To the Graduate Council:

I am submitting herewith a thesis written by S. Todd Phillips entitled "Structural Response of Van Trailers When Subjected to Loading and Hauling." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Civil Engineering.

Dr. J. Harold Deatherage, Major Professor

We have read this thesis and recommend its acceptance:

Edwin G. Burdette

Accepted for the Council:

Associate Vice Chancellor and Dean of the Graduate School

Structural Response of Van Trailers When Subjected to Loading and Hauling

A Thesis
Presented for the
Master of Science
Degree
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S. Todd Phillips
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Abstract

This study is a comprehensive investigation of the structural response of van trailers when subjected to loading and hauling. Full scale testing was used to determine the behavior of the trailer's main components during loading and hauling. As a result two different configurations of trailers were tested using three different test method. Strains and deflections were measured for the wall frames as well as the floor beams. In all cases these strains and deflections exceeded acceptable limits. Strains in the floor beams were approaching 2.5 times the yield strain of the material. The aluminum extrusions in the wall frames were subjected to strain well over their endurance limit during every loading cycle. The trailers were clearly under-designed.

Table Of Contents

List of Figures

List of Tables

Chapter 1

Introduction

1.1 Background

Over-the-road trucks haul a large part of our nations' freight. Keeping the commodities moving requires an enormous number of tractors and trailers. Maintaining these vital organs of interstate commerce is essential to keeping them on the road. Maintenance is a large part of a trucking company's budget. Minimizing maintenance costs directly correlates to profit margins. Not only does the cost of maintenance increase overhead costs, but also the loss of billable road time reduces income. To cover the high overhead involved in trucking it is essential to keep the trucks on the road. There are two essential parts of the carrier unit, the tractor and the trailer. This thesis focuses on the trailer and the means by which it supports its payload.

Paper is a main ingredient for many different products. Raw paper is a dense material. A load of paper is governed by its gross weight rather than trailer space. Rolls of paper weigh between 6000 pounds and 7000 pounds and are approximately five feet in diameter. These large rolls require a sizable forklift to load them on the trailer. The forklift along with its payload is the most structurally significant load the trailer will experience. Structural tests have shown that axle loads from a loaded forklift can induce substantial stresses to the trailer structure. Dynamic loads also are significant as the trailer experiences various road conditions. These conditions include but are not limited to bridge approaches, railroad crossings, and pavement transitions. All of these loading conditions have been investigated.

This study was initiated as a result litigation involving the premature and excessive maintenance requirements of the trailers in question. Excessive deformations of the floor beams result in premature failure of the wood decking inside the trailer thus incurring maintenance costs. Billable road time is lost while the maintenance is performed.

1.2 Trailer Design Theory

The trailers in question are 53 feet van trailers (see Figures 1, 2 and 3 on the following pages). These trailers protect the paper products during transportation. The following three pages contain schematic drawing of the trailers structure.

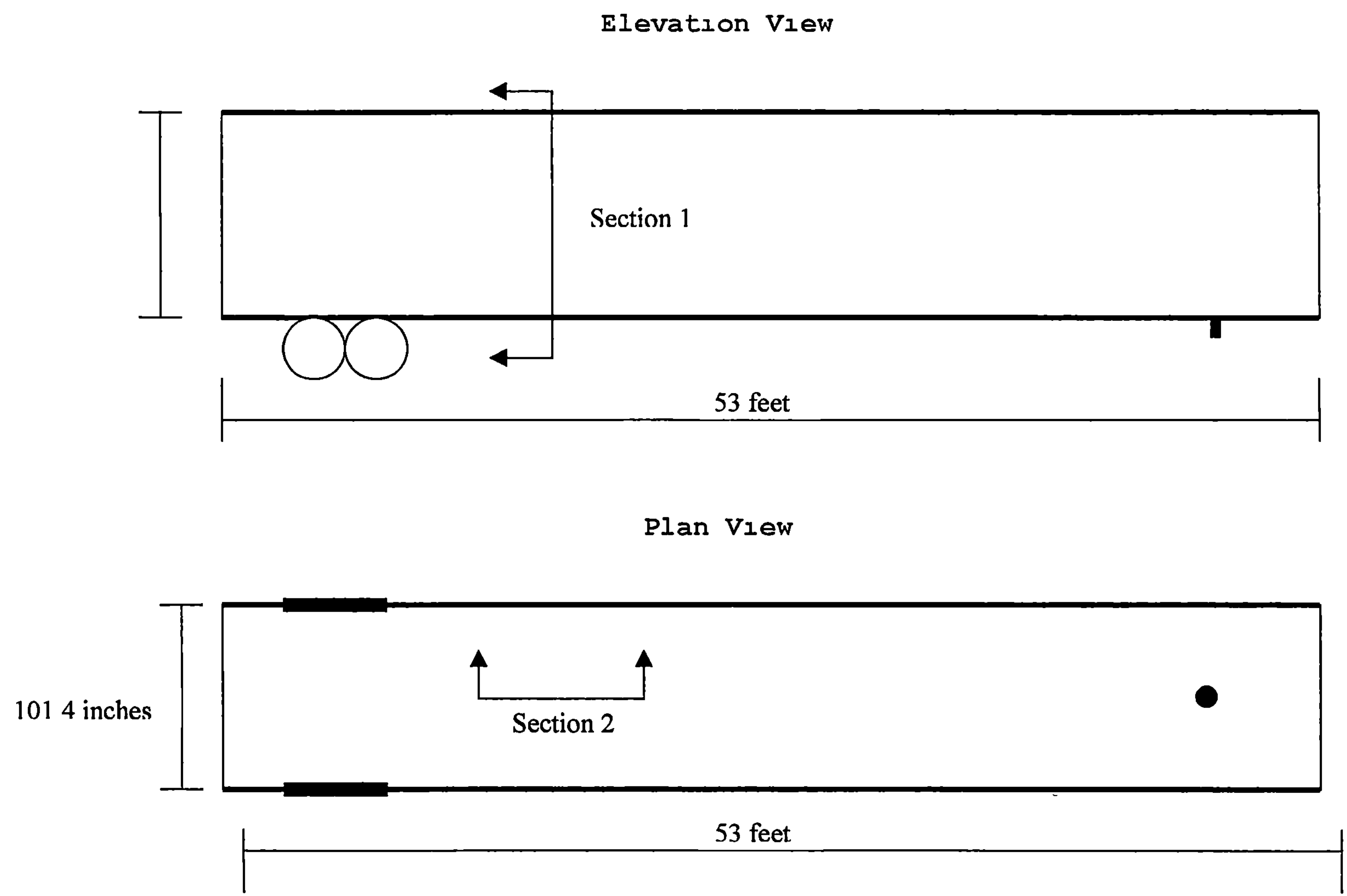

Figure 1. Trailer Schematic

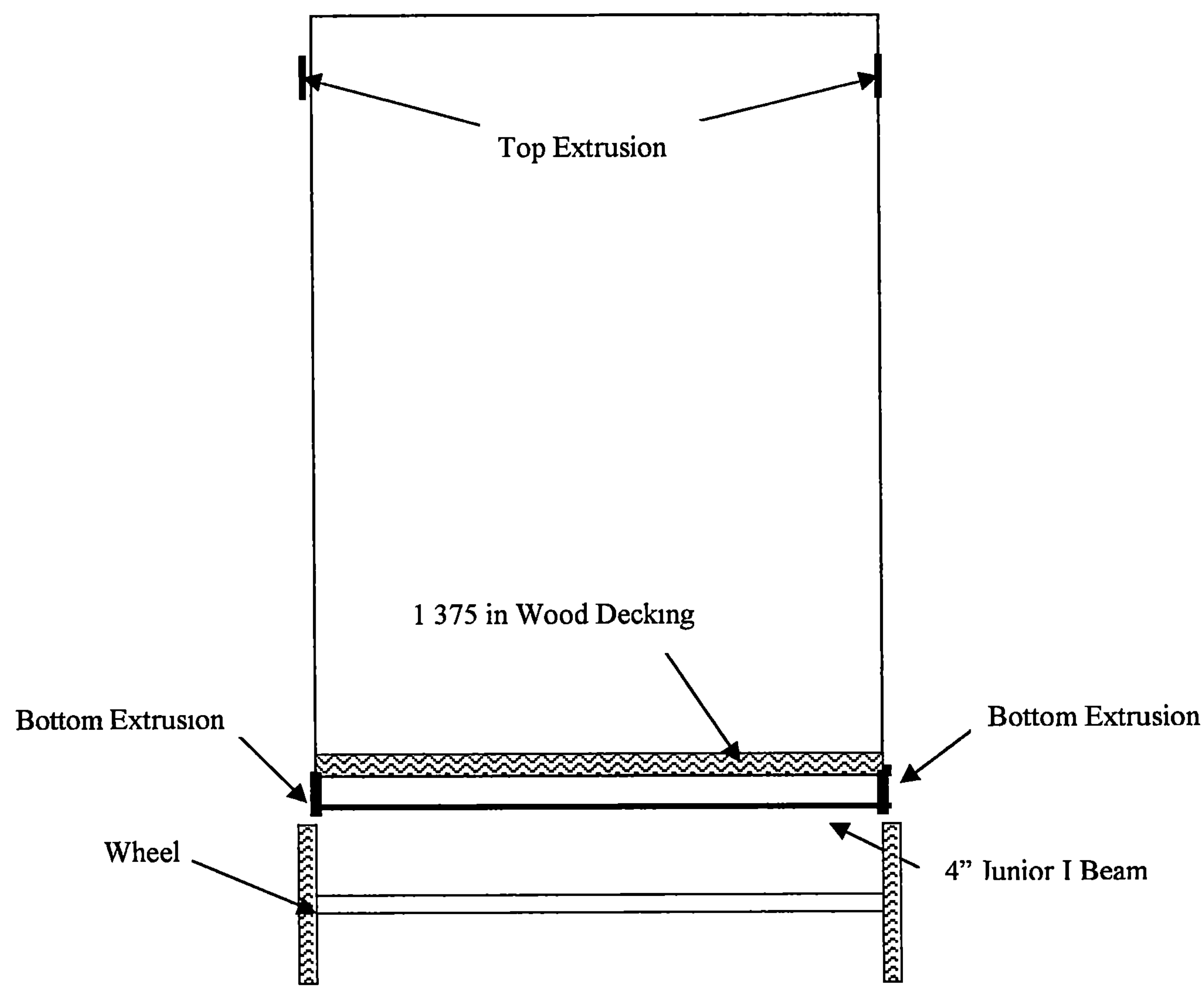

Figure 2. Section 2 Schematic

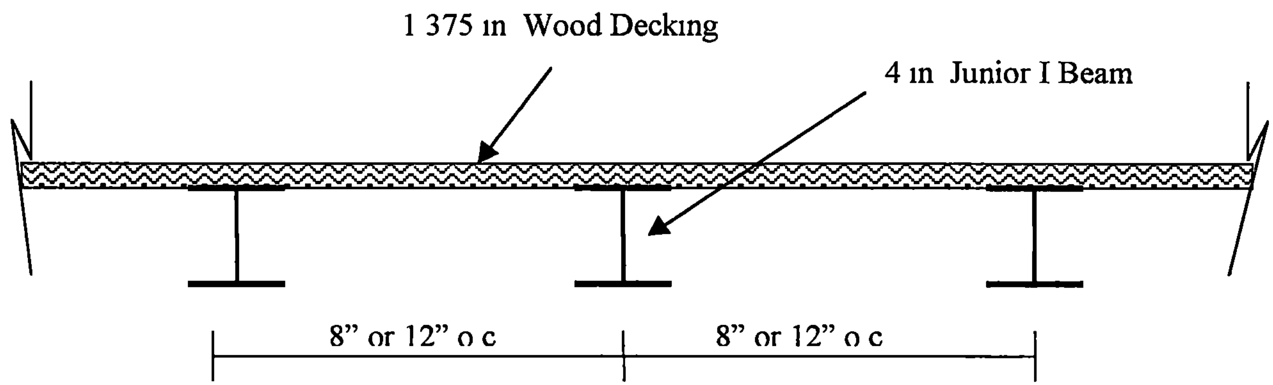

Figure 3. Section 2 Schematic

Trailer manufactures often state that van trailers are designed using monocoque shell theory. Monocoque construction consists of thin shell design to resist all loads. Monocoque is derived from a French word meaning "shell only". Monocoque design theory is clearly not employed for the subject trailers. The walls are constructed in a manner that could be considered semi-monocoque construction. Semi-monocoque construction is a thin shell reinforced by stiffening members to prevent the shell from buckling from internal or external pressures. The trailer structure more appropriately behaves like a "plate girder" when supporting paper rolls, as explained further in Section 1.4, "Structural Action."

1.3 Applicable Standards

Currently there are no applicable standards or regulation which govern the structural design of over the road trailers. The National Highway Transportation Safety Administration (NHTSA) governs the brake and lighting systems and other safety features but is absent of criteria for structural design of the trailers. Hence, the trailer manufacturer determines appropriate design criteria and selects factors of safety and materials based on expected usage or purchaser's performance specifications.

1.4 Structural Action

The paper roll is typically loaded onto the trailer using a forklift whose capacity exceeds the weight of the paper. Weights of the paper rolls vary significantly, with the heavier rolls approaching 7000 pounds. The paper rolls are placed directly on the 1.375-inch thick laminated hardwood decking serving as the floor of the trailer. This decking is attached with screws to 4 inch Junior I beams that are spaced at 8 or 12 inches on centers. These I beams are fastened to aluminum extrusions which run the length of the trailer. These aluminum extrusions form the bottom of the sidewalls. A similar aluminum extrusion is located at the top of the sidewall. These two extrusions, top and bottom of each wall, support the applied bending stresses during loading and hauling. Thus, the trailer is supported by "plate girders" with the extrusions acting as "flanges" of the girder and the exterior skin acting as the "web" of the girder. The walls are held in plane by the plastic roof. The load is then reacted by the fifth wheel and the axles.

