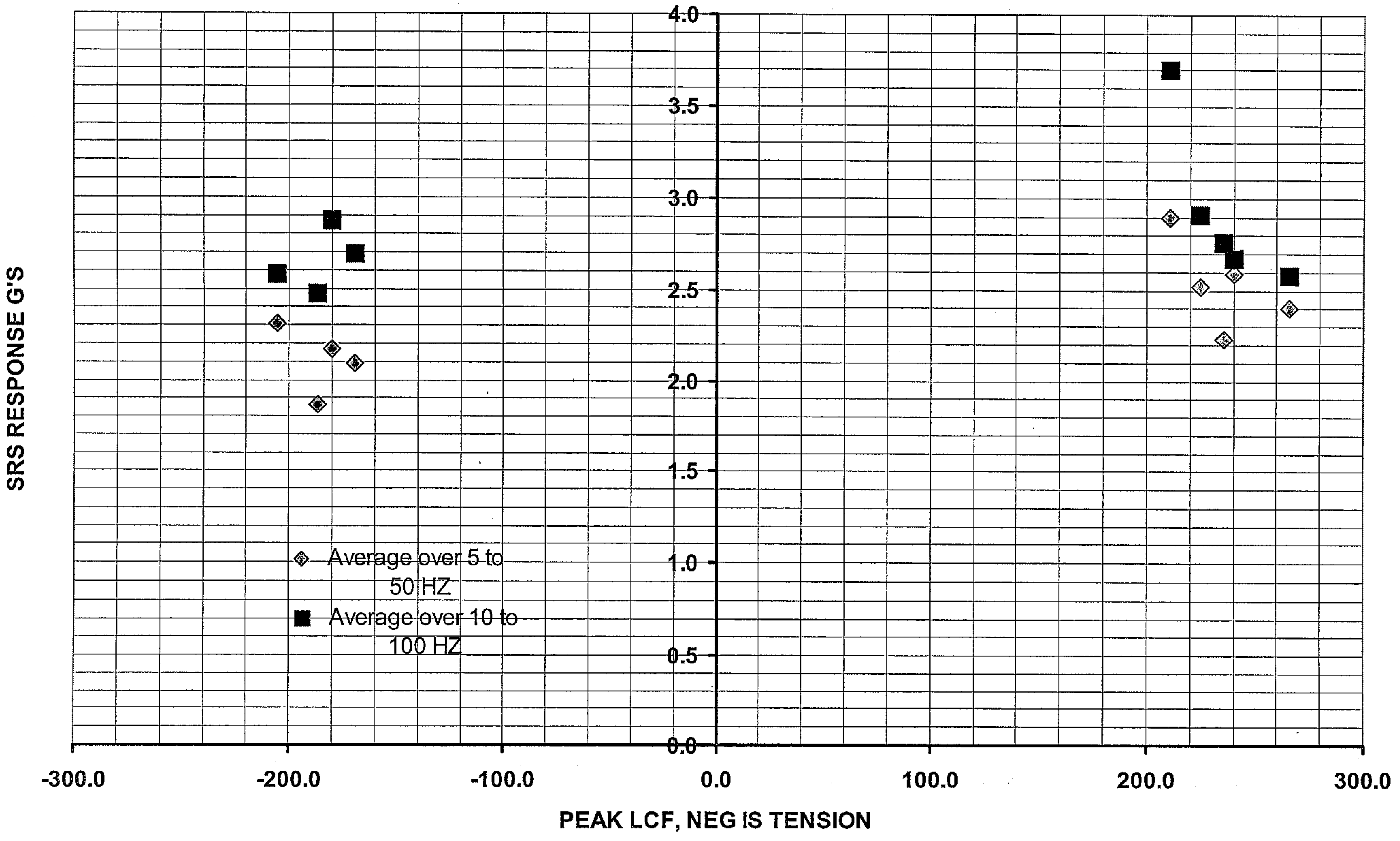


PLOT A26 - AVERAGE VERTICAL SRS RESPONSE (5 - 50 HZ) VERSUS PEAK VCF
SEQ 2, 3, & 4, ACCEL 6

