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DYNAMIC ANALYSIS TO ESTABLISH NORMAL SHOCK AND VIBRATION OF RADIOACTIVE MATERIAL SHIPPING PACKAGES

QUARTERLY PROGRESS REPORT
OCTOBER 1, 1979 - DECEMBER 31, 1979

Hanford Engineering Development Laboratory

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ABSTRACT

A computer program MARCS (Modal Analysis of a Rail Car-Cask System) was written to perform a modal analysis on the systems represented by the CARDT and CARDS (Cask Rail Car Dynamic Simulator) models. Parameters generated by MARCS will be used to generate frequency response spectra. A preliminary evaluation of the performance of CARDS was made by comparing calculated results with response variables measured during Test 3 of the series of tests conducted at the Savannah River Laboratories, Aiken, SC.

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SUMMARY OF PROGRESS

2. DATA COLLECTION AND REDUCTION

A meeting to discuss the quality of the data obtained from the rail car impact tests conducted at the Savannah River Laboratories (SRL), Aiken, SC, in July and August of 1978 was held at the Sandia Laboratories in Albuquerque, New Mexico on December 4, 1979. It was learned that data on the vertical acceleration of points on the rail car, and the horizontal acceleration of the trucks, were lost due to "over-ranging" of the accelerometers used. Good measurements of the horizontal accelerations of the rail car and cask, and the vertical accelerations of the cask, were obtained.

3. VALIDATE MODEL

A computer program MARCS (Modal Analysis of a Rail Car-Cask System) was written to supplement the cask-rail car dynamic models CARDT (Cask Rail Car Dynamic Simulator Test) and CARDS (Cask Rail Car Dynamic Simulator). The function of MARCS is to perform a modal analysis on vibrating systems, such as those represented by the CARDS and CARDT models, to determine parameters which may be used to generate frequency response spectra.

Partial tuning of the CARDS model has been carried out using variation of parameters and successive approximations to minimize Theil's multiple inequality coefficient. The first parameter varied and set was the time shift required to obtain the best fit when values of calculated and experimental response variables were superimposed. A time shift of 0.038 second was established.

A preliminary evaluation of the performance of the CARDS model was made by comparing calculated results with six response variables measured during Test 3 of the series conducted at SRL. Comparisons were made for two cases, one using measured coupler force as the excitation force, and one using calculated coupler force. A Theil's multiple inequality coefficient of 0.06 was obtained for the first case, and a value of 0.172 obtained for the second case (this coefficient is 0 at perfect agreement and 1 at the poorest agreement).

INTRODUCTION

This study was initiated in October 1977, as stated in previous progress reports. The objective of this study is to determine the extent to which the shocks and vibrations experienced by radioactive material shipping packages during normal transport conditions are influenced by or are sensitive to various structural parameters of the transport system (i.e., package, package supports, and vehicle). The purpose of this effort is to identify those parameters which significantly affect the normal shock and vibration environments so as to provide the basis for determining the forces transmitted to radioactive material packages. Determination of these forces will provide the input data necessary for a broad range of package-tiedown structural assessments.

Progress on this study from October 1, 1979 to December 31, 1979 will now be discussed.

PROGRESS TO DATE

This study is divided into six tasks as discussed in previous progress reports. Progress on each of these tasks will now be discussed.

1. DEVELOP DYNAMIC MODEL

There was little activity in this task during this reporting period. The bulk of the effort during this period was devoted to validation of the model by comparison of calculated results with results from Test 3 of the rail car coupling tests conducted at the Savannah River Laboratory (SRL) in July and August of 1978 (see Section 3, VALIDATE MODEL). These comparisons were quantified using Theil's inequality coefficients as figures of merit. In addition, methods for the comparison of frequency response spectra were examined for use as a complementary validation technique.

2. DATA COLLECTION AND REDUCTION

Tapes containing measured response data from the rail car humping tests conducted at SRL in July and August of 1978 were received from Sandia Laboratories. These tapes were processed for use on the UNIVAC and time plots produced. These tapes were provided by Sandia to replace results lost in transcription during our data reduction effort.

A meeting to discuss the quality of the data obtained from the SRL rail car impact tests was held at the Sandia Laboratories in Albuquerque, New Mexico on December 4, 1979. It was learned that data on the vertical acceleration of points on the rail car, and the horizontal acceleration of the trucks, were lost due to the use of piezoelectric (PE) accelerometers. These accelerometers were not functional at the frequency range of the rail car and truck response to be measured.

Measurements of vertical acceleration were made for points on the car structure at the struck end, far end, and above the truck center at the struck end using two PE accelerometers and one piezoresistive (PR) accelerometer. Apparently the frequency of the vertical rail car motion at these locations was outside the range of the PE accelerometers, so the data recorded could not be used. A PR accelerometer is capable of measurements at these frequencies. The vertical acceleration of the rail car structure at the struck end was monitored using a PR accelerometer, but these data were lost due to either "clipping" (over-ranging) or substructure "noise". The horizontal accelerations of the rail car and cask, and the vertical accelerations of the cask, were recorded without difficulty.

3. VALIDATE MODEL

A computer program MARCS (Modal Analysis of a Rail Car-Cask System) was written to supplement the cask-rail car dynamic models CARDT (Cask Railcar Dynamic Simulator Test) and CARDS (Cask Rail Car Dynamic Simulator).

The function of MARCS is to perform a modal analysis on vibrating systems, such as those represented by the CARDS and CARDT models, to determine parameters which may be used to generate frequency response spectra. MARCS determines the natural frequencies and characteristic shapes of the principal modes of vibration of the cask-rail car systems by iteration using the energy-based Rayleigh algorithm in conjunction with the Schmidt orthogonalization procedure (Reference 1). The frequencies and characteristic shapes are used to reduce each of these systems to one equivalent single-degree-of-freedom (1 DOF) equation of motion for the construction of response spectra curves. These 1 DOF equations of motion are used to obtain the maximum response for each frequency and mode shape.

MARCS was successfully tested using a simple system with known characteristics; however, the generation of response spectra for the CARDT and CARDS systems may be more difficult. The classical methods of modal analysis used in MARCS require the assumption of constant stiffness coefficients, whereas the CARDS model uses many coefficients which vary throughout the simulation as complex nonlinear functions of some of the response variables. Specifically, stiffness coefficients in the coupler, suspension, and tiedown subsystems are complex nonlinear functions of velocity, displacement, etc. Several approximations may be used to simplify the variation of these coefficients. One possible approach would be to use a piece-wise constant approximation of the variation. That is, a variation may be represented by a series of time increments in which the stiffness coefficients are held constant. However, the rapidly varying nature of the system might make this impractical. The CARDS model might be too complex for a modal analysis using such classical textbook methods as those used in the MARCS program. Less elegant, but suitable, alternatives will be investigated.

One alternate approach to determining response spectra is presented by Harris and Crede in Reference 2. This method considers the relative motion between the rail car (considered as a support) and the cask as a new variable. This allows the transformation of the equation of motion to a 1 DOF system for certain conditions.

If response spectra can be derived from both calculated results from the models and the corresponding experimental data, then the comparison of these spectra will be used as an additional means of validating the analytical models. This approach to model validation will also identify those frequencies where the model and the experiment are in agreement, as well as those frequencies where they do not produce the same results. This approach to model validation will be used to complement the use of Theil's inequality coefficients as a validation technique (References 3 and 4).

Partial tuning of the CARDS model has been carried out using variation of parameters and successive approximations to minimize Theil's <u>multiple</u> inequality coefficient (TMIC). The first parameter varied was the time shift required to obtain the best fit when values of calculated and experimental response variables were superimposed. This time shift was established by trying a number of values while evaluating Theil's two-variable inequality coefficient for the coupler force, and Theil's multiple inequality coefficient. Minimum values of these coefficients (indicating the best agreement) occurred for a time shift of 0.038 second. Time traces of system response variables obtained from SRL test instrumentation show a period of slight activity before impact. In the CARDS model, time zero represents impact, where the simulation begins. The time shift of 0.038 second fixes the common zero point on the time traces of the experimental data for further comparisons.

A preliminary assessment of how well the CARDS model simulates the behavior of the cask-rail car system for the conditions of Test 3 of the SRL experiments was made by comparing, for two cases, both visually and quantitatively, the calculated and experimental values of coupler force, longitudinal force of interaction between the cask and rail car, horizontal acceleration of the rail car, horizontal acceleration of the cask, vertical acceleration of the cask at the far end, and vertical acceleration of the cask at the struck end. In both cases, the coupler force was the force of excitation causing the system to vibrate. In the first case, the experimentally measured coupler force was used. In the second case, the coupler force used was that calculated by the CARDS model. Visual comparisons are presented in Figures 1 through 7 for the first case, and in Figures 8 through 14 for the second case. Quantitative comparisons of each pair of individual response variables were made using Theil's two-variable inequality coefficients. A simultaneous quantitative comparison of all the response variables was made using Theil's multiple inequality coefficient. The quantitative comparisons are summarized in Table 1.