1.5 Research Purpose

The purpose of this research was to determine the structural response of these trailers when subjected to forklift loading and over the road hauling. Full-scale structural tests were performed to determine the actual applied stresses during loading and hauling.

Chapter 2

Deformation Study

The first goal of the research was to assess the damage to the trailer floor beams resulting from over-the-road hauling of rolled paper. The assessment of damage was determined via a permanent deformation study. A total of forty-one trailers were investigated. Although this number is only approximately 8 percent of the defective trailers it can be considered a statistically representative sample. The permanent set on eighteen beams were measured on eleven of the above stated trailers. This is approximately half of the total number of floor beams on the trailers. The other half was obscured from measurement by various obstacles including the fifth wheel, axles, turn signals, as well as other standard assemblies. Table 1 on the following page contains the previously stated measurements. The maximum three averages are in bold to indicate the beams, which were experiencing the most permanent deformation. These beams were the focus of the next set of measurements.

Table 1. Permanent Deformation In Floor Beams

Beam #	Trailer A	Trailer B	Trailer C	Trailer D	Trailer E	Trailer F	Trailer G	Trailer H	Trailer I	Trailer J	**Average**
20	0 219	0.234	0 245	0.206	0.270	0.278	0 358	0.187	0 294	0.328	0 262
21	0 284	0 269	0.278	0 277	0 319		0 458	0.210	0 304	0 399	0.311
22	0.307	0 255	0 280	0 294	0 390	0.343	0.497	0.219	0.368	0.442	0 340
23	0.312	0 290	0 309	0.314	0.354	0.279	0.497	0 229	0.315	0.434	0.333
24	0.331	0 271	0 303	0.309	0.338	0.304	0 477	0 196	0.373	0.499	0.340
25	0 309	0 310	0 308	0.310	0.359	0.332	0.483	0 243	0.328	0.447	**0.343**
26	*	*	*	*	*	*	*	*	*	*	*
27	0.305	0 308	0 295	0.389	0.322	0.298	0 464	0.302	0.312	0 445	0.344
28	0.302	0.292	0 282	0.405	0.329	0.300	0.462	0.235	0 304	0.353	**0.326**
29	0.315	0.310	0.243	0.421	0 281	0.310	0 466	0 258	0.300	0.341	0.325
30	0 307	0.330	0 260	0.364	0 274	0.321	0.455	0 279	0.329	0.274	0.319
31	0.379	0.325	0.269	0.379	0.258	0 346	0.460	0.286	0.319	0 293	0 331
32	0 370	0 357	0.293	0 365	0.256	0 328	0 479	0.272	0.353	0.354	0.343
33	0.348	0 363	0 278	0.379	0.312	0.333	0.466	0.243	0 366	0.319	0.341
34	0.382	0.372	0.257	0 382	0 292	0.294	0 509	0.280	0 422	0.319	**0.351**
35	0 307	0 350	0 276	0 366	0.255	0.310	0 542	0.231	0.388	0.351	0.338
36	0 313	0 295	0 261	0.345	0.289	0.280	0 495	0.229	0.430	0.362	0.330
37	0.272	0 242	0 255	0.292	0.270	0.263	0 471	0.195	0 359	0.335	0.295
38	0.279	0 227	0.186	0.250	0.230	0 243	0 322	0.131	0.317	0.315	0.250
39											
40											

* Beam 26 Could not be measured due to turn signal assembly

As shown in Table 1 a definite trend developed. Beams 25, 28 and 34 had the three highest maximum averages. At this point the study was narrowed to nine beams, 22-24, 28-30, 34-36. Due to an oversight in the field, Beam 25 was not included. The nine selected beams were then measured on the thirty additional trailers. Table 2 is a summary of these measurements. Again the maximum averages are in bold. The maximum average deformations were not found on the same beams as the previous study. The maximums were on beams 22, 30, and 34. After the collected data were analyzed, it was decided to gage Beams 23, 28 and 34; these beams represent the full spectrum of permanent deformations measured. Beam 34 had the highest recorded deformations as the other two stated beams' deformations were of no particular significance. These beams or their equivalents were gaged for all of the following tests.

Table 2. Measured Permanent Deformation in Selected Floor Beams

Beam	22	23	24	28	29	30	34	35	36
Trailer AA	0 369	0.386	0.41	0 326	0 331	0 307	0 374	0.342	0.34
Trailer BB	0.234	0.22	0.206	0.324	0 326	0 329	0 383	0 348	0.322
Trailer CC	0.303	0.373	0.336	0.304	0.327	0.332	0.384	0 409	0 366
Trailer DD	0.345	0.376	0.343	0.253	0.211	0 216	0 222	0 256	0 244
Trailer EE	0 367	0 373	0 351	0.341	0.289	0.315	0 233	0 246	0 228
Trailer FF	0 241	0 239	0 202	0.267	0.273	0.278	0.344	0 381	0 331
Trailer GG	0.281	0.271	0 298	0.205	0 223	0.254	0.384	0.406	0.397
Trailer HH	0 381	0 372	0 146	0.374	0 385	0.366	0.487	0 469	0.467
Trailer II	0 348	0 327	0 351	0 271	0.221	0.262	0.339	0 283	0.299
Trailer JJ	0.318	0 308	0.353	0.357	0 367	0.385	0.356	0.306	0.312
Trailer KK	0.307	0 261	0.28	0 246	0 262	0.264	0 266	0.285	0 282
Trailer LL	0 41	0.406	0.445	0.345	0 355	0.37	0 352	0.312	0 261
Trailer MM		0.293	0.298	0.363	0 325	0 397	0.431	0.379	0.315
Trailer NN	0.27	0.295	0.277	0.301	0.301	0 286	0.348	0.37	0 376
Trailer OO	0 377	0.377	0.399	0.404	0.398	0.341	0.354	0.374	0 37
Trailer PP	0.335	0.291	0.323	0.33	0.403		0.309	0.28	0 279
Trailer QQ	0.319	0.334	0.303	0.312	0.323	0.359	0 268	0 271	0 242
Trailer RR	0 33	0.297	0 301	0 369	0.415	0 42	0 499	0 478	0.438
Trailer SS	0.22	0 234	0 207	0 202	0.244	0.222	0 289	0 32	0.328
Trailer TT	0 381	0 368	0 339	0.347	0.352	0.321	0 367	0.388	0 387
Trailer UU	0 207	0 132	0.208	0 196	0.248	0 25	0.313	0.307	0.305
Trailer VV	0 338	0.371	0.322	0.408	0 397	0 393	0.48	0.476	0.382
Trailer WW	0.373	0 382	0 393	0 443	0.444	0 468	0.407	0 388	0.344
Trailer XX	0 28	0.301	0 299	0.314	0.29	0.272	0.223	0.236	0.218
Trailer YY	0.376	0.394	0 411	0 396	0.407	0.409	0 46	0 464	0.41
Trailer ZZ	0.397	0.456	0 433	0 335	0 368	0.375	0 399	0 29	0 239
Trailer AB	0 344	0 332	0 315	0 349	0 36	0.371	0.416	0.405	0.382
Trailer BC	0.476	0 38	0.446	0 323	0 322	0 287	0.311	0.313	0 3
Average	**0.331**	0.327	0.321	0 322	0 327	**0.328**	**0.357**	0.349	0 327

Chapter 3

Testing

3.1 Trailer Selection

Four different trailers with two different configurations and manufacturers were selected for testing. The first configuration, a standard van trailer with floor beams 12 inches on centers, represented three of the four test trailers. Two of these trailers were randomly picked from the carrier's fleet. The third was selected because of its load history. The trailer had been on loan to a local band since its delivery; therefore, it had not experienced paper loading or hauling. The final trailer was a standard van trailer, similar to the previous three, but made by a different manufacturer with floor beams at eight inches on centers. This trailer was not sought for its different origin but for its different beam spacing. The proprietary differences in the trailers were not investigated and assumed negligible for the investigation.

3.2 Load Test 1

The initial test was to measure the strains associated with a loaded forklift traveling through the trailers. This test was performed on two of the trailers with floor beams at 12 inches on centers and the trailer with floor beams at 8 inches on centers.

The test trailer was parked at a loading dock. The forklift ramp was placed within the open cargo doors. The test was started as the loaded forklift, Figure 4, approached the dock ramp.

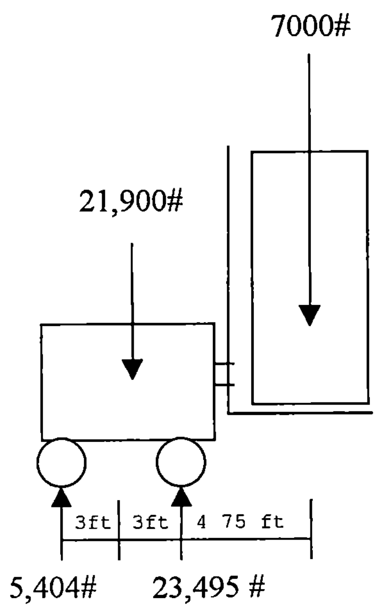

Figure 4. Loaded Forklift Schematic

Following entry into the trailer the forklift traveled to the front of the trailer staying as close to the trailer centerline as possible. As the test proceeded the beams experienced the maximum forklift axle load of approximately

24 kips as shown above. Once at the front of the trailer the operator backed out following the same path. The test was stopped with the exit of the forklift from the trailer. This test was repeated for two additional trailers including the trailer with beams at 8 inches on centers.

3.3 Loading Test 2

Loading Test 2 was a full loading of the test trailer. The objective was to measure the maximum stresses experienced by the floor beams and the walls during a typical loading cycle. The floor beams supported approximately the same load as in the previous test; however, the wall strains were significantly larger due to the contribution of multiple paper rolls.

As with the previous test the test trailer was parked at a loading dock. Again, the dock ramp was placed in the open doorway. The test began as the forklift approached the dock ramp. The trailer was loaded with a full load of paper, approximately 46000 pounds. The paper rolls were placed in a fashion that balanced the load between the axles and the fifth wheel, which is the normal loading procedure, as illustrated on the following page in Figure 5. The loading scheme was similar to everyday practices for the purpose of testing.

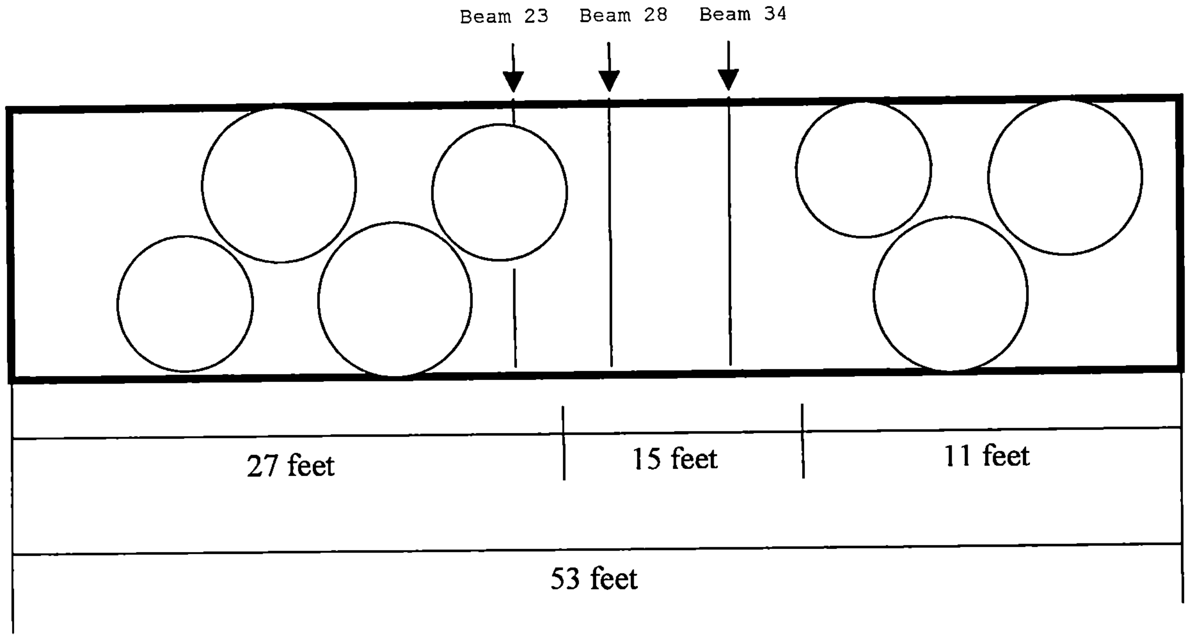

Figure 5. Typical Load Placement

The paper rolls shown above vary between 6000 and 7000 pounds. After all of the rolls were in place and the forklift was back on the loading dock, the test was stopped.

3.4 Road Test

The objective of this final test was to determine the dynamic effect of over-the-road hauling on the floor beams and walls. The test was performed on a trailer with floor beams at 12 inches on centers. Dynamic amplification factors were determined from this test for the instrumented components. The trailer was loaded in a manner similar to the previous tests with the exception of the load placement. The paper rolls in this test were of different diameter and thus of different weights; therefore, the load placement was different. The test was started prior to loading as with the other tests. After loading, the trailer was then subjected to a three hour "over the road" test. During the test the trailer experienced road conditions such as, but not limited to, bridge approaches, railroad crossings, as well as other prevalent road conditions.