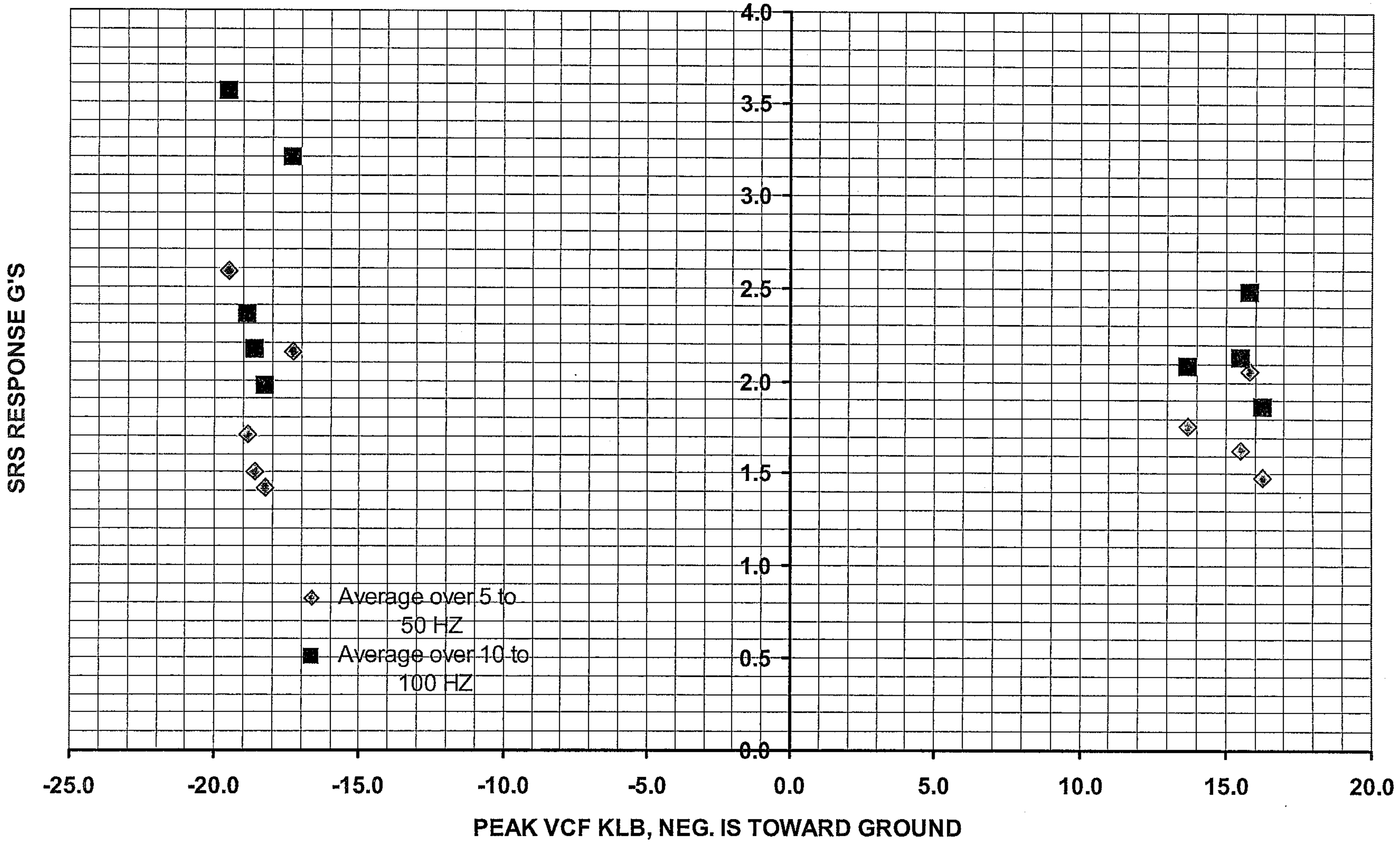
PLOT A27 - AVERAGE VERTICAL SRS RESPONSE (5 - 50 HZ) VERSUS PEAK VCF
SEQ 1, 2, 3, & 4, ACCEL 6