The Theil's inequality coefficients in Table 1 indicate that good agreement between calculated and experimental results was obtained for all but the vertical accelerations. The vertical accelerations of the cask produced two-variable inequality coefficients above 0.5. Theil's multiple inequality coefficient for Case 1 is 0.06, and Case 2 is 0.172. (Theil's inequality coefficients range from a value of 0 at best agreement to a value of 1 at worst agreement).

Theil's two-variable inequality coefficient (TIC) for a single response variable is defined and discussed in Reference 3. Theil's multiple, or overall inequality coefficient (TMIC), is a figure of merit based on the number of observations or data points, the values of several individual response variables selected at discrete points, and the two-variable inequality coefficients (TICs) defined by Equation 5 in Reference 3. The two-variable (calculated and experimental variable values) inequality coefficients are combined to generate the TMICs. The TMIC is defined by Equation 16 in Reference 4. A correction was made to this equation after an evaluation revealed that the factor 2 in the denominator is a mistake carried over from the original reference (Reference 5). This factor was removed.

The horizontal motion of the rail car is strongly influenced by the cask and the trucks. To confirm this conclusion, the CARDS model was temporarily adjusted to disconnect all components that tend to decrease the magnitude of the deceleration of the rail car (i.e., the cask and trucks), thus isolating the rail car. A simulation run was then made to determine the horizontal acceleration of the rail car. Results using the experimentally measured coupler force are presented in Figures 10 and 11. Results using the calculated coupler force are presented in Figures 3 and 4. Figures 3 and 10 show the calculated results compared to experimental data filtered at 100 Hz. Figures 4 and 11 show the calculated results compared to unfiltered experimental data. It is evident that the calculated and experimental results for the full system compare well, but the deceleration of the isolated rail car is substantially greater. The deceleration of the isolated car, as might be expected, follows the coupler force curve. The experimental data used in this comparison contained high frequency noise which had to be filtered out before the comparisons in Figures 3 and 10 could be made. Filtering these high frequency noise (higher than 100 Hz) components from the experimental data was accomplished using the Fast

Fourier Transform (FFT) program.

4. COLLECT PARAMETER DATA

ENSCO, Incorporated is continuing a study to provide parameter data on the railway equipment used in the coupling tests conducted at SRL, and on equipment which may be encountered in future studies. ENSCO will also supply data from similar independent experiments to supplement the SRL data for model validation. They will also provide information on draft gear modeling, cargo shifting, and on the mix of rail car types present in an anvil train.

5. PARAMETRIC AND SENSITIVITY ANALYSIS

There was no activity in this task during this reporting period.

6. INTERIM REPORT

There was no activity in this task during this reporting period.

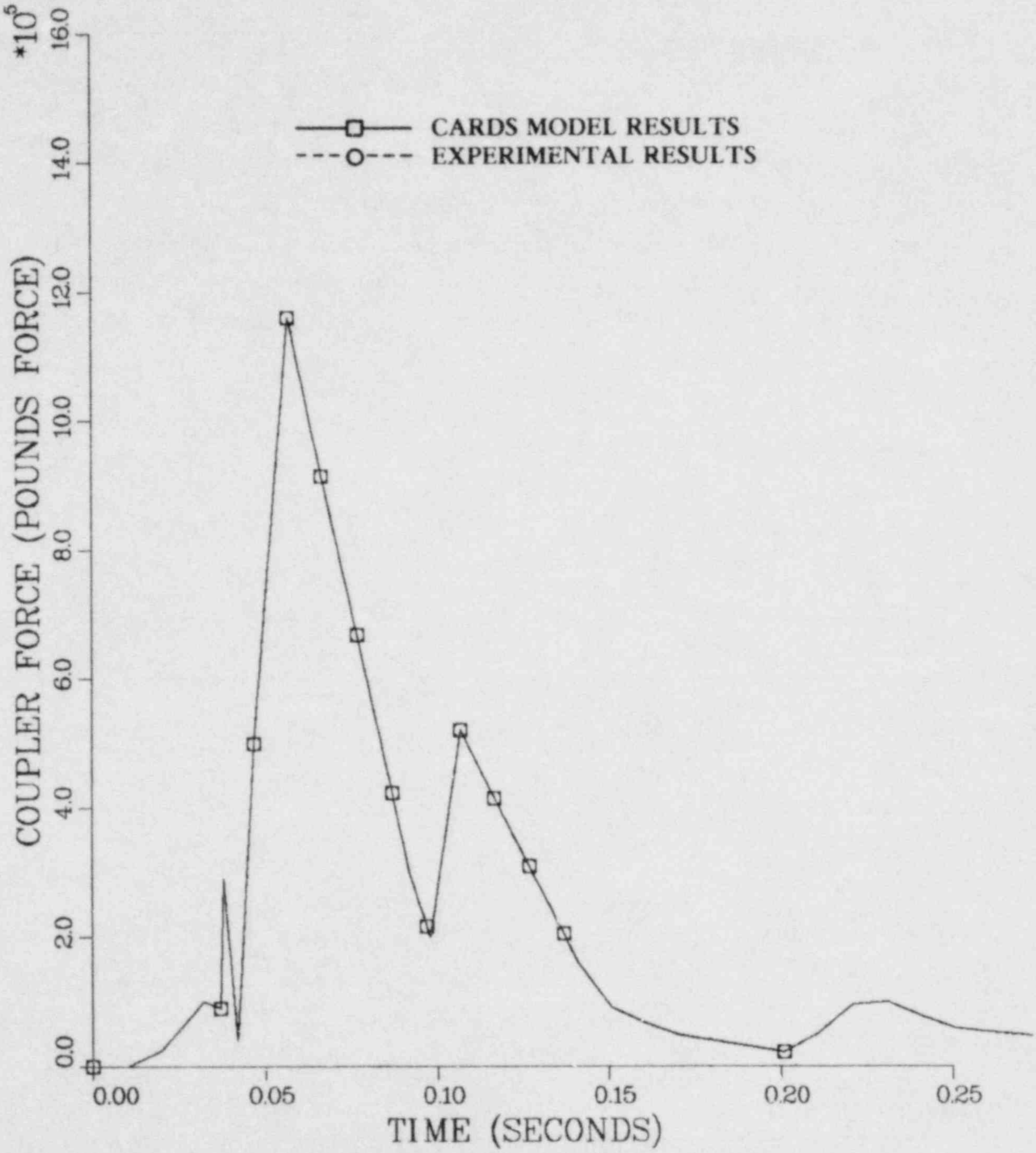

FIGURE 1. Coupler Force vs Time During Impact of Cask-Rail Car with Four Hopper Cars Loaded with Ballast (Test 3 - Instrument 3) (Case 1: Measured Coupler Force). Experimental Force is substituted for Calculated Force in this Graph.