Chapter 4

Data Acquisition

4.1 Instrumentation

The data acquisition system contained three vital parts; the MEGADAC data collector, its accompanying software, Test Control Software (TCS), and gages including strain gages as well as Linear Variable Differential Transformers (LVDT). The MEGADAC data collector reads the voltage changes from each gage. These voltage changes are then read by TCS and converted to either microstrains or inches whichever the case may be. The strain gages were resistance strain gages in which a change in the length corresponds to a change in resistance, which in turn is read by the MEGADAC and converted by TCS to microstrains and stored in the test file. Deflections are read from the LVDTs in a similar manner. As the probe of the LVDT travels, the inductance of the system changes, which is read by the MEGADAC, and converted and stored by TCS as deflection in inches.

4.2 Gaging Beams

As stated previously in Chapter 2, Beams 23, 28, and 34 were instrumented. Both strain gages and LVDT's were installed. Strain gages were placed on the bottom flange at the centerline and at each end of the three beams. The gages at the end were used to determine the degree of fixidy of the connections, which was important for theoretical models that follow. The strain gage at the centerline was to determine the maximum strain that the beams experienced. Figure 3 illustrates the strain gage placements.

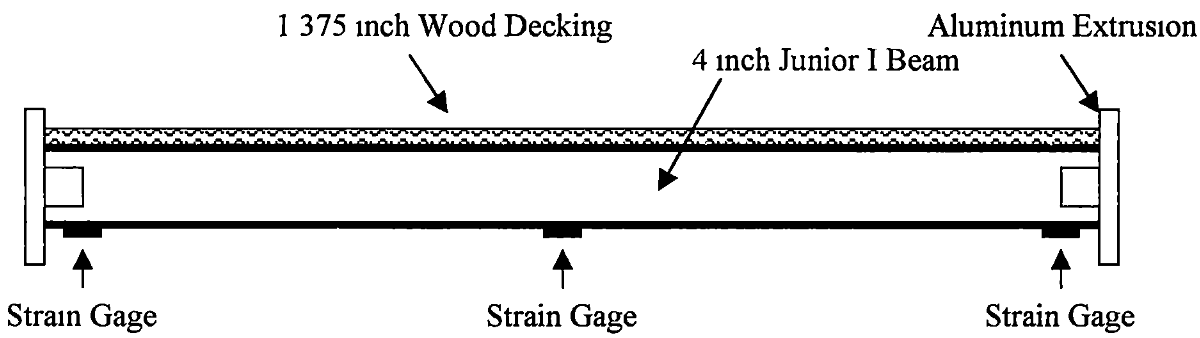

Figure 6. Strain Gage Placement on Floor Beams

LVDTs were placed as close as possible to the strain gauges shown in Figure 6 The LVDTs on the end of the beams were used to zero out the frame's deflection. The LVDTs placed at the centerline of the beams were used to read the maximum deflection of the beams. LVDTs were used for Load Test 1 and 2 but not for the Road Test due to obvious reasons.

4.3 Gaging Frame

Both types of instrumentation were used on the walls of the trailer. From this point forward the sidewalls are referred to as the frame. The top and bottom of the frame (walls) were comprised of the aluminum extrusions discussed earlier. The gages were placed directly on both the top and bottom extrusions. Strain gages were placed at the midpoint between the supports, which were the axles on the rear of the trailer and the fifth wheel in the front. This midpoint was the point of maximum moment for the frame. The strain gage placement is illustrated in Figure 7

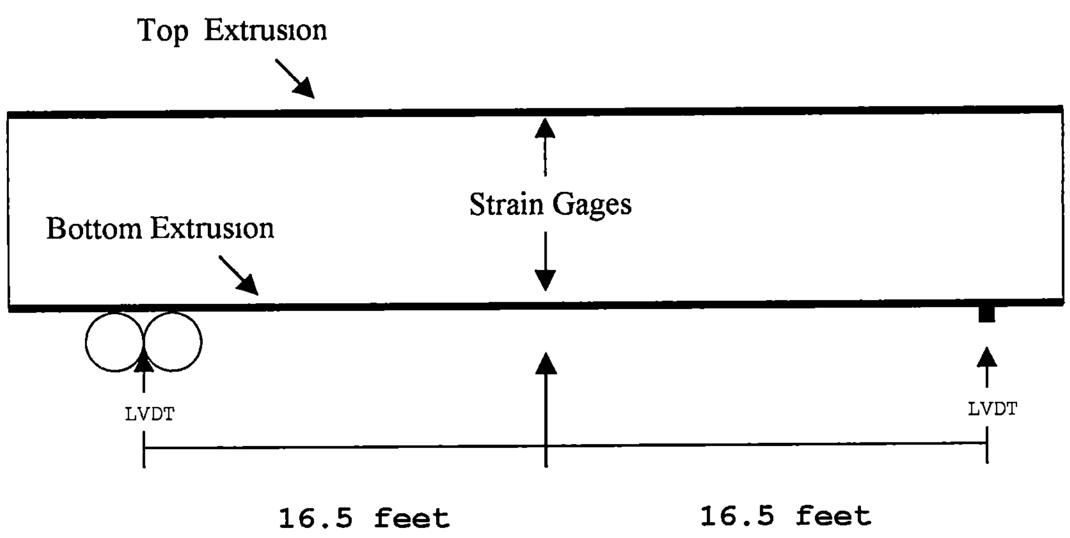

Figure 7. Gage Placement on Frame

LVDTs were placed at both supports, the fifth wheel and between the axles, shown above. These LVDTs allowed the spring deflections due to the tractor's and trailer's suspension to be zeroed out. These LVDTs, along with the LVDTs placed at the end of Beams 23, 28, and 34, were used to determine frame deflections.

Chapter 5

Data Analysis

5.1 Data Exportation

Data analysis began with the exportation of the test data from Test Control software to Microsoft Excel. Excel is a spreadsheet program, which allows the analysist to manipulate the large numbers of data points involved. After all seven tests were exported and formatted to Excel, the analysis began.

5.2 Beam Strain During Loading Tests

Beam strains were plotted verses time for all of the tests. It was not possible to plot the measured strains on the three beams during full loading test on a single plot; therefore, each beam was plotted on separate figures. The data became cluttered. Figure 8 shows Beam 23 during a Load Test 2 on Trailer 1. Figure 9 is a plot of the time interval as the first roll of paper was placed on Trailer 1. The other plots of measured beam strains are contained in Appendix A. The peaks on the strain vs. time plot are the forklift's front axle crossing the beam.

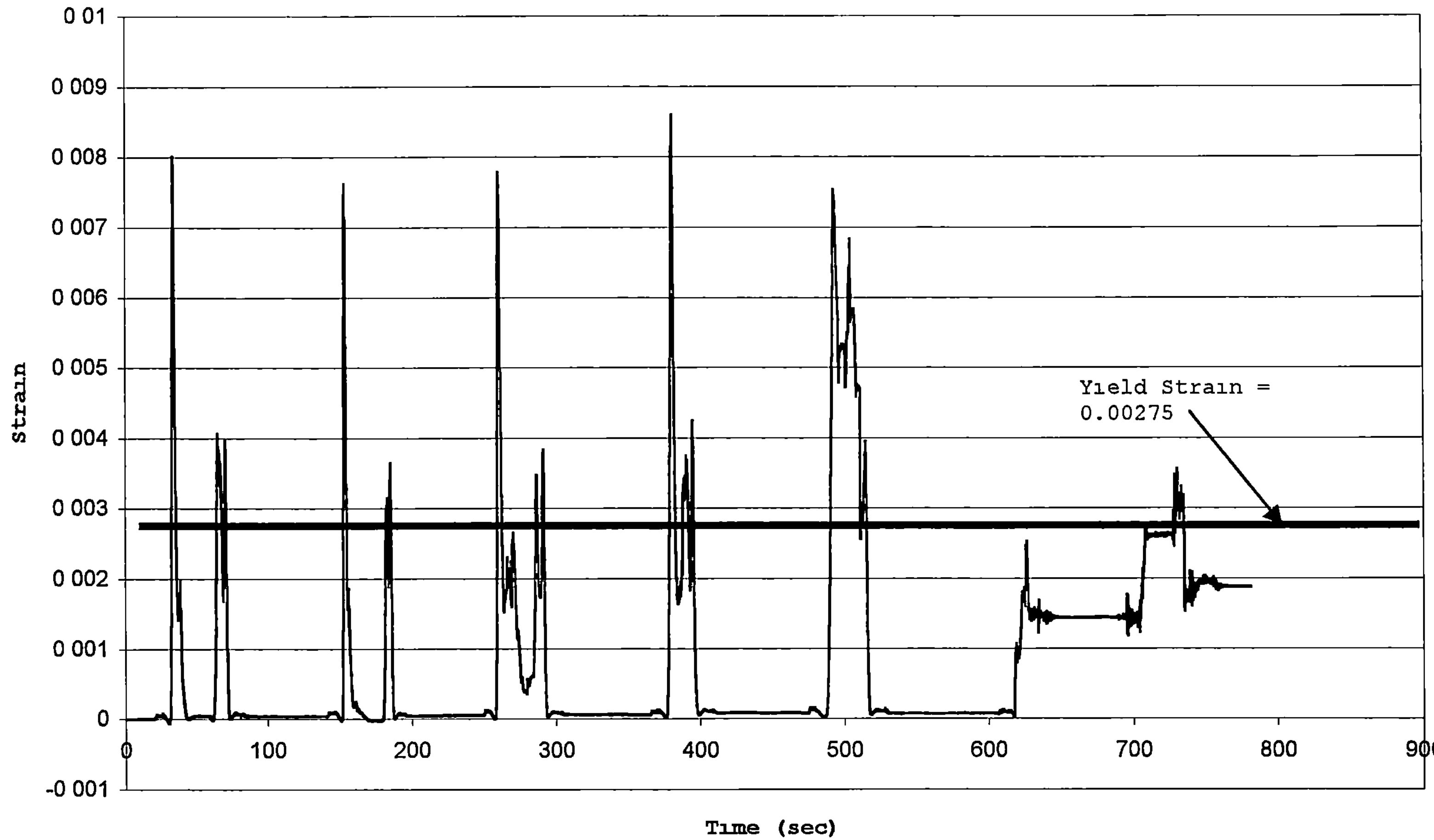

Figure 8. Measured Strains, Load Test 2 , Trailer 1, Beam 23

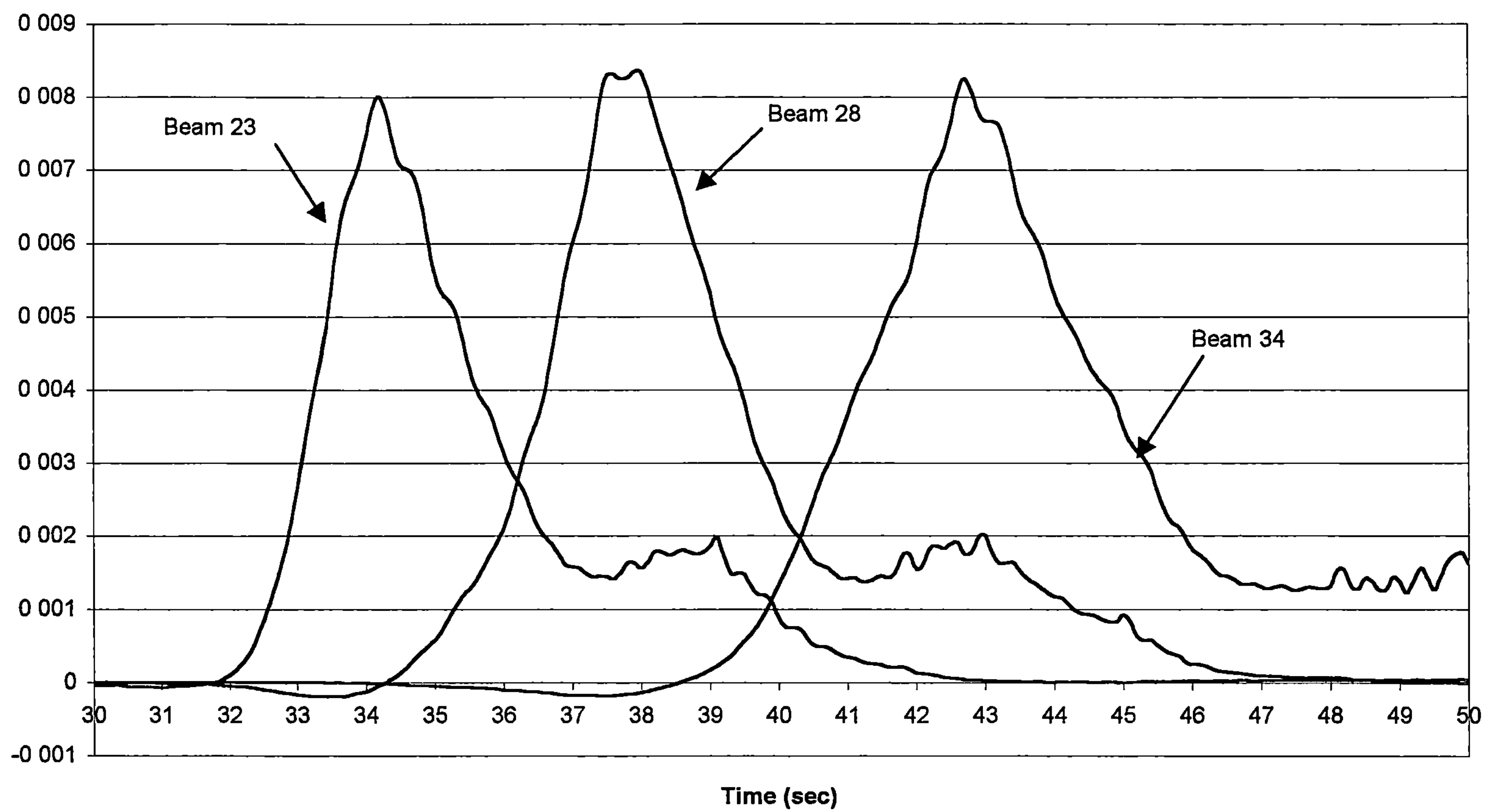

Figure 9. Measured Strains, Load Test 2, Trailer 1
(30-50 seconds)

The forklift rolls over Beam 23 five times during this loading. For the analysis, every time a loaded forklift crosses the beam, the beam has experienced one loading. All of the beam loadings for Trailers 1 and 2 involving Load Tests 1 and 2 are summarized in Table 3. The beam loadings for Trailer 3 for Load Test 1 and 2 are shown in Table 4. Trailer 3 had a different beam spacing than Trailers 1 and 2. The beams did not have the same number of loadings per test due to their position on the trailer. For instance Beam 23 had more loadings during a full loading cycle because it was closest to the door. The forklift crossed this beam in order to place rolls of paper beyond Beam 23 position. Beam 34 had the least loading since it was closest to the front of the trailer. After the first roll of paper was placed in the trailer, it was not possible for the forklift to travel beyond Beam 34.