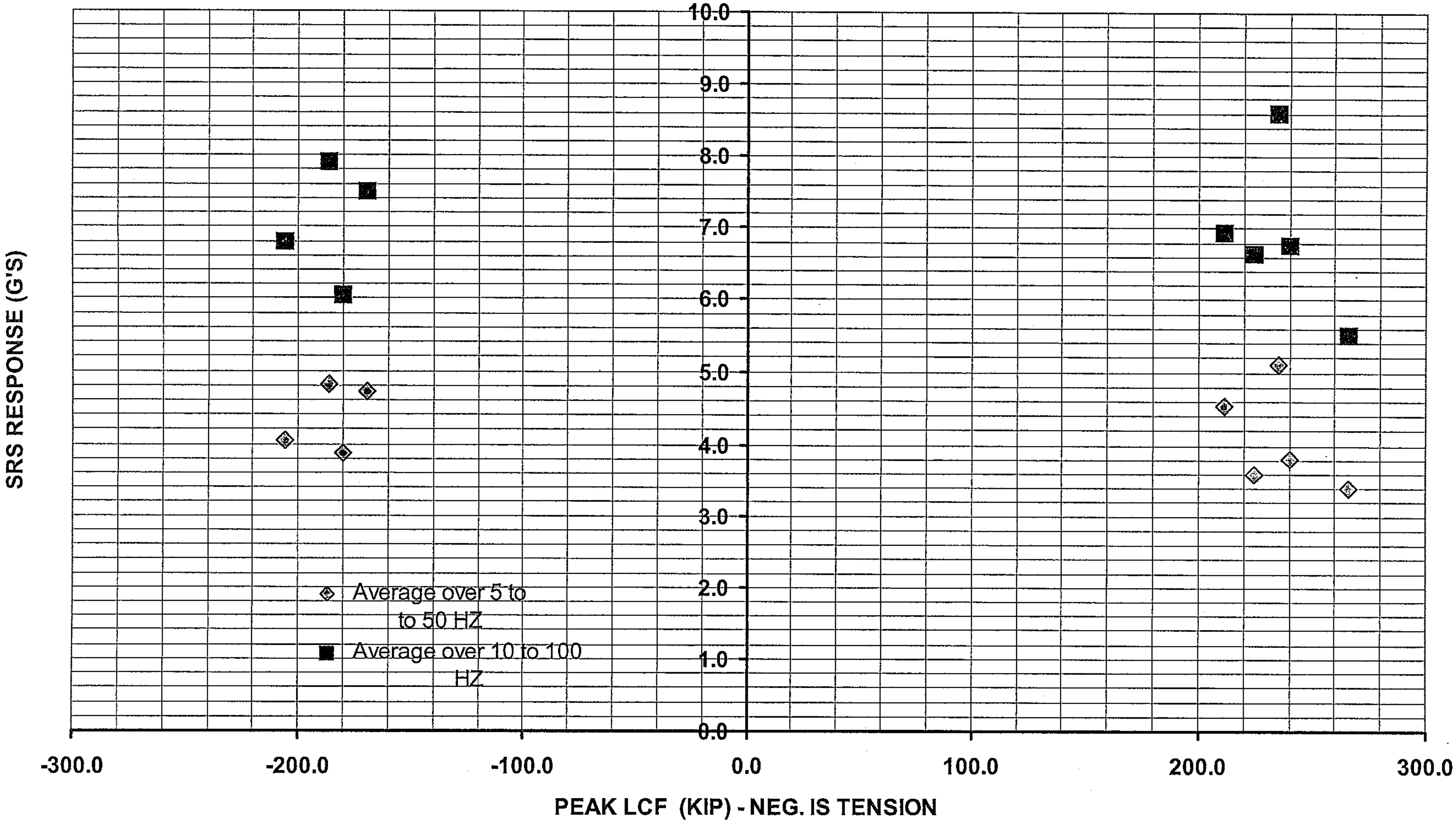
PLOT A30 SRS RESPONSE VERSUS PEAK LCF, ACCEL 18 LONG
APRIL 14/15