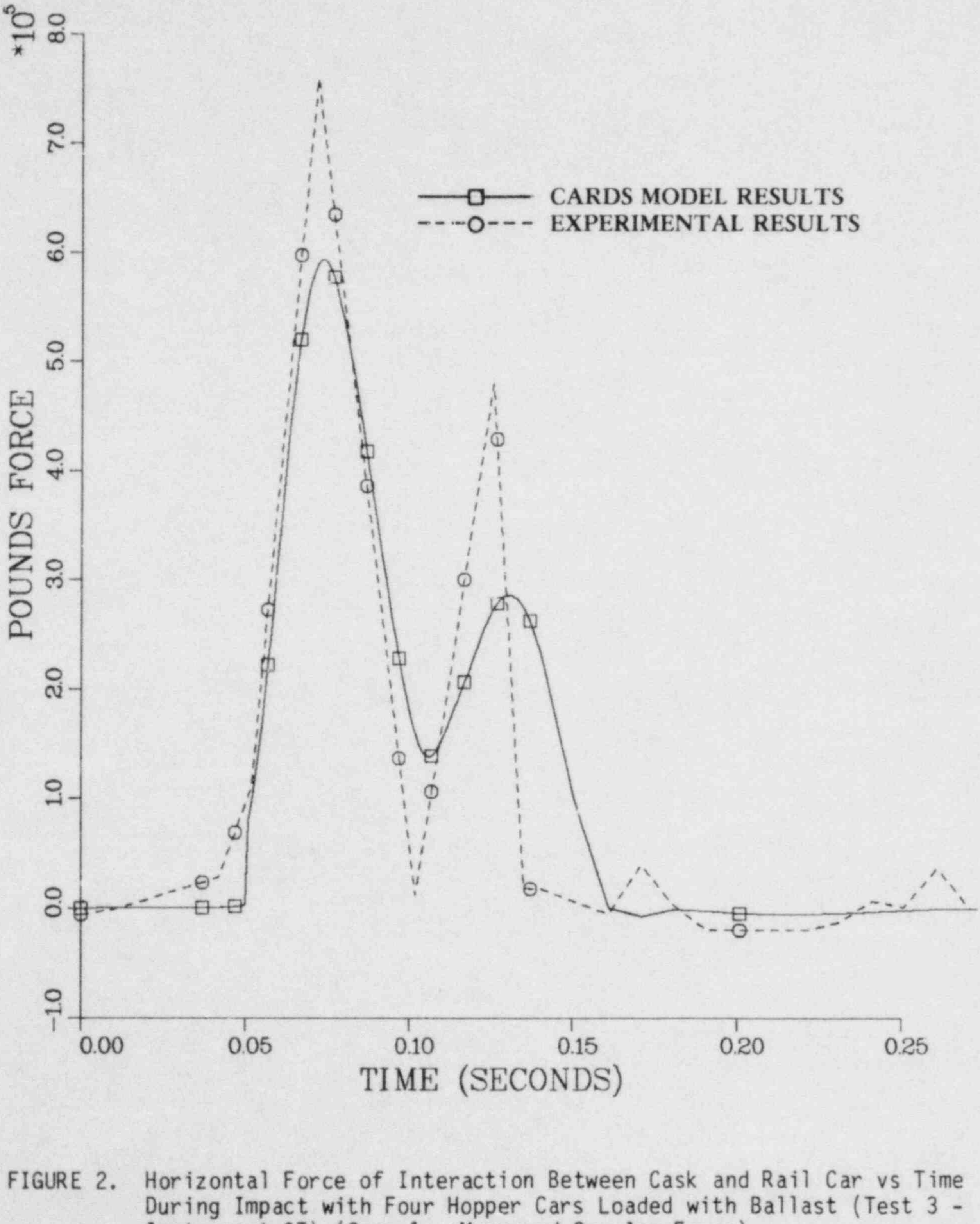

FIGURE 2. Horizontal Force of Interaction Between Cask and Rail Car vs Time During Impact with Four Hopper Cars Loaded with Ballast (Test 3 - Instrument 27) (Case 1: Measured Coupler Force).

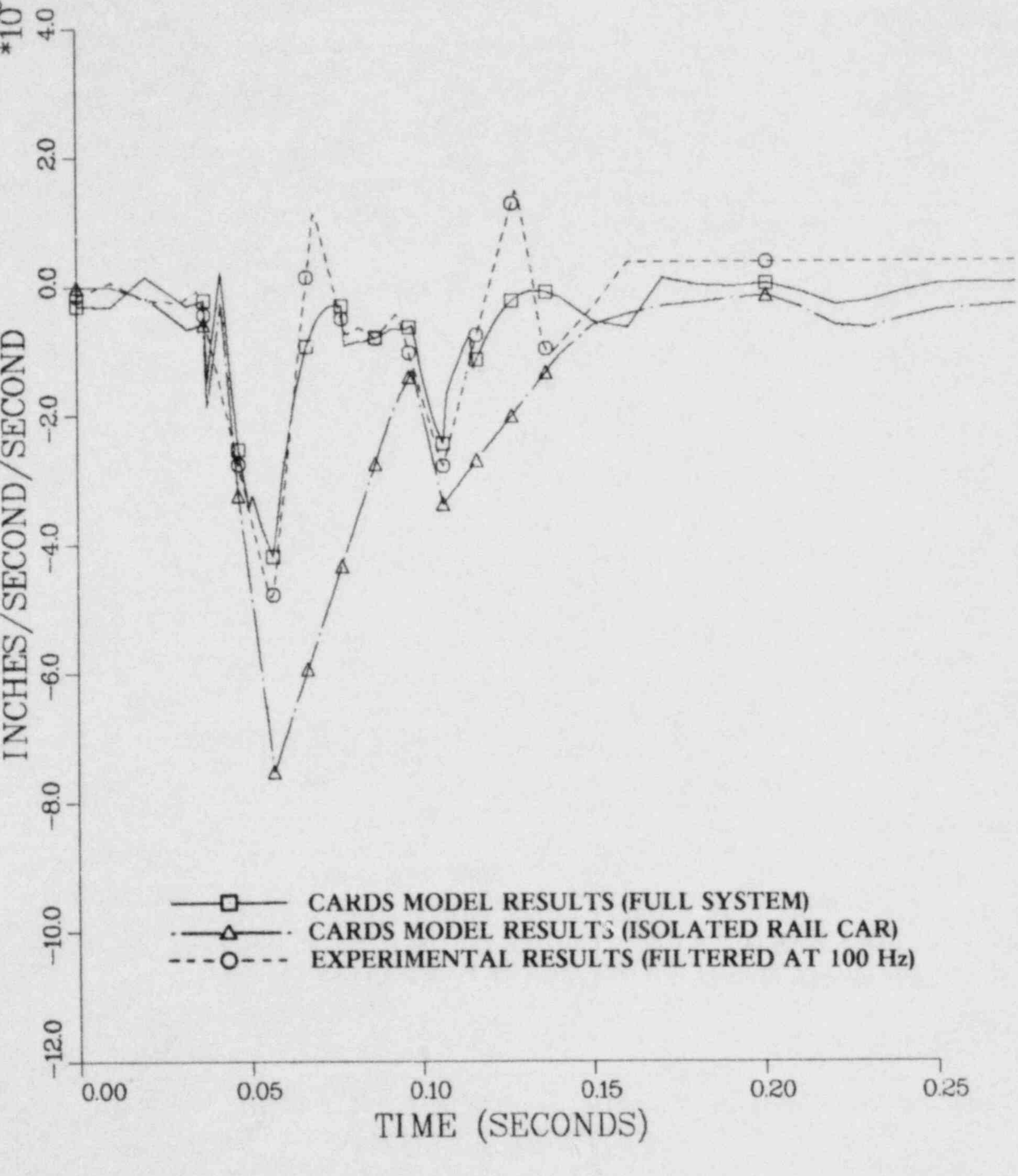

FIGURE 3. Horizontal Acceleration of the Cask-Rail Car During Impact with Four Hopper Cars Loaded with Ballast (Test 3 - Instrument 12: Filtered at 100 Hz) (Case 1: Measured Coupler Force).