Following pages contain histograms of the measured strains previously summarized in Tables 3 and 4. Figure 10 is the histogram of the measured strains from Trailers 1 and 2 generated from the data set summarized in Table 3 as well as the actual yield

Table 3. Measured Strains

Trailer 1 and 2 With Floor Beams at 12" O.C

Trailer 1, Load Test 1

Beam 23, Trailer 1

	Strain
23-1*	0.00691
23-2	0.00671
28-1	0.00711
28-2	0.00712
34-1	0.00685
34-2	0.00691

Trailer 1, Load Test 2

23-1	0.00801
23-2	0.00751
23-3	0.00765
23-4	0.00859
23-5	0.00745
28-1	0.00835
28-2	0.00845
28-3	0.00838
28-4	0.01068
34-1	0.00825
34-2	0.00662

Trailer 2, Load Test 1

23-1	0.00663
23-2	0.00653
28-1	0.00673
28-2	0.00667
34-1	0.00653
34-2	0.00672

Trailer 2, Load Test 2

23-1	0.00702
23-2	0.00657
23-3	0.00640
23-4	0.00557
23-5	0.00531
28-1	0.00761
28-2	0.00699
28-3	0.00675
34-1	0.00753
34-2	0.00729
34-3	0.00647

Mean	0.00720
Standard Deviation	0.00098
Maximum	0.1068

Table 4. Measured Floor Beam Strains

Trailer 3 with Floor Beams at 8" O.C

Trailer 3, Load Test 1

	Strain
33-1	0.00537
33-2	0.00543
42-1	0.00521
42-2	0.00509
52-1	0.00535
52-2	0.00528

Trailer 3, Load Test 2

33-1	0.00528
33-2	0.00612
33-3	0.00491
42-1	0.00494
42-2	0.00719
42-3	0.00500
52-1	0.00514
52-2	0.00524
52.3	0.00764

Average Strain	0.00555
Standard Deviation	0.00082
Maximum	0.00764

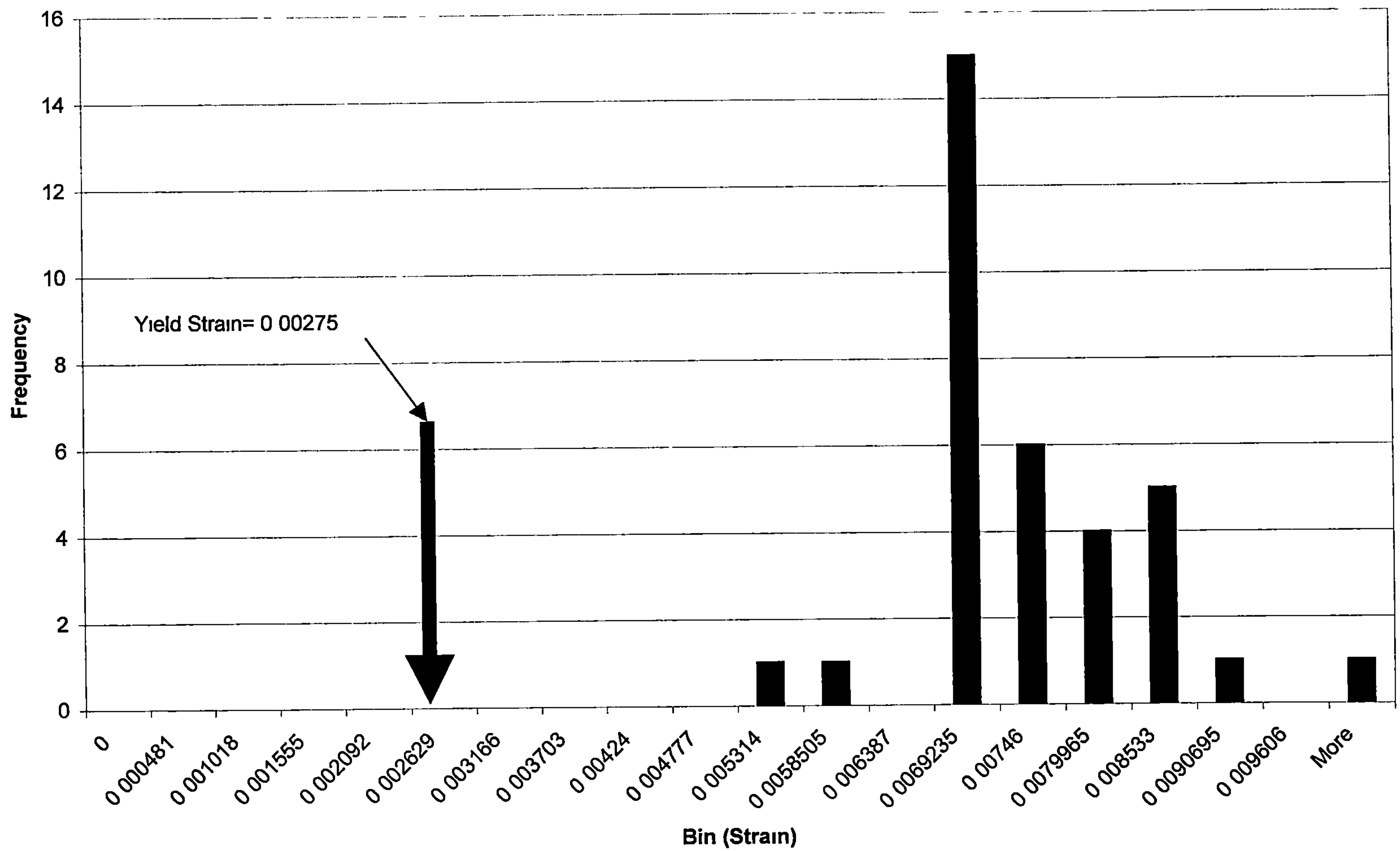

Figure 10. Histogram of Measured Floor Beam Strains Trailers 1 and 2

strain of the metal beams. By normal design standards the yield strain should occur at a strain almost two times the median strain. It can be seen from these data that the floor beams could be expected to experience yielding during every loading cycle with forklift axle loads similar to those in the load tests. Figure 8 is the histogram of strains for Trailer 3 generated from the data set in Table 4. Figure 11 also has the actual yield strain shown on the figure. The histogram is a very good tool for visualizing the variance in the strains of the different loadings. The variance in these strains is due to different forklift paths and differences in the paper roll weight. The shown variances were expected due to the random nature of normal loading.

5.3 Beam Deflections

Beam deflections at the centerline of the floor beams were plotted for Load Tests 1 and 2 for all three of the trailers, Figure 12 is the plot of the deflections of floor Beam 23 on Trailer 1 during Load Test 2. The deflection data were not as accurate as the strain data due to the nature of the tests. As the forklift traveled through the trailer there was a lot of movement, making deflection measurement difficult.