PLOT A31 SRS RESPONSE VERSUS PEAK VCF, ACCEL 18 VERT
APRIL 14/15



PLOT A32 SRS RESPONS VERSUS PEAK LCF, ACCEL 6 LONG., APRIL 14-15



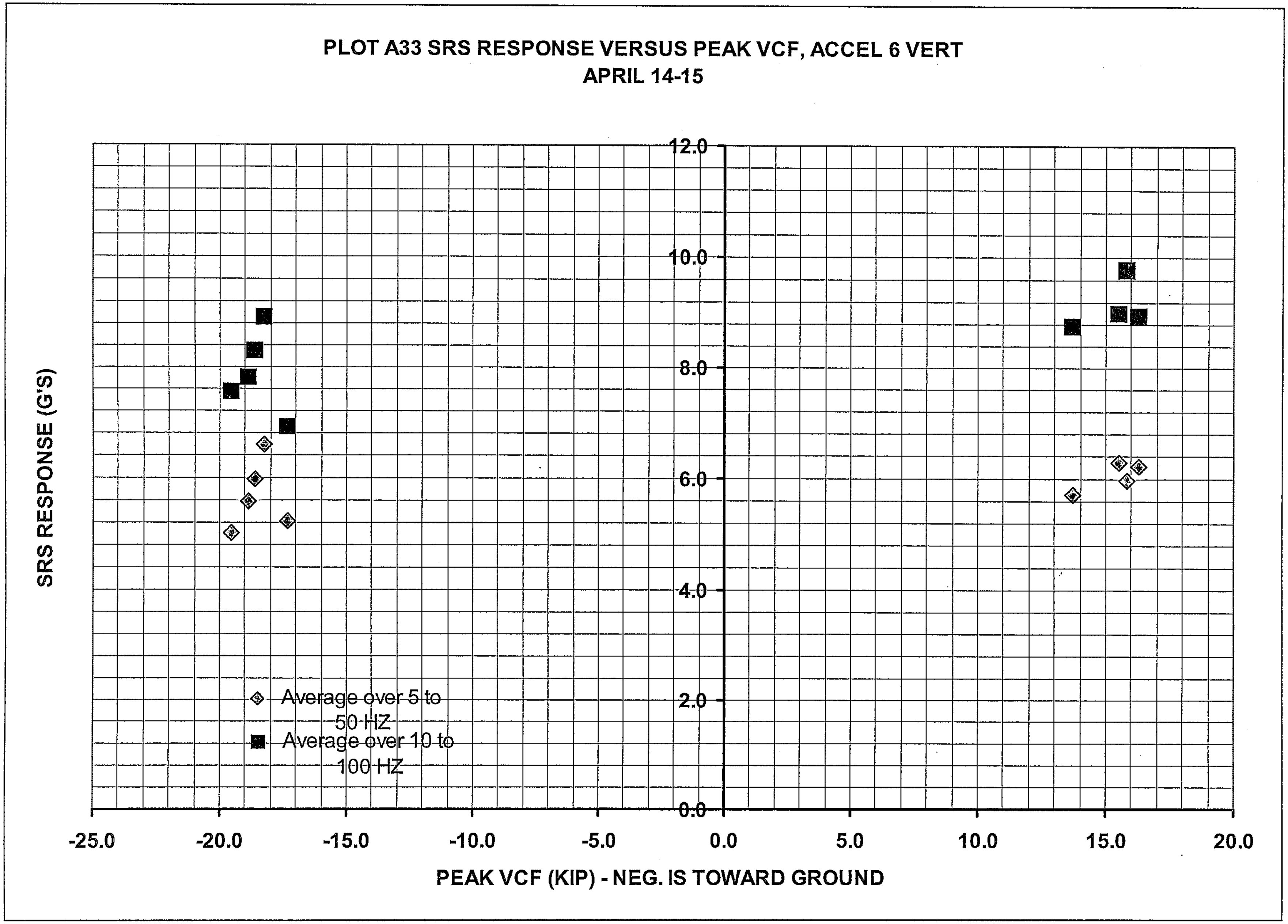

PLOT A33 SRS RESPONSE VERSUS PEAK VCF, ACCEL 6 VERT
APRIL 14-15
SRS RESPONSE (G'S)
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-25.0
-20.0
-15.0
-10.0
-5.0
0.0
5.0
10.0
15.0
20.0
PEAK VCF (KIP) - NEG. IS TOWARD GROUND
◇ Average over 5 to 50 HZ
■ Average over 10 to 100 HZ