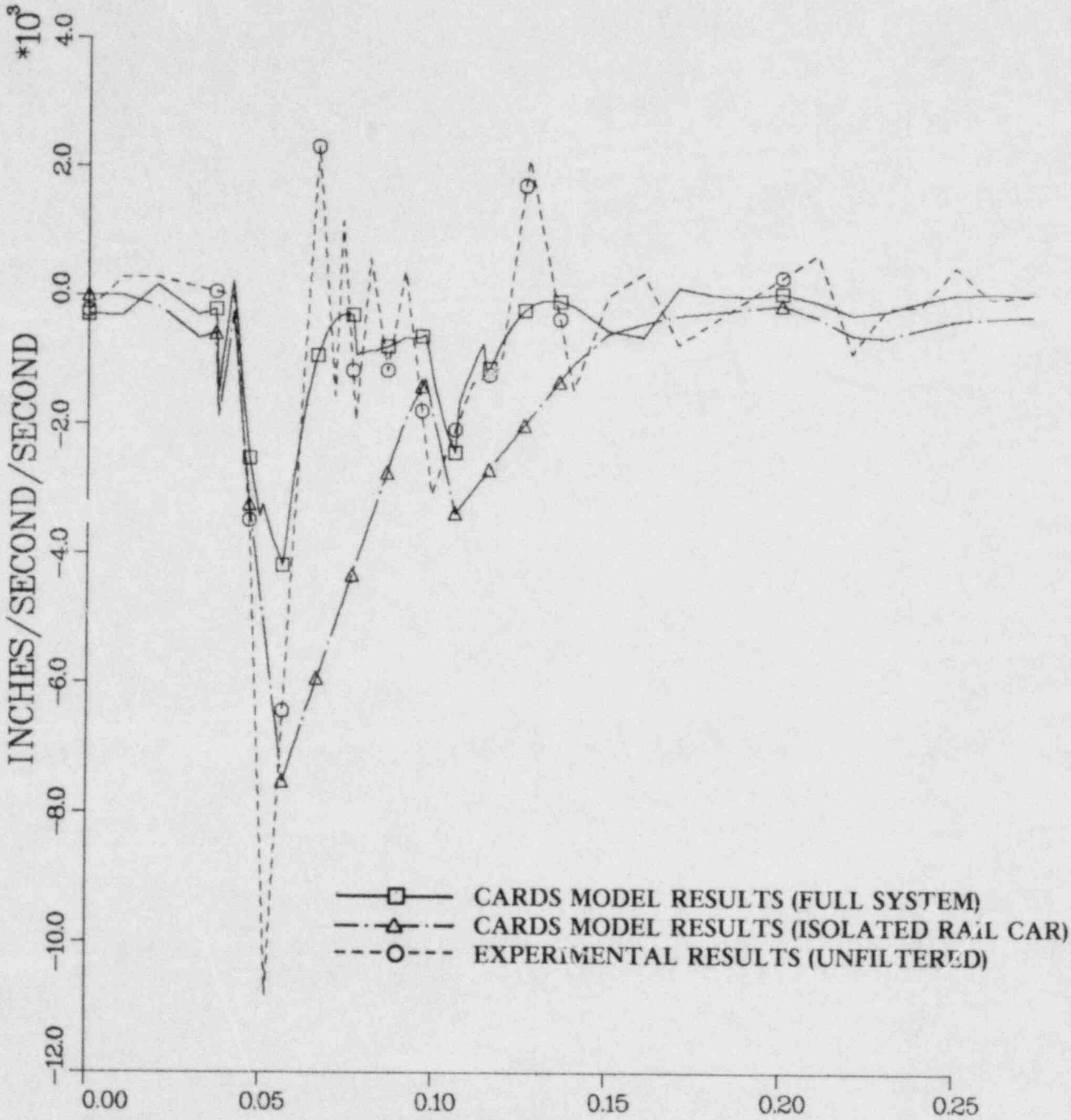

FIGURE 4. Horizontal Acceleration of the Cask-Rail Car During Impact with Four Hopper Cars Loaded with Ballast (Test 3 - Instrument 12: Unfiltered) (Case 1: Measured Coupler Force).

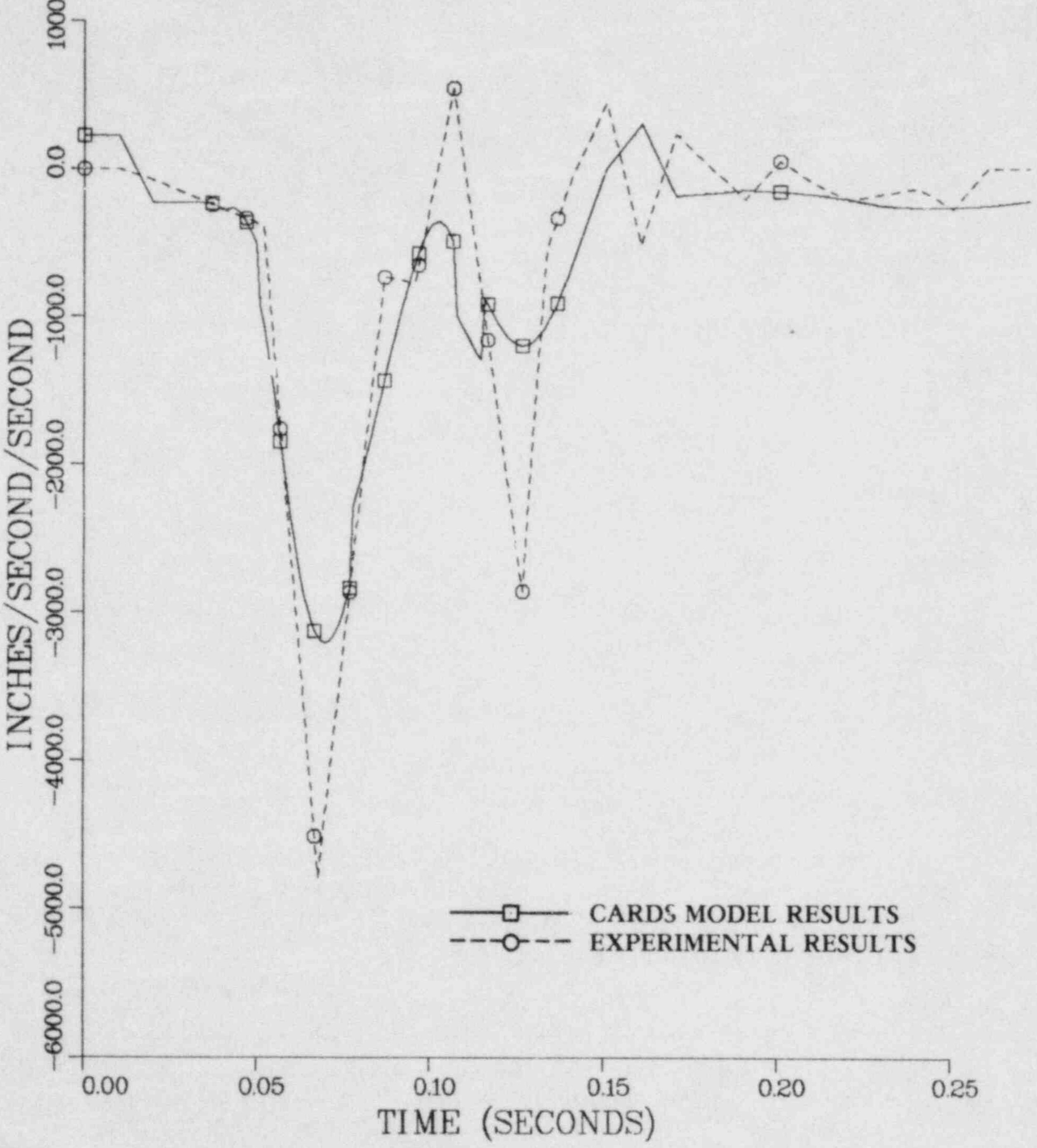

FIGURE 5. Horizontal Acceleration of the Cask During Impact with Four Hopper Cars Loaded with Ballast (Test 3 - Instrument 8: Unfiltered) (Case 1: Measured Coupler Force).

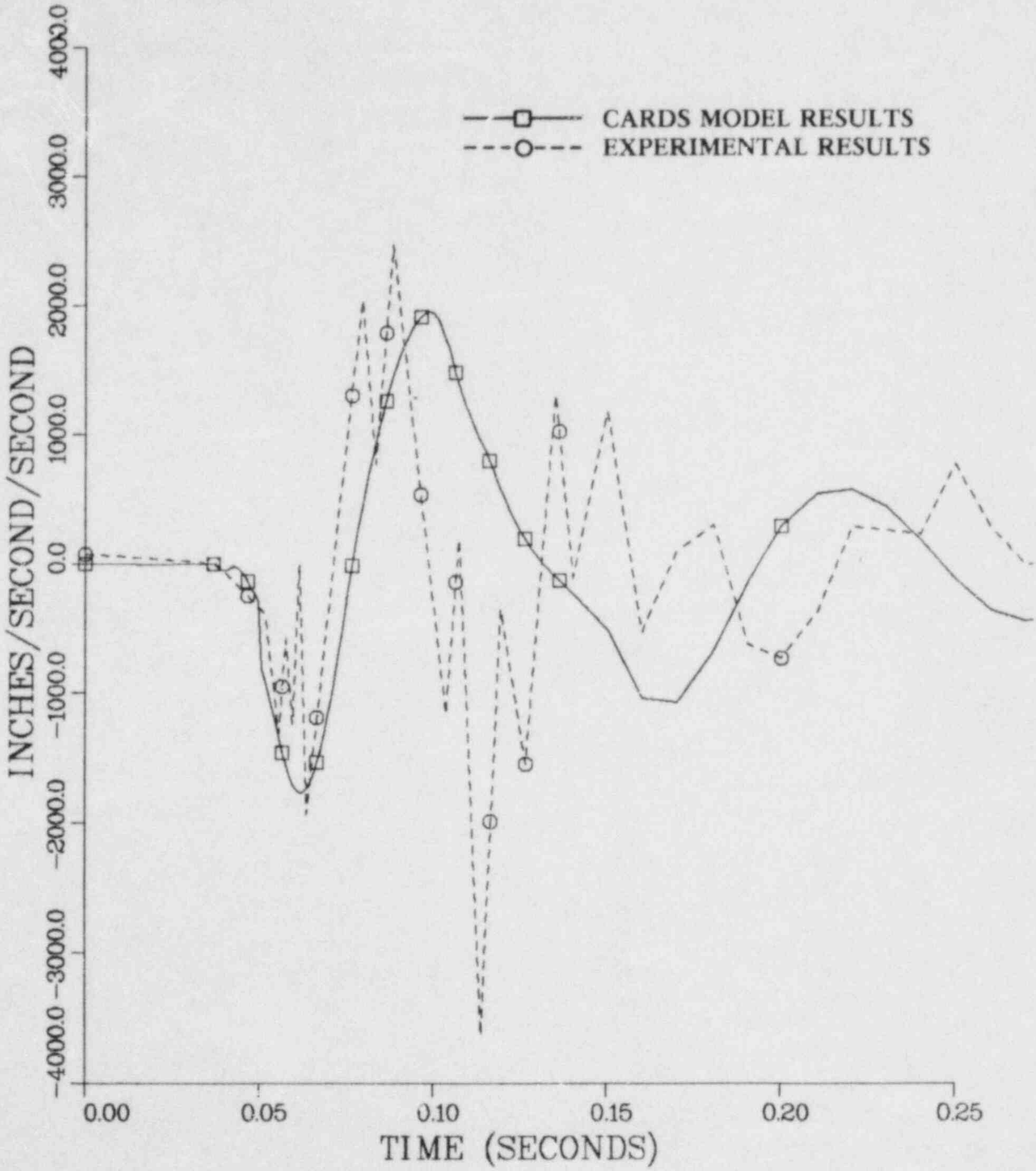

FIGURE 6. Vertical Acceleration of the Cask at the Struck End During Impact with Four Hopper Cars Loaded with Ballast (Test 3 - Instrument 9: Unfiltered) (Case 1: Measured Coupler Force).