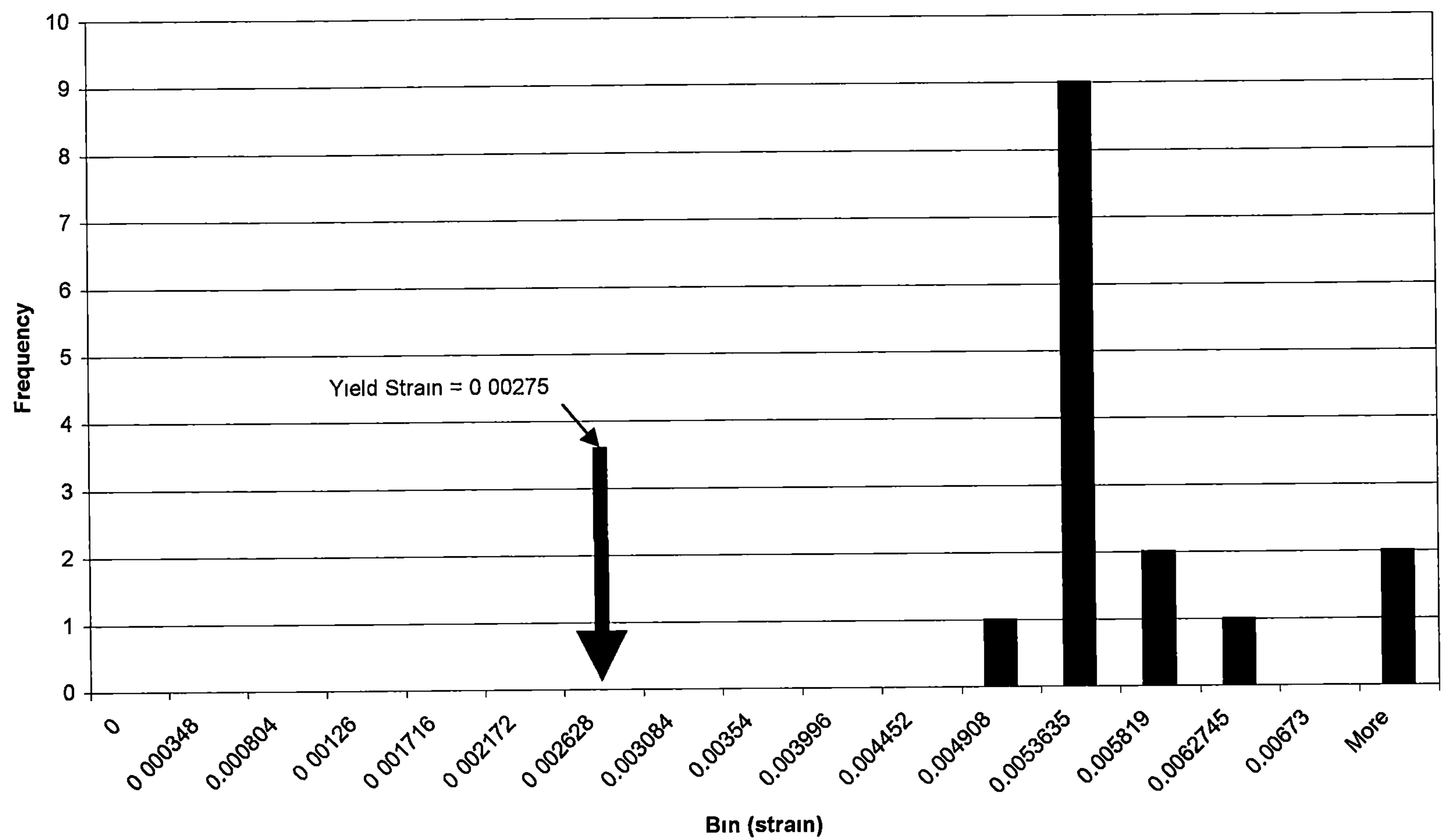

Figure 11. Histogram of Measures Floor Beam Strains Trailer 3

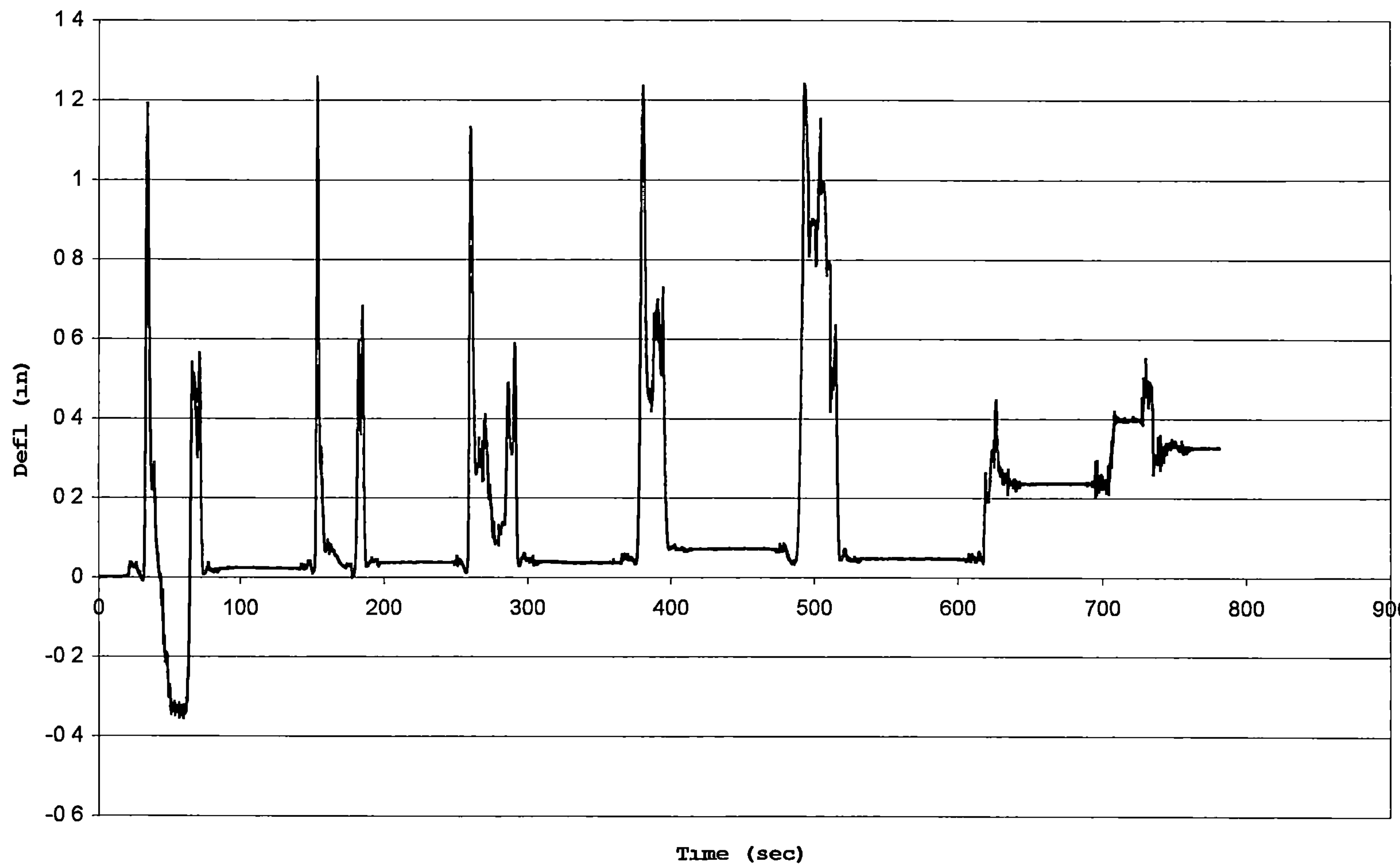

Figure 12. Measured Deflections, Load Test 2, Trailer 1, Beam 23

The LVDT's cannot be adjusted for the horizontal movement of the trailer. The probe of the LVDT's "walk" with the horizontal shimmering of the trailer. The deflection data were very near to the actual deflections but the horizontal movement introduced some error. Figure 12 on the previous page is a plot of Beam 23's deflection during a Load Test 2 of Trailer 1. It has the same shape of Figure 5, which is the plot of the strain for the same test. This is expected since the strain was being measured at the same place as the deflection. Tables 5 and 6 are the summaries of the measured beam deflections during both of the Load Tests. Table 5 is the summary for Trailers 1 and 2, and Table 6 is the summary for Trailer 3.

5.4 Frame Strains During Loading

Aluminum extrusion strains were plotted verses time for Load Tests 1 and 2. As expected the maximum strains occurred in Load Test 2 due to the additional weight of multiple paper rolls. The maximum strain of 0.00299 occurred in Trailer 2 during Load Test 2 shown on Figure 13. The maximum average strain of the three trailers during Load Test 2 was 0.00270.

Table 5. Measured Deflections

Trailer 1 and 2 With Floor Beams at 12" O.C

Trailer 1, Load Test 1

Beam 23, Trailer 1

	Deflection
23-1*	1.3
23-2	1.27
28-1	1.33
28-2	1.25
34-1	1.31
34-2	1.2

Trailer 1, Load Test 2

23-1	1.19
23-2	1.26
23-3	1.12
23-4	1.23
23-5	1.24
28-1	1.13
28-2	1.23
28-3	1.05
28-4	1.44
34-1	1.1
34-2	0.77

Trailer 2, Load Test 1

23-1	1.2
23-2	1.22
28-1	1.21
28-2	1.22
34-1	1.1
34-2	1.15

Trailer 2, Load Test 2

23-1	1.03
23-2	1.12
23-3	1.11
23-4	0.73
23-5	0.76
28-1	1
28-2	1.15
28-3	1.09
34-1	0.87
34-2	1.07
34-3	

Mean	1.13
Standard Deviation	0.16
Maximum	1.44

*Note notation Beam 23 Loading 1, same for remainder

Table 6. Measured Floor Beam Deflections

Trailer 3 with Floor Beams at 8" O.C

Trailer 3, Load Test 1

	Deflection
33-1	0.80
33-2	0.81
42-1	1.00
42-2	1.00
52-1	1.00
52-2	0.97

Trailer 3, Load Test 2

33-1	0.92
33-2	0.80
33-3	0.80
42-1	0.87
42-2	0.80
42-3	0.77
52-1	0.92
52-2	0.90
52.3	0.78

Average	0.88
Standard Deviation	0.09
Maximum	1.00

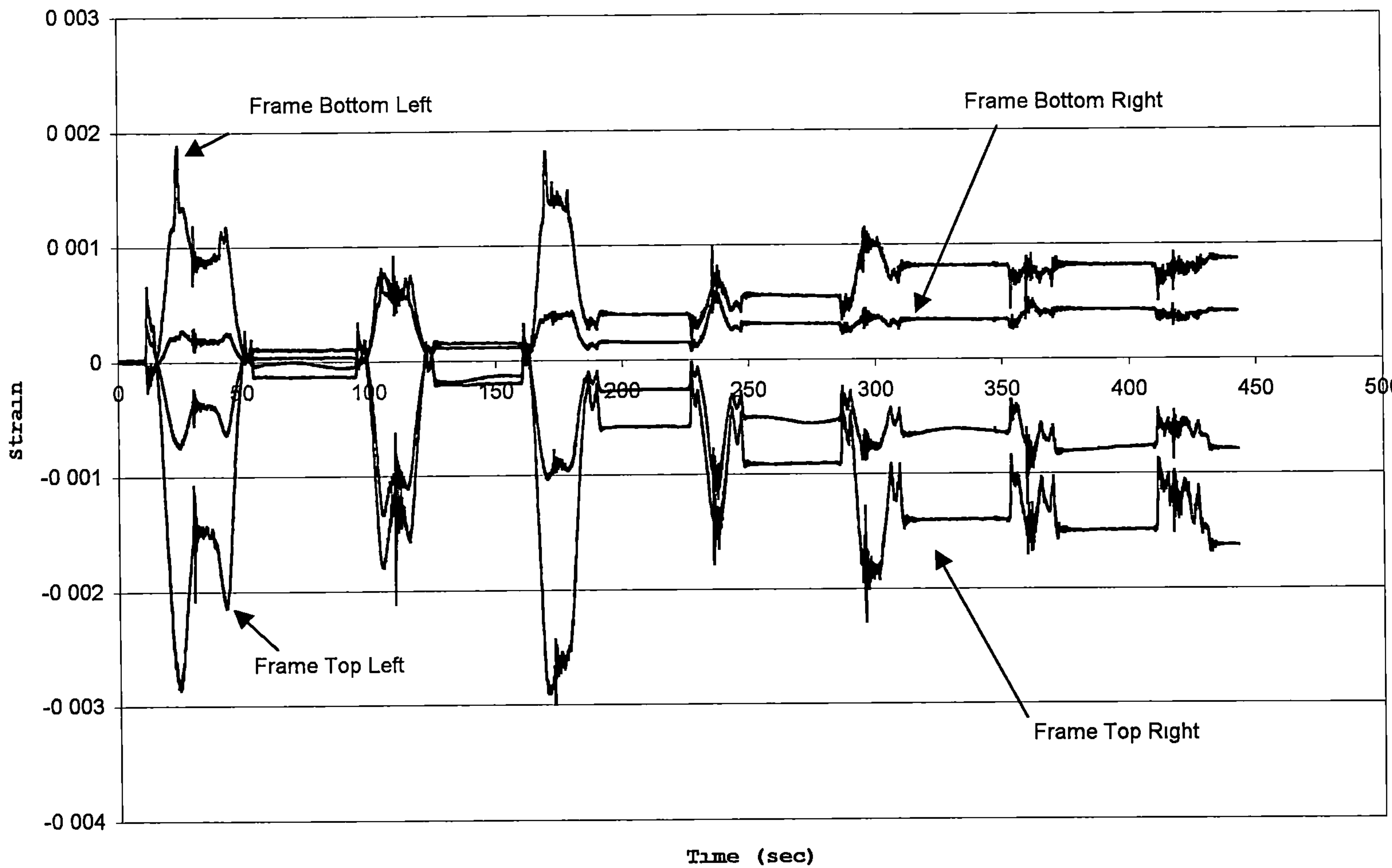

Figure 13. Measure Strains, Load Test 2, Trailer 2, Frame

The maximum strains occurred in all of the tests while the forklift was still on the trailer, illustrating the significant contribution of the forklift's weight. The plots for both Load Tests 1 and 2 for the remaining trailers are contained in Appendix A.

5.5 Road Test

Due to the length of the Road Test, only segments of the collected data were analyzed. Strain amplifications were investigated during the selected time periods. Time periods were selected that had large "spikes". These time periods were used to determine dynamic amplification factors and natural frequencies for the instrumented components. The plot of the top right extrusion of the frame during a selected time period, Figure 14, shown on the following page represents some of the amplifications seen during the Road Test. The natural frequency of the frame was 20 hertz during the analyzed time period; due to the influence of the frame the floor beams had the same frequency. The dynamic amplification factor for the frame and the floor beams during the same time period was 1.7.

5.6 Theoretical Models

Two different critical floor beam stress stages were modeled. The first modeled stress stage was the yield

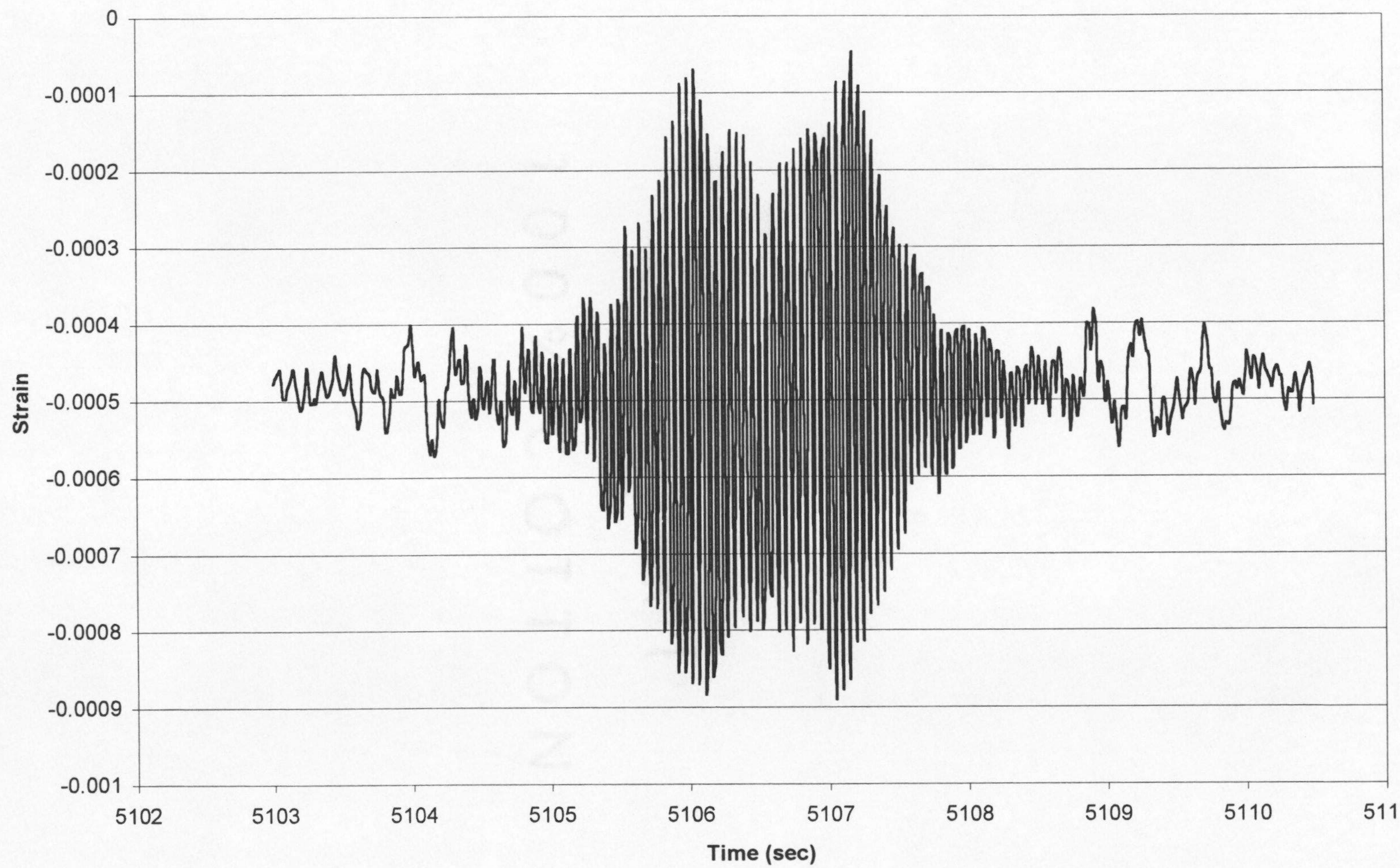

Figure 14. Measured Strains, Road Test, Frame Top Right

moment of the floor beams acting compositely with the hardwood decking. In order to model the beams as composite with the decking, the transformed moment of inertia was calculated as 6.114 in^4 compared to 2.63 in^4 for a beam acting alone. These calculations are contained in Appendix B. The yield moment and corresponding axle load for beams spaced 12 inches on centers were 12.30 kip feet and 10.38 kips respectively. The plastic moment calculation for floor beams spaced at 12″ on centers is also contained in Appendix B. The plastic moment for a beam described above is 14.33 kip feet, which corresponds to an axle load of 12.1 kips. Shear flow was also calculated for the same composite beam. The shear flow for the loaded beam was 0.614 kips per inch. The strength of each connection between the decking and the beam was calculated as 0.339 kips.