TABLE A1

SUMMARY OF TCOE FAST TEST DATA

DATE	CAR LOCATION	TRAIN DIRECTION	TOTAL NO. OF CARS	SAMPLE RATE	DATA USEABLE	MAX LCF	MIN LCF	MAX VCF	MIN VCF
3/23/03 - 3/24/03	6th from front	ccw - bypass	76	4096	no				
3/24/03 - 3/25/03	6th from front	ccw - bypass	75	4096	no				
3/25/03 - 3/26/03	6th from end	cw - bypass	76	4096	yes	222.6	-152.4	22.5	-10.5
3/26/03 - 3/27/03	6th from end	cw - bypass	76	4096	yes	203.2	186.9	41.6	-11.4
3/30/03 - 3/31/03	6th from end	ccw - main loop	76	4096	poor	166.1	-236.8	21.1	-31.2
3/31/03 - 4/01/03	6th from end	ccw - main loop	76	4096	no				
4/7/03 - 4/8/03	4th from front	ccw - bypass	78	4096	yes	1	-185.3	21	-8.2
4/13/03 - 4/14/03	6th from end	ccw - bypass	77	4096	no				
4/14/03 - 4/15/03	6th from end	ccw - main loop	76	2048	yes	263.5	-219.2	20.5	-23.8
4/15/03 - 4/16/03	8th from front	cw - main loop	77	2048	yes	177	-253.6	41.2	-13.6
4/16/03 - 4/17/03	8th from front	cw - main loop	77	2048	yes	-19.9	-173.3	19.4	-6.2
4/20/03 - 4/21/03	6th from end	ccw - main loop	76	2048	yes	164.5	-214.7	27	-17.4
4/21/03 - 4/22/03	6th from end	ccw - main loop	75	4096	yes	193.8	-269.9	31.8	-19.5

TABLE A2

PEAK & SRS ACCELERATION RESPONSE VERSUS PEAK COUPLER FORCE April 14/15
ACCELEROMETERS 18L AND 18V

FILE NAME	PEAK LCF KLB	PEAK VCF KLB	PEAK POS. LAT ACCEL	PEAK NEG. LAT ACCEL	PEAK POS. VERT ACCEL	PEAK NEG. VERT ACCEL	LAT SRS 5-50HZ	LAT SRS 10-100HZ	VERT SRS 5-50HZ	VER SRS 10-100H
			18L	18L	18V	18V	18L	18L	18V	18V
414225311	211.1	-17.3	4.0	-4.8	6.0	-4.1	2.9	3.7	2.2	3.2
414225405	-169.3	13.7	4.0	-3.1	5.2	-3.4	2.1	2.7	1.8	2.1
414225805	-186.5	15.8	2.6	-4.9	3.9	-4.4	1.9	2.5	2.1	2.5
414230528	235.5	-18.3	4.2	-3.3	4.3	-2.5	2.2	2.8	1.4	2.0
414230614	-180.1	15.5	3.1	-5.2	3.9	-2.7	2.2	2.9	1.6	2.1
414230921	224.7	-19.5	4.5	-3.9	2.6	-3.4	2.5	2.9	2.6	3.6
414232248	-205.7	16.3	3.0	-2.5	3.0	-2.3	2.3	2.6	1.5	1.9
414232513	240.4	-18.6	6.5	-4.4	4.5	-4.4	2.6	2.7	1.5	2.2
414235259	265.8	-18.9	4.6	-3.7	3.9	-3.4	2.4	2.6	1.7	2.4

TABLE A3

PEAK & SRS ACCELERATION RESPONSE VERSUS PEAK COUPLER FORCE April 14/15

ACCELEROMETERS 6L AND 6V

FILE NAME	PEAK LCF KLB	PEAK VCF KLB	PEAK POS. LAT ACCEL 6L	PEAK NEG. LAT ACCEL 6L	PEAK POS. VERT ACCEL 6V	PEAK NEG. VERT ACCEL 6V	LAT SRS 5-50HZ 6L	LAT SRS 10-100HZ 6L	VERT SRS 5-50HZ 6V	VERT SRS 10-100HZ 6V
414225311	211.1	-17.3	2.2	-6.8	3.2	-7.0	4.5	6.9	5.2	6.9
414225405	-169.3	13.7	2.4	-7.5	3.2	-8.5	4.7	7.5	5.7	8.8
414225805	-186.5	15.8	4.7	-9.1	7.3	-8.9	4.8	7.9	6.0	9.8
414230528	235.5	-18.3	2.9	-9.9	3.8	-7.8	5.1	8.6	6.6	8.9
414230614	-180.1	15.5	3.2	-6.5	3.6	-7.2	3.9	6.1	6.3	9.0
414230921	224.7	-19.5	5.2	-6.8	6.2	-7.7	3.6	6.7	5.0	7.6
414232248	-205.7	16.3	2.6	-6.9	2.7	-7.3	4.1	6.8	6.2	9.0
414232513	240.4	-18.6	2.7	-7.3	3.3	-7.6	3.8	6.8	6.0	8.3
414235259	265.8	-18.9	3.0	-5.8	2.8	-5.6	3.4	5.5	5.6	7.8