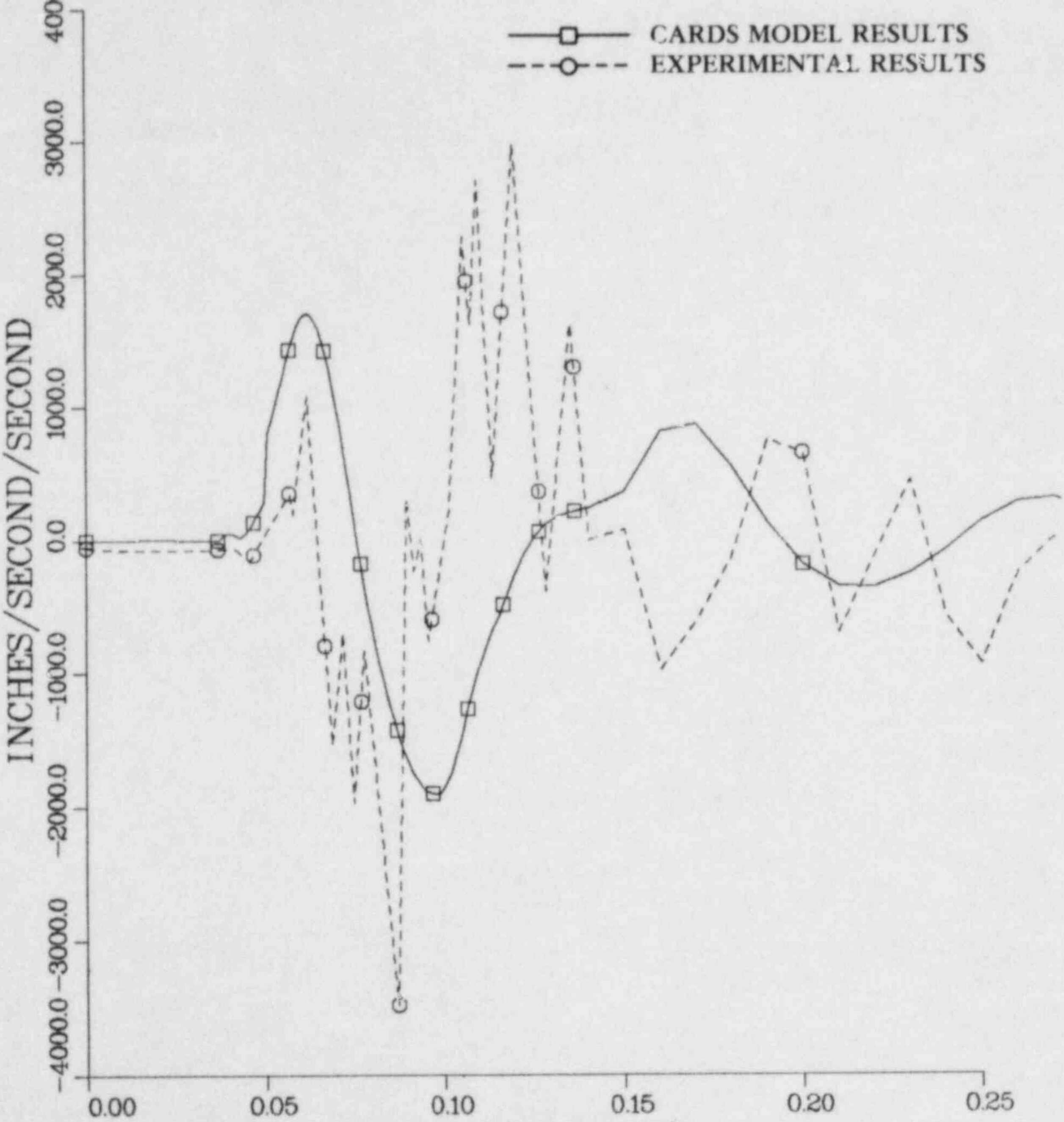

FIGURE 7. Vertical Acceleration of the Cask at the Far End During Impact with Four Hopper Cars Loaded with Ballast (Test 3 - Instrument 11: Unfiltered) (Case 1: Measured Coupler Force).

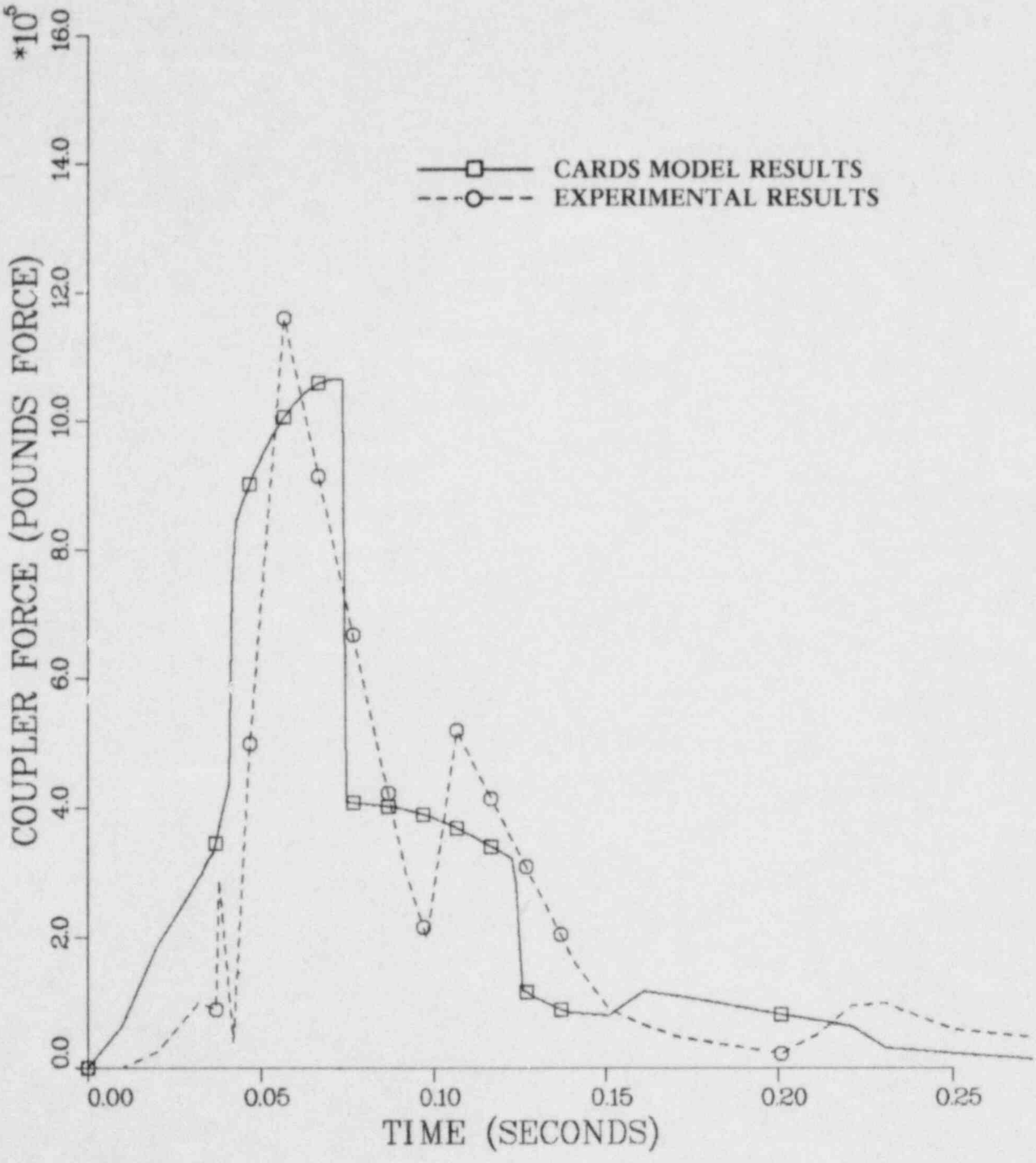

FIGURE 8. Coupler Force vs Time During Impact of Cask-Rail Car with Four Hopper Cars Loaded with Ballast (Test 3 - Instrument 3) (Case 2: Calculated Coupler Force).