Chapter 6

Discussion of Results

6.1 Beam Response During Loading

Beam strains during both loading tests were significantly higher than expected. Both configurations of trailers, trailers with beams at 8 inches on centers and those with floor beams at 12 inches on centers, experienced strains well above the yield strain which is best illustrated with the histograms set forth in Chapter 5. Figure 9 is a histogram of measured floor beam strains during both load tests for Trailers 1 and 2 with the yield strain also identified. Figure 10 contains the same information for Trailer 3. These histograms show that the floor beams can be expected to yield during every loading cycle. The measured median floor beam strain for Trailers 1 and 2 was at more than 2.5 times the yield strain, and the median strain for Trailer 3 was approximately 2 times the yield strain. The load corresponding to the calculated plastic moment, 12.1 kips, is exceeded by 11.4 kips due to the axle load of the loaded forklift which indicates that approximately 5.7 kips has to be redistributed to the two adjacent beams whose yield capacity is 10.38 kips. The adjacent beams are near capacity when compared to design standards; i.e., the applied load approaches half of the allowable load. Floor beam deflections were also excessive. The maximum measured beam deflection for Trailers 1 and 2 and Trailer 3 was 1.44 inches and 1.00 inches respectively. An allowable deflection of L/180 would result in a deflection of 0.57 inches compared to the measured deflections of 1.00 inches and 1.44 inches; thus, the measured deflections are significantly higher than this widely accepted limit. This is the least stringent limit used in building construction with both concrete and steel. The calculated shear flow for the beam wood interaction was 0.614 kips per inch. This shear flow is larger than the capacity of a single connection, which is 0.339 kips. To effectively transfer the shear load, the screws would need to be placed three to an inch instead of the 3 to 4 inches on centers normally used. This connection failure greatly reduces the composite action.

Load distribution between the floor beams during the loading operation is a design consideration. It has been reported, by one manufacturer, that five beams are considered to carry the forklift axle loads. Examination of the strain data would indicate that this is not the case. Figure 6 represents a single loading cycle. When the front axle is over beam 34 the rear axle is directly over beam 28. Therefore the strains on beam 28 represent the percentage of the rear axle load carried by that beam. The measured strain corresponds to approximately 100 % of the axle load.

6.2 Frame Strains During Loading

The average maximum strain in the aluminum extrusions, the top and bottom of the frame, was 0.00270, which corresponds to a stress of 27 kips per square inch (ksi). Although this stress is below the yield stress of 40 ksi for 6061-T6 aluminum extrusions, it is above the endurance limit of 14 ksi. Repeated loading above this limit may result in fatigue failure. The extrusions can be expected to exceed the endurance limit for every loading cycle according to the performed tests; therefore, fatigue is an important design consideration.

6.3 Road Test

Dynamic amplifications of 1.7 were measured during the 3 hour and 18 minute road test. The amplifications were approximately the same for the floor beams and frame extrusions. The natural frequency for the trailer frame is approximately 20 hertz (see Figure 14). Consideration needs to be given to the amplification when posting the allowable load of trailers. Either the capacity of the structure should be decreased to account for the load amplification or the structure of the trailer should be "beefed up."

Chapter 7

Conclusions

Trailers should be designed for the maximum expected loads applied during their service life. Some van trailers are subjected to significantly higher loads during loading than the loads imposed during hauling. Loading loads certainly need to be considered in the design. It is not evident that the additional load due to the forklift was considered in the design of the trailers investigated. All investigated components were over stressed under normal loading operations. The redundancy of the structure prevents catastrophic failures but doesn't prevent significant damage to the trailer during each loading cycle. Serviceability is sacrificed and maintenance increased. Safety may also be compromised with long-term usage.

The following specific conclusions result from the previously described structural tests.

1. The floor beams are loaded beyond their yield limit during every loading cycle.
2. The composite floor beams are reached their plastic moment during every loading cycle.

3. The connections between the wood decking and steel floor beams are failing with every loading cycle.
4. Floor beam deflections are high with respect to the member's length.
5. The aluminum extrusions are exposed to stresses beyond the endurance limit.
6. Permanent deformation was evident in all trailers investigated.
7. Low cycle fatigue may cause failures below yield due to the stress ranges the floor beams experience.

List of References

List of References

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2. Rivello, Robert M., Thoery and Analysis of Flight Structures. McGraw-Hill Book Company. New York, 1969