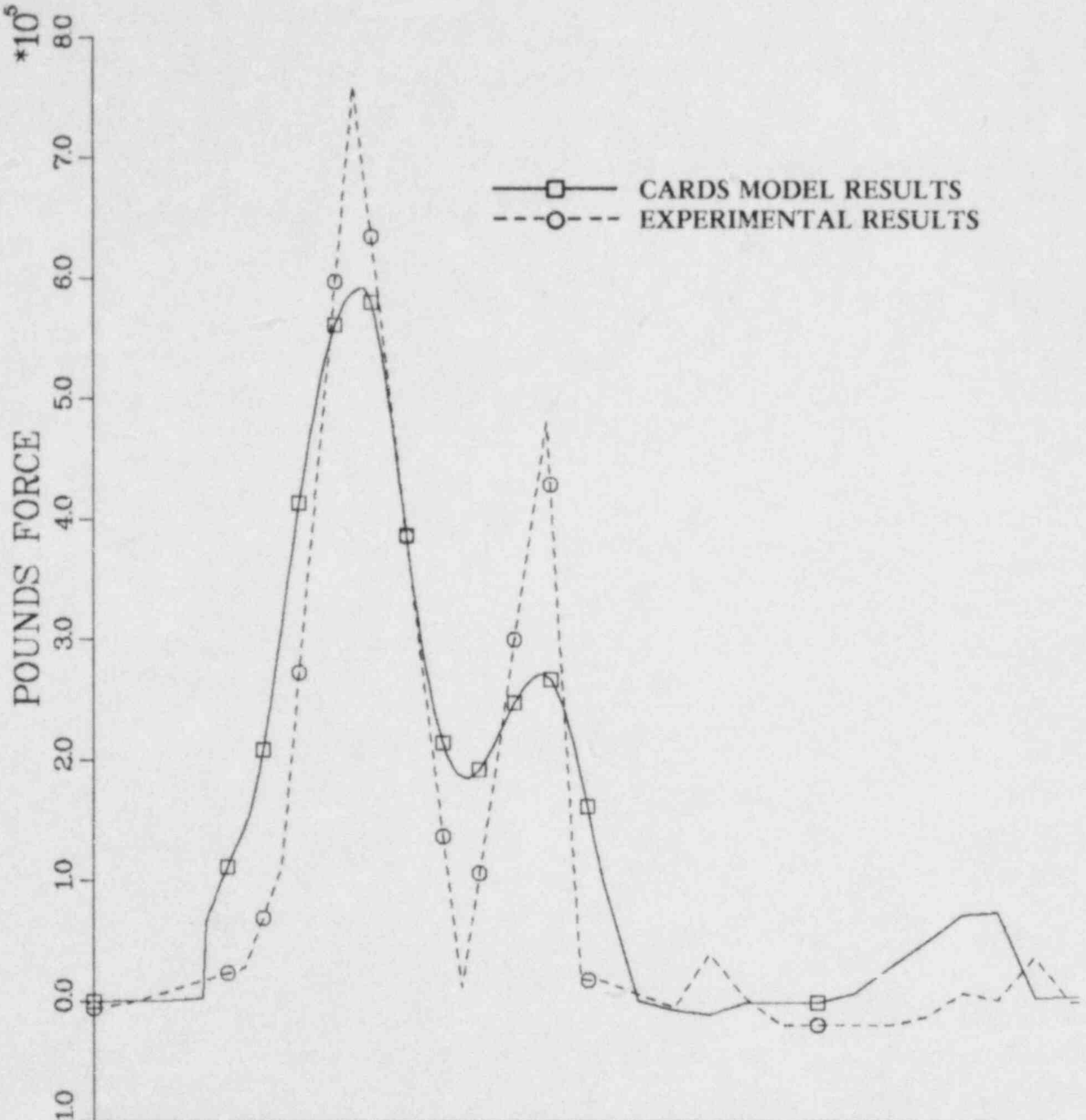

FIGURE 9. Horizontal Force of Interaction Between Cask and Rail Car vs Time During Impact with Four Hopper Cars Loaded with Ballast (Test 3 - Instrument 27) (Case 2: Calculated Coupler Force).

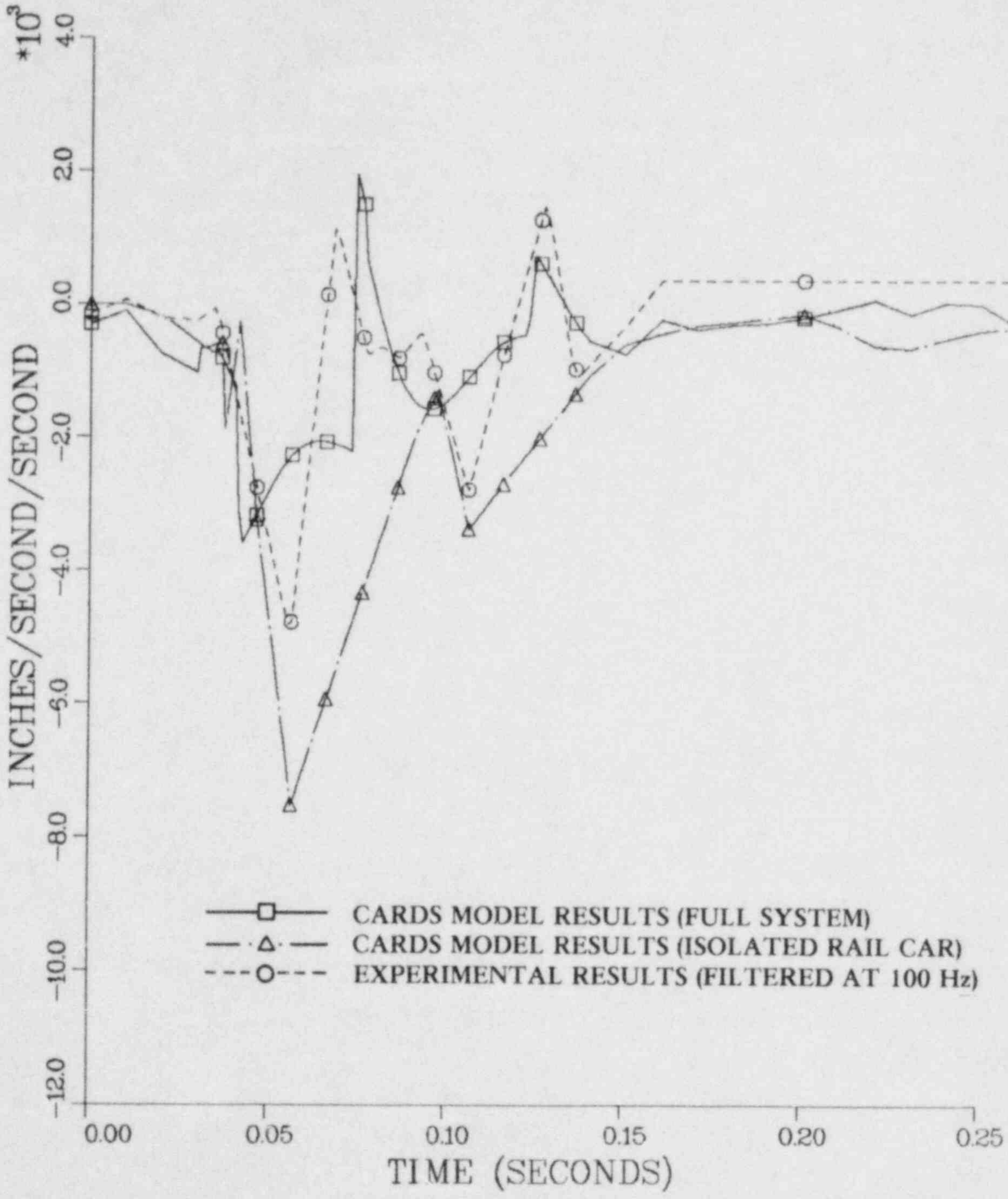

FIGURE 10. Horizontal Acceleration of the Cask-Rail Car During Impact with Four Hopper Cars Loaded with Ballast (Test 3 - Instrument 12: Filtered at 100 Hz) (Case 2: Calculated Coupler Force).

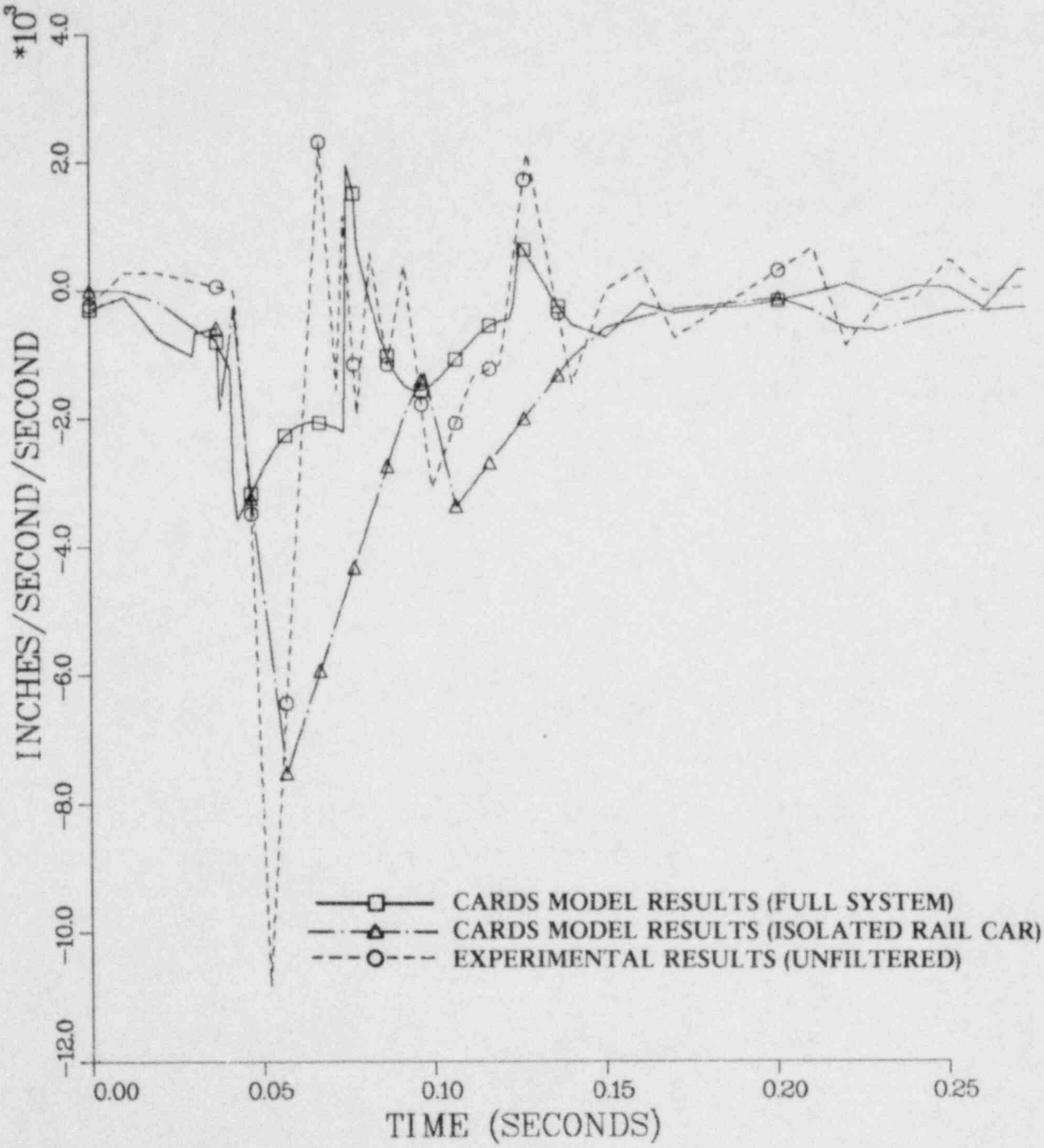

FIGURE 11. Horizontal Acceleration of the Cask-Rail Car During Impact with Four Hopper Cars Loaded with Ballast (Test 3 - Instrument 12: Unfiltered) (Case 2: Calculated Coupler Force).

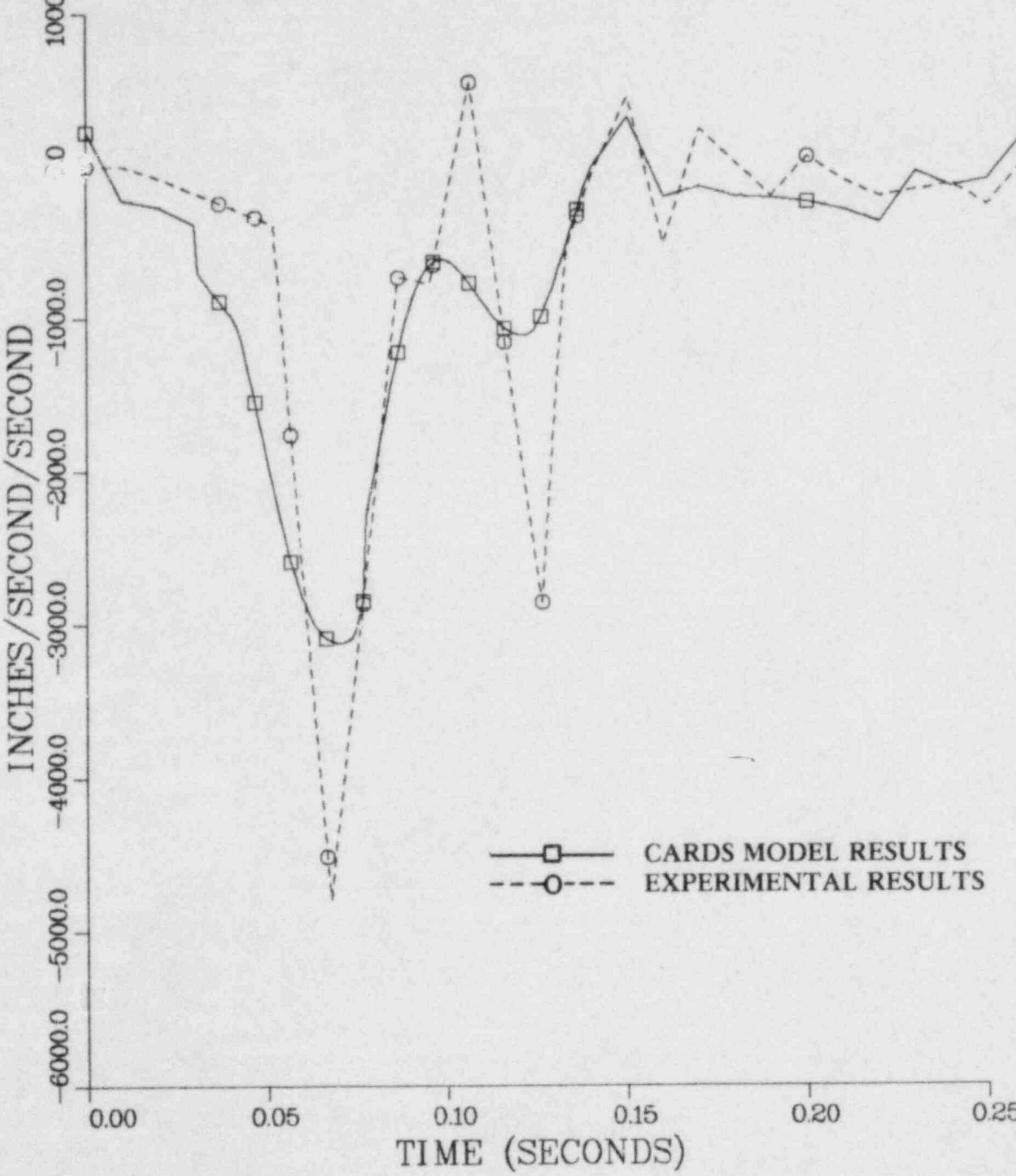

FIGURE 12. Horizontal Acceleration of the Cask During Impact with Four Hopper Cars Loaded with Ballast (Test 3 - Instrument 8: Unfiltered) (Case 2: Calculated Coupler Force).