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Appendices

Appendix A

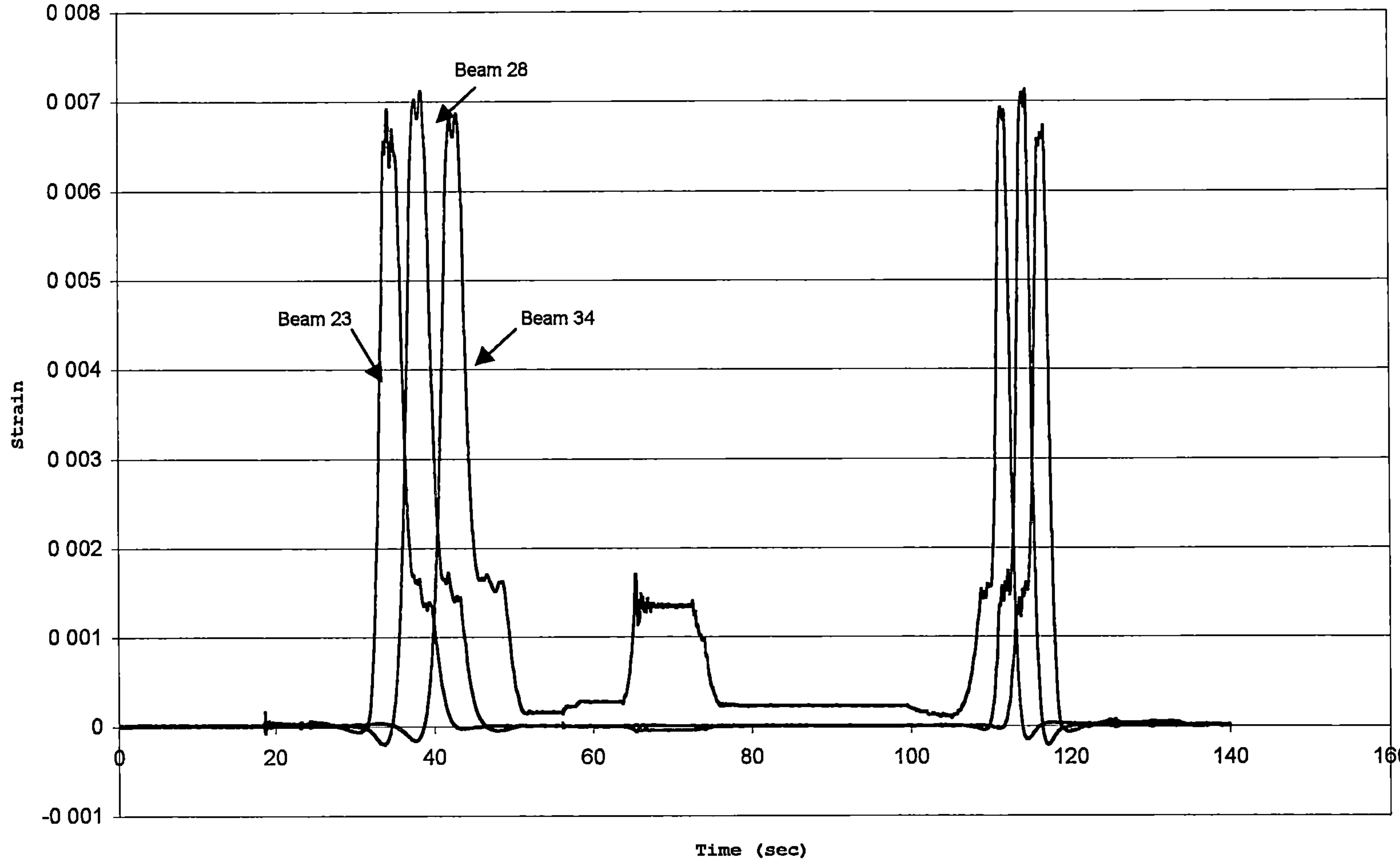


Figure A-1 Measured Strains, Load Test 1, Trailer1, Beams

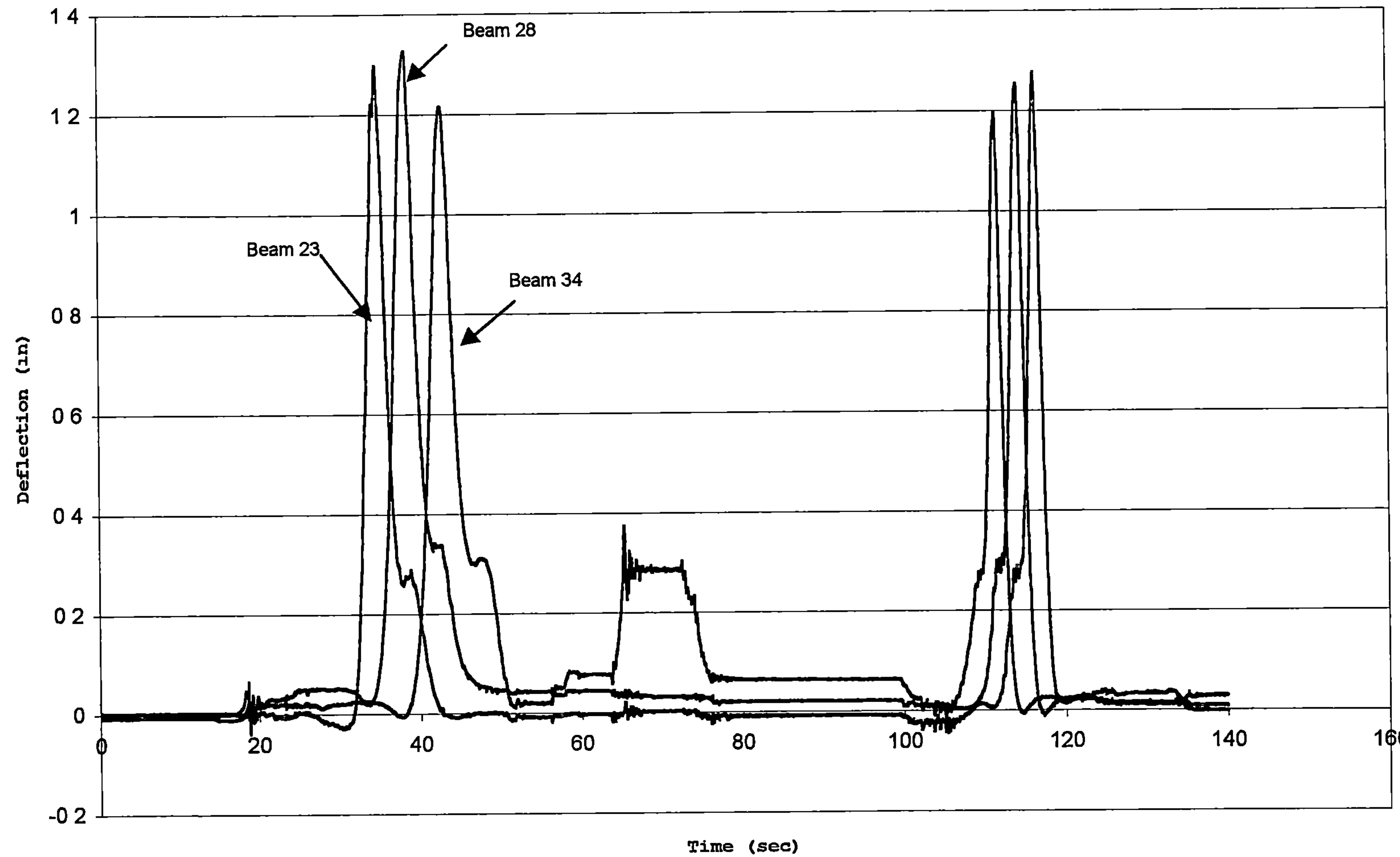


Figure A-2 Measured Deflections, Load Test 1, Beams

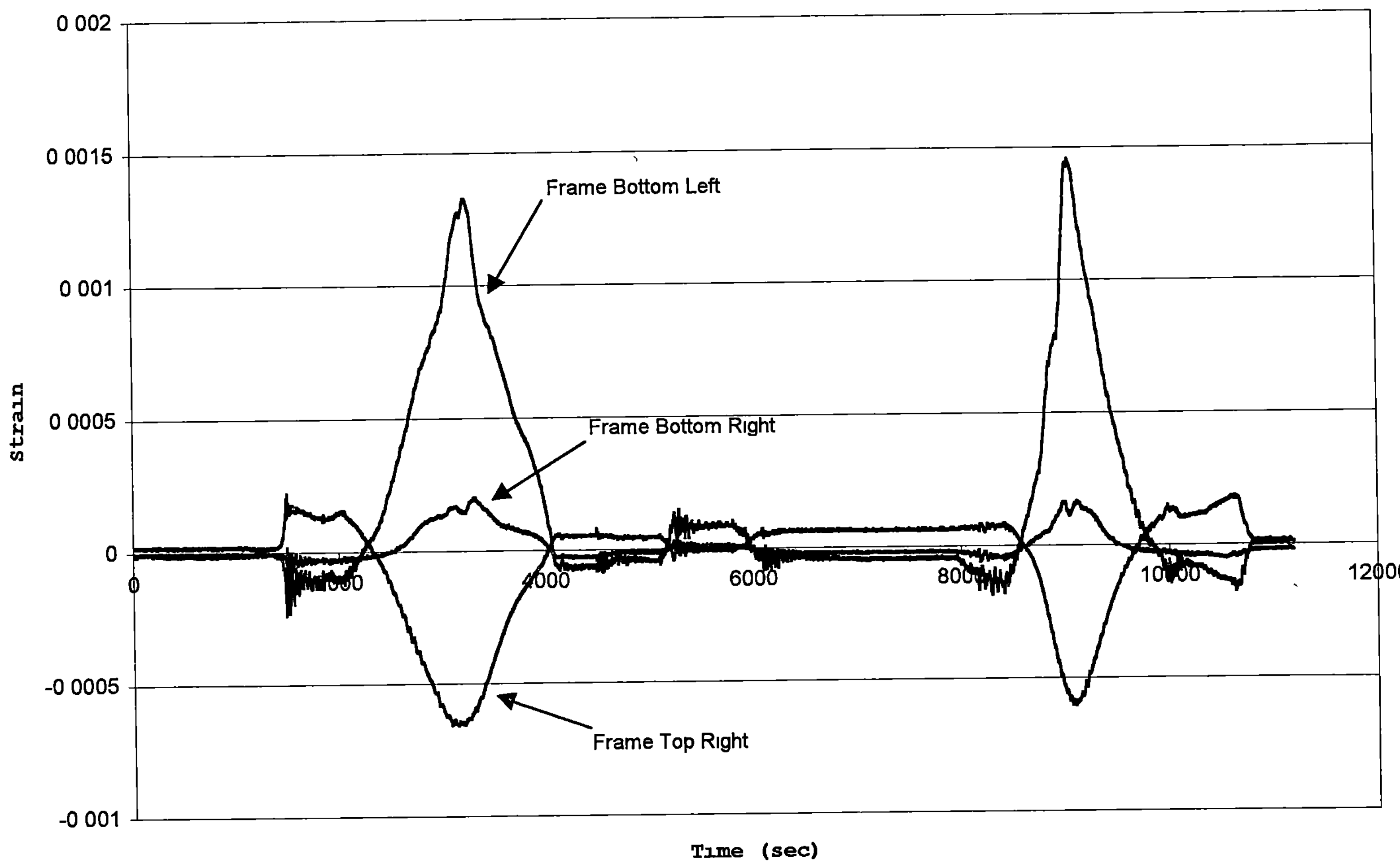


Figure A-3. Measured Strains, Load Test 1, Trailer 1, Frame

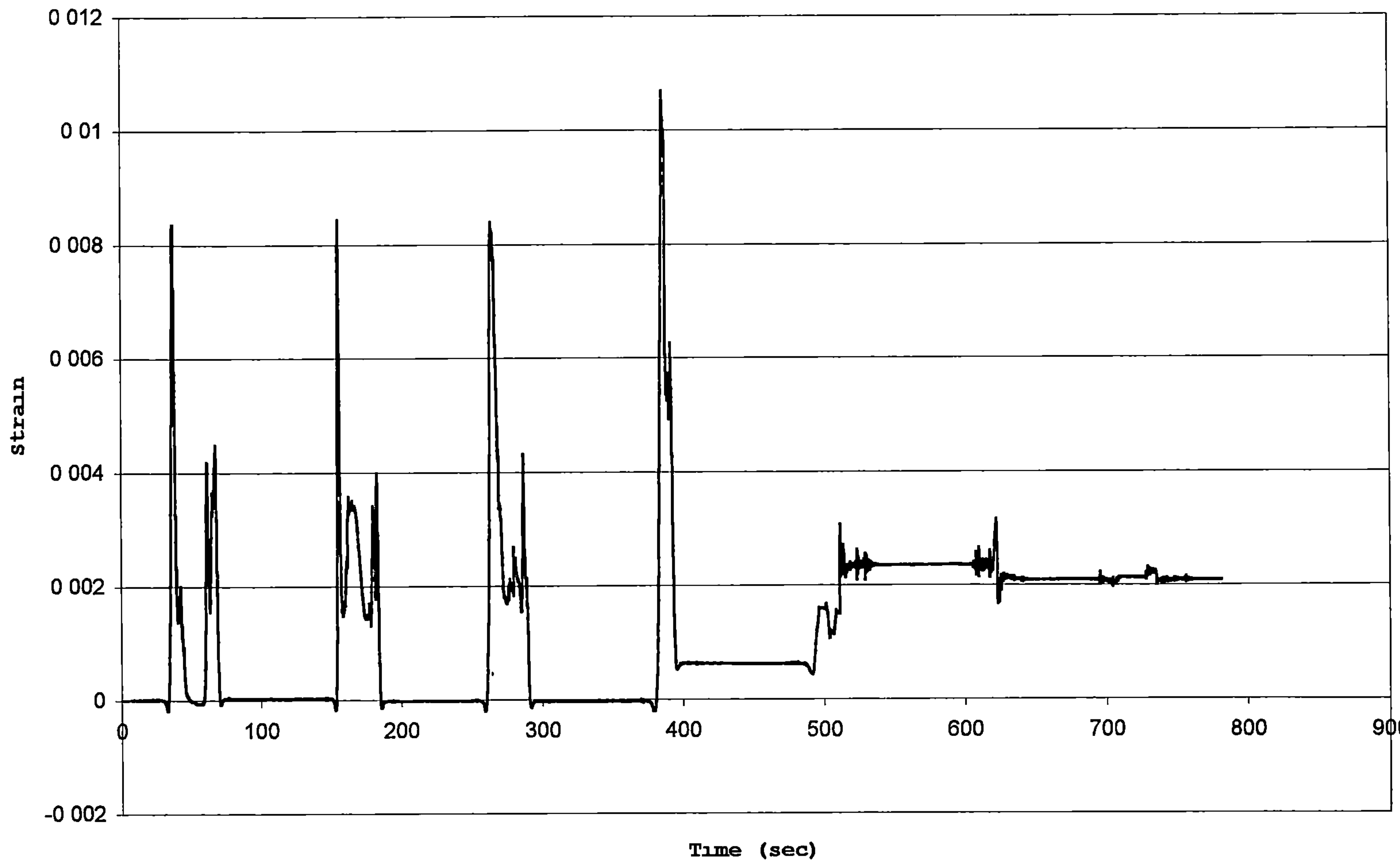


Figure A-4. Measured Strains, Load Test 2, Trailer 1, Beam 28

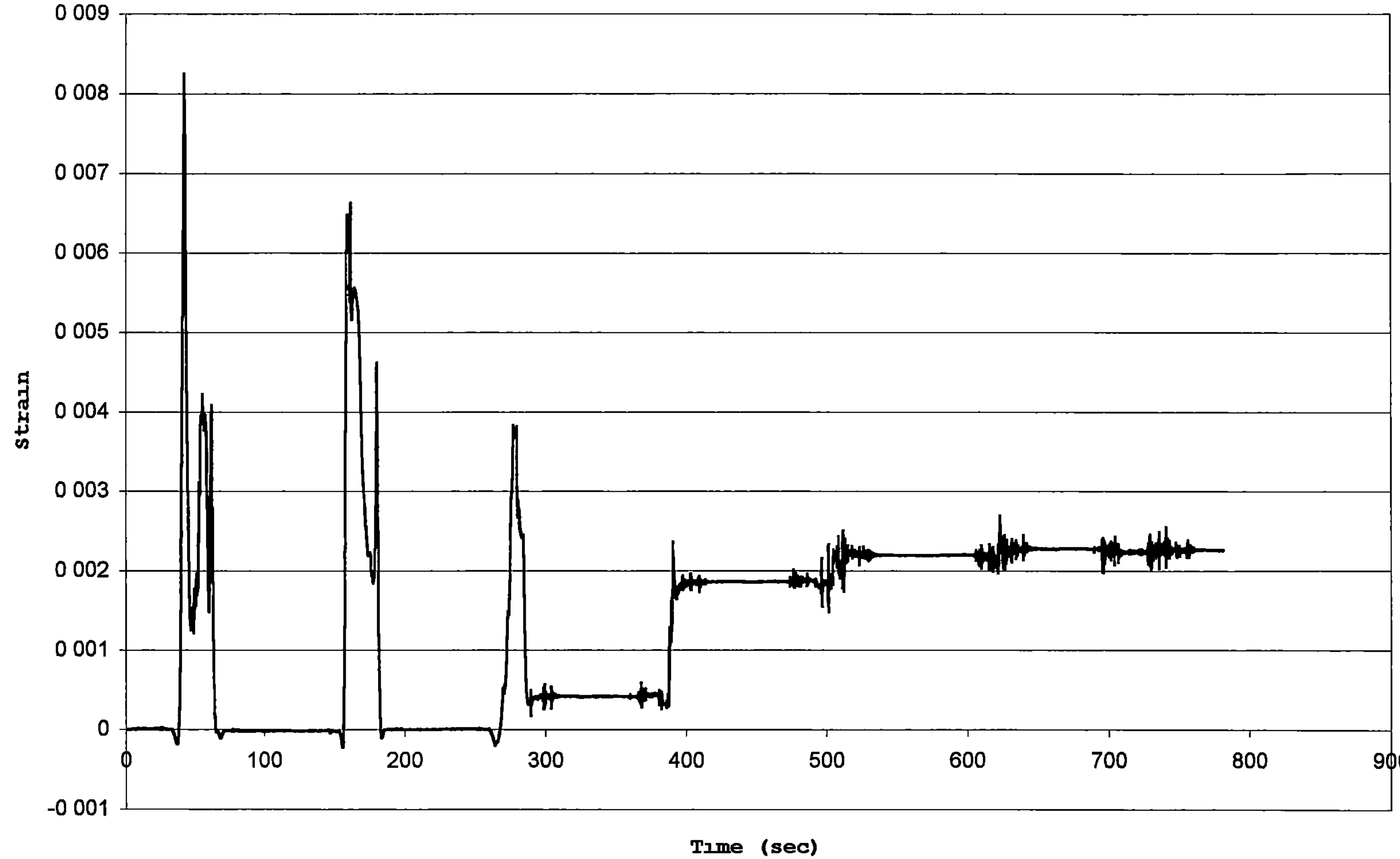


Figure A-5. Measured Strains, Load Test 2, Trailer 1, Beam 34

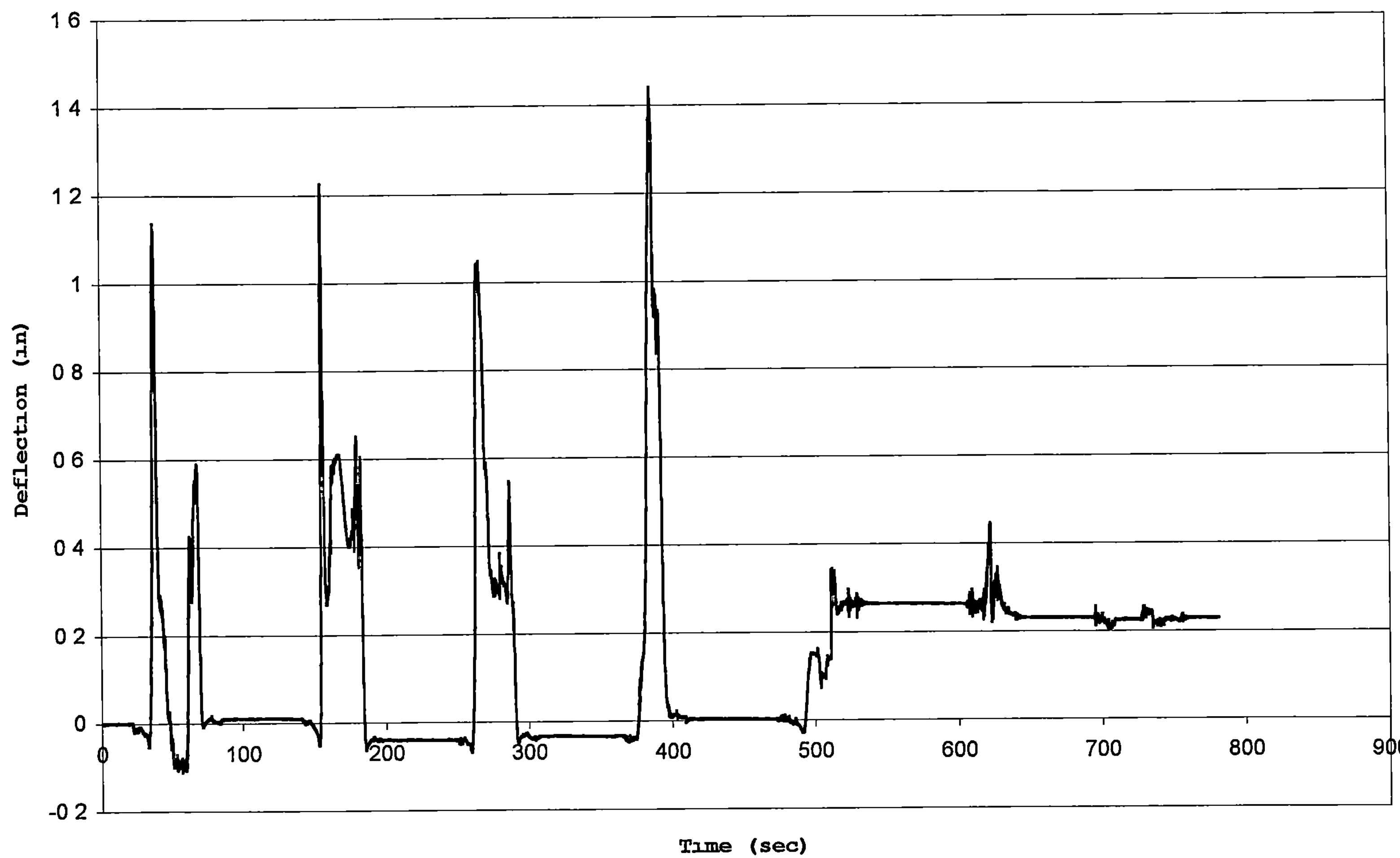


Figure A-6.Measure Deflections, Load Test 2, Trailer 1, Beam 28

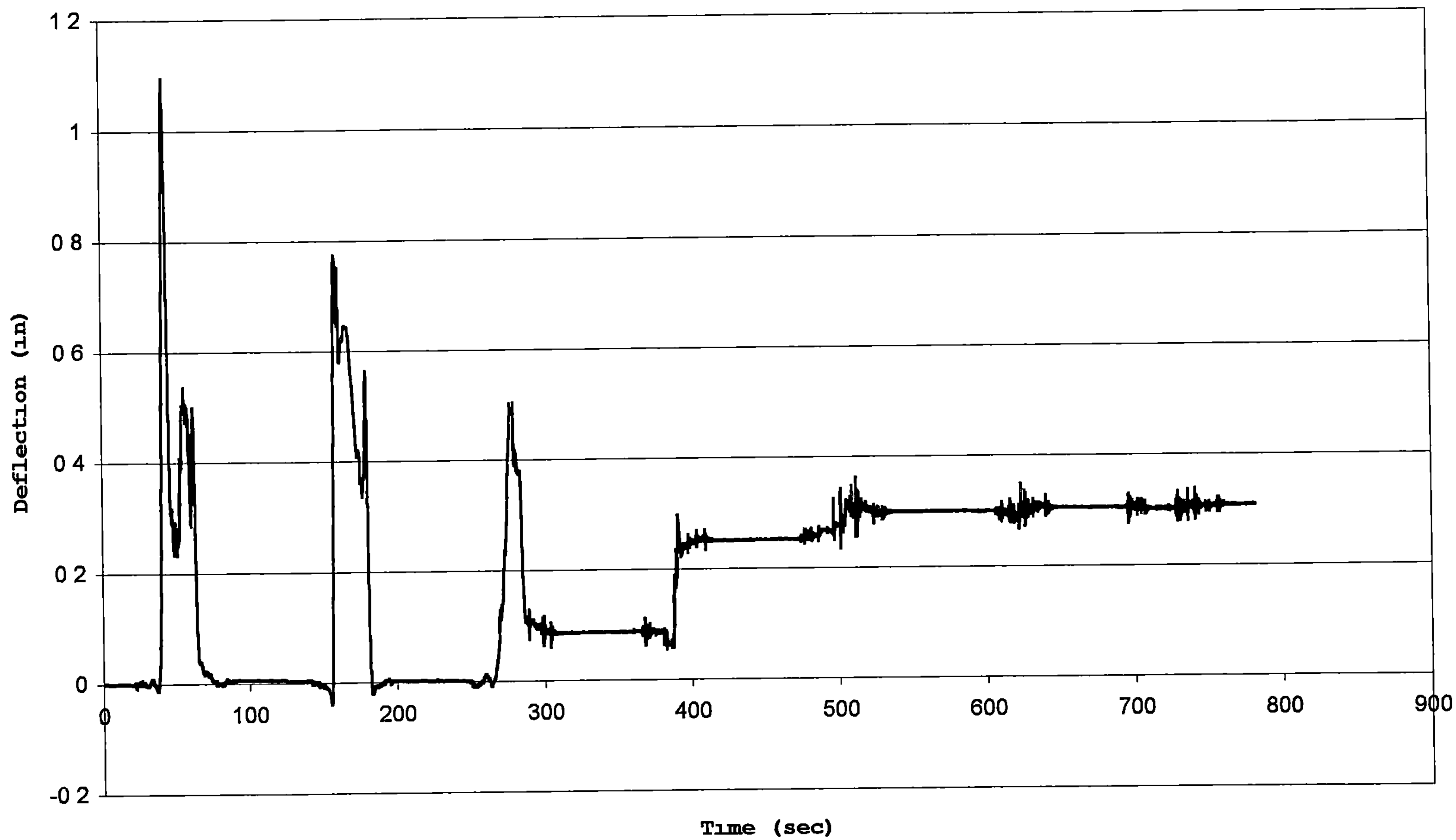


Figure A-7. Measured Deflections, Load Test 2, Trailer 1, Beam 34

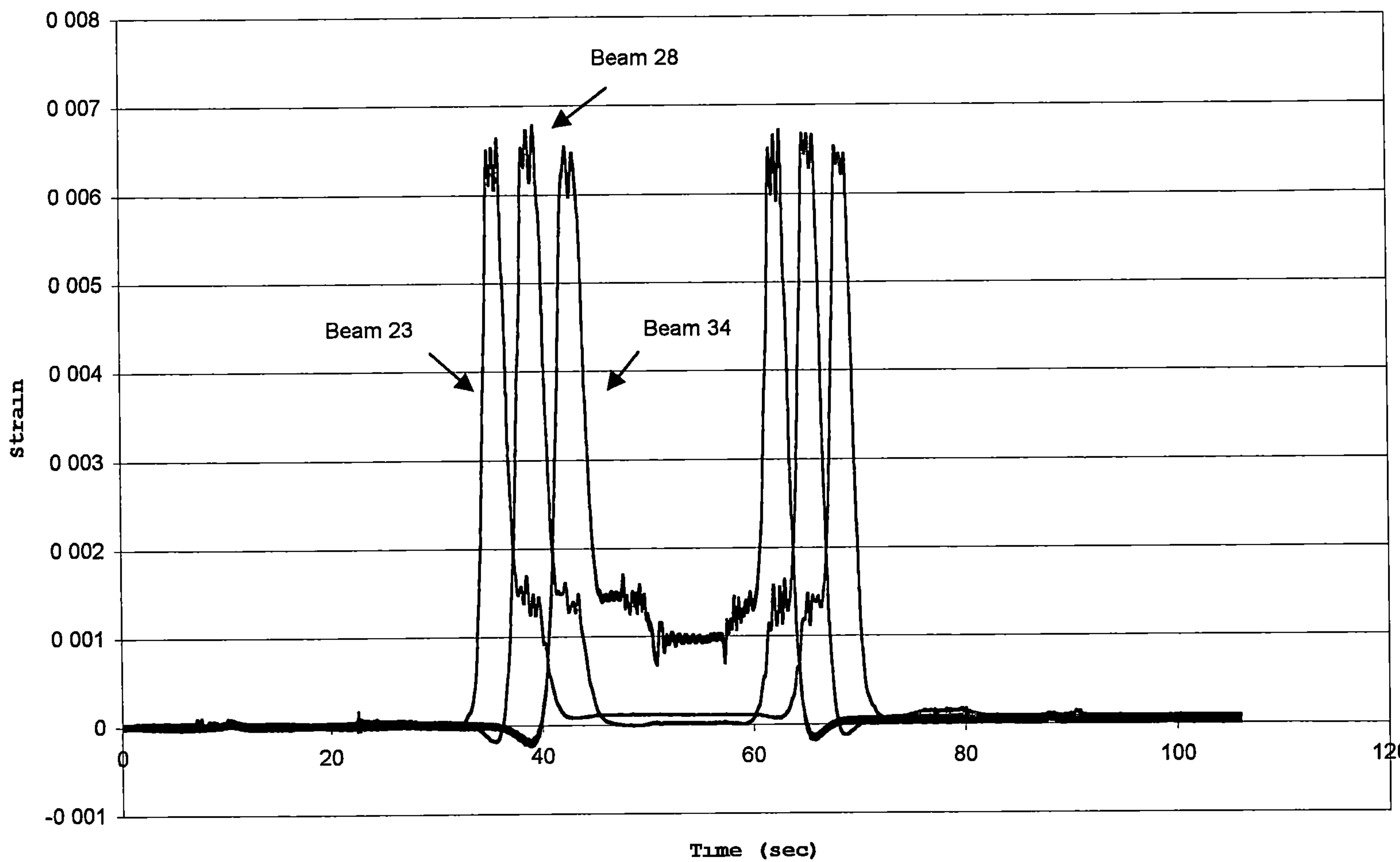


Figure A-8. Measured Strains, Load Test 1, Trailer 2, Beams

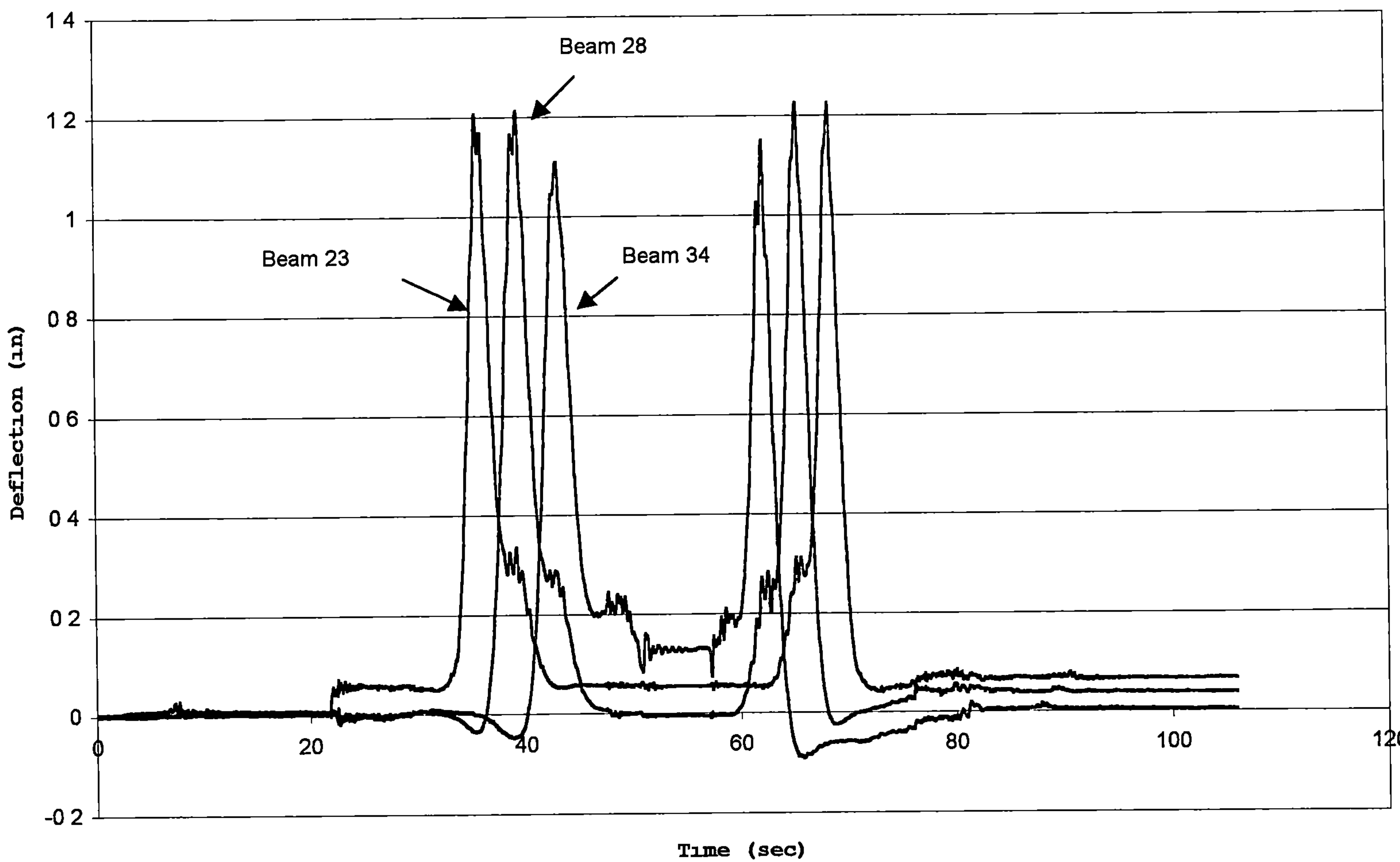


Figure A-9. Measured Deflections, Load Test 1, Trailer 2, Beams