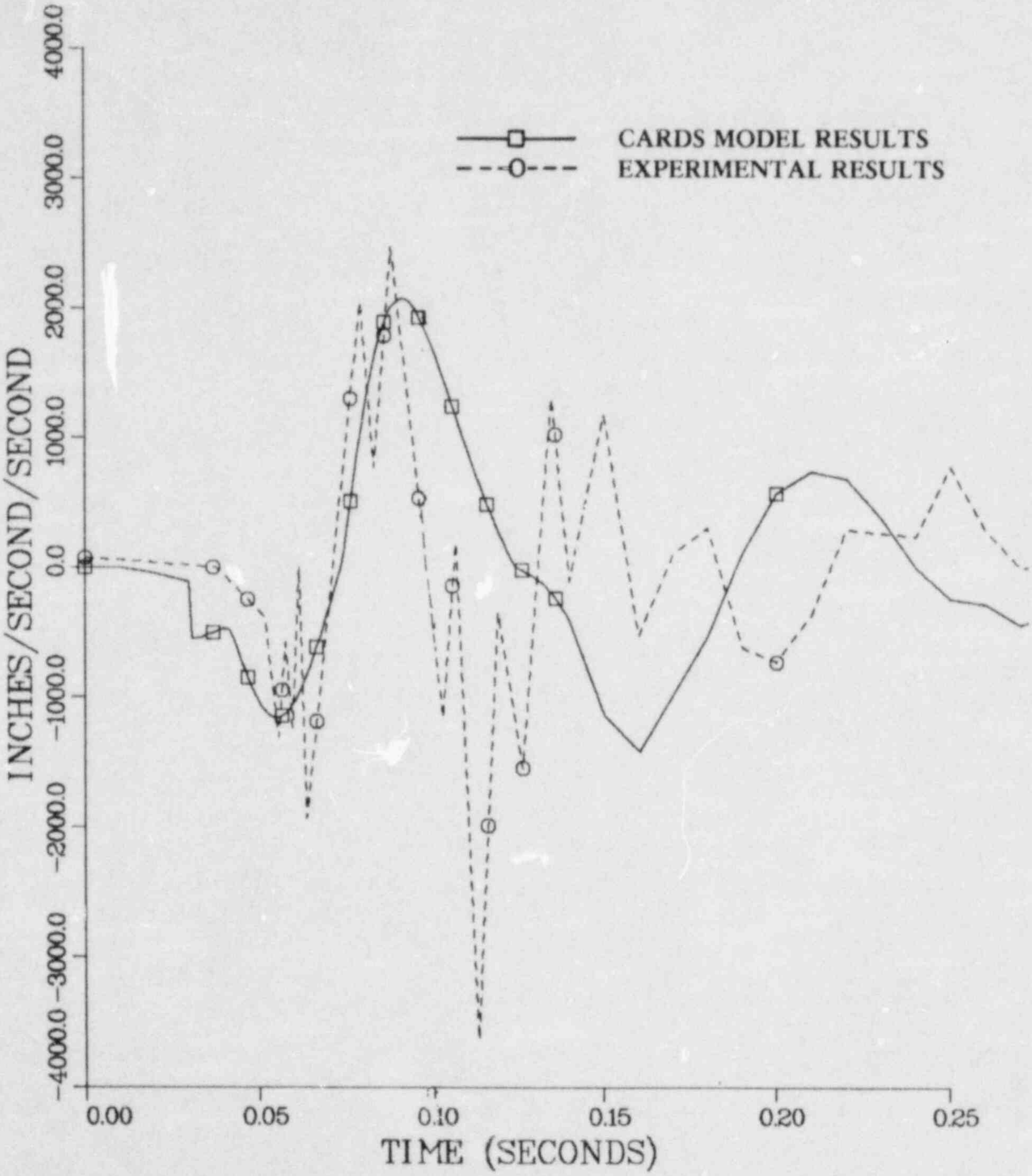

FIGURE 13. Vertical Acceleration of the Cask at the Struck End During Impact with Four Hopper Cars Loaded with Ballast (Test 3 - Instrument 9: Unfiltered) (Case 2: Calculated Coupler Force).

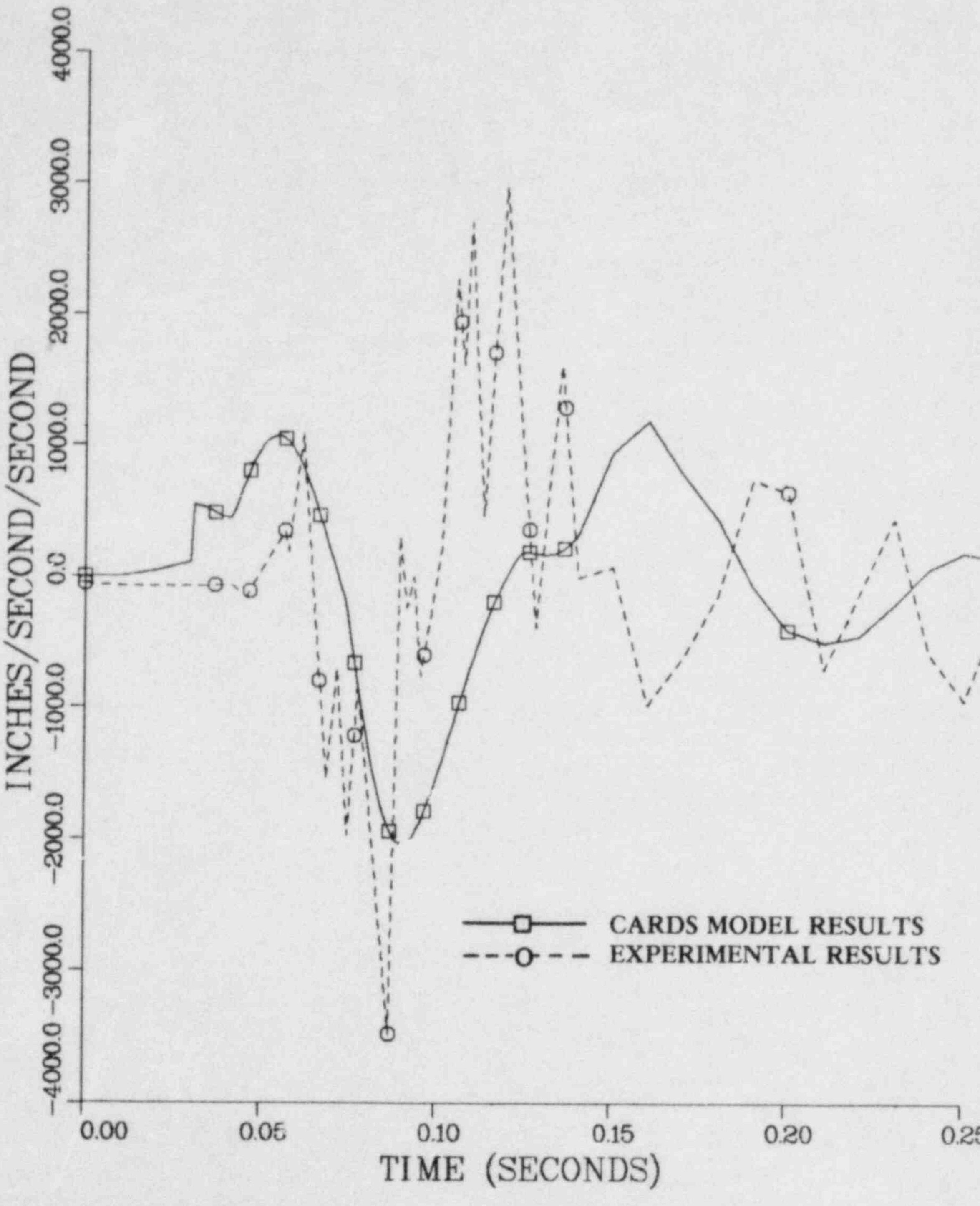

FIGURE 14. Vertical Acceleration of the Cask at the Far End During Impact with Four Hopper Cars Loaded with Ballast (Test 3 - Instrument 11: Unfiltered) (Case 2: Calculated Coupler Force).

TABLE 1

THEIL'S INEQUALITY COEFFICIENTS FOR RESPONSE VARIABLES DETERMINED USING CALCULATED AND MEASURED COUPLER FORCE

Response Variable	Case 1	Case 2
	Measured Coupler Force	Calculated Coupler Force
	Theil's Two-Variable Inequality Coefficients*	Theil's Two-Variable Inequality Coefficients*
Coupler Force	0.0	0.178
Longitudinal Force of Interaction Between Cask and Rail Car	0.155	0.155
Horizontal Acceleration of Cask	0.190	0.232
Horizontal Acceleration of Rail Car	0.391	0.490
Vertical Acceleration of Cask at Far End	0.701	0.627
Vertical Acceleration of Cask at Struck End	0.632	0.582
Theil's Multiple Inequality Coefficient*	0.060	0.172

*A value of 0 indicates the best agreement and a value of 1 indicates the poorest agreement.

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1. J. M. Biggs, Introduction to Structural Dynamics. 1st Ed., McGraw Hill Book Company, New York, 1964.

2. C. M. Harris and C. Crede, Shock and Vibration Handbook, Volume 2, (p. 31-2) and Volume 3 (p. 50-10), McGraw Hill, New York, 1961.

3. S. R. Fields and S. J. Mech, Dynamic Analysis to Establish Normal Shock and Vibration of Radioactive Material Shipping Packages, Quarterly Progress Report (January 1, 1979 - March 31, 1979), NUREG/CR-0880 (HEDL-TME 79-29), Hanford Engineering Development Laboratory, Richland, WA, September 1979.*

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16. ABSTRACT (200 words or less)

A computer program MARCS (Modal Analysis of a Rail Car-Cask System) was written to perform a modal analysis on the systems represented by the CARDT and CARDS (Cask-Rail Car Dynamic Simulator) models. Parameters generated by MARCS will be used to generate frequency response spectra. A preliminary evaluation of the performance of CARDS was made by comparing calculated results with response variables measured during Test 3 of the series of tests conducted at the Savannah River Laboratories, Aiken, SC.

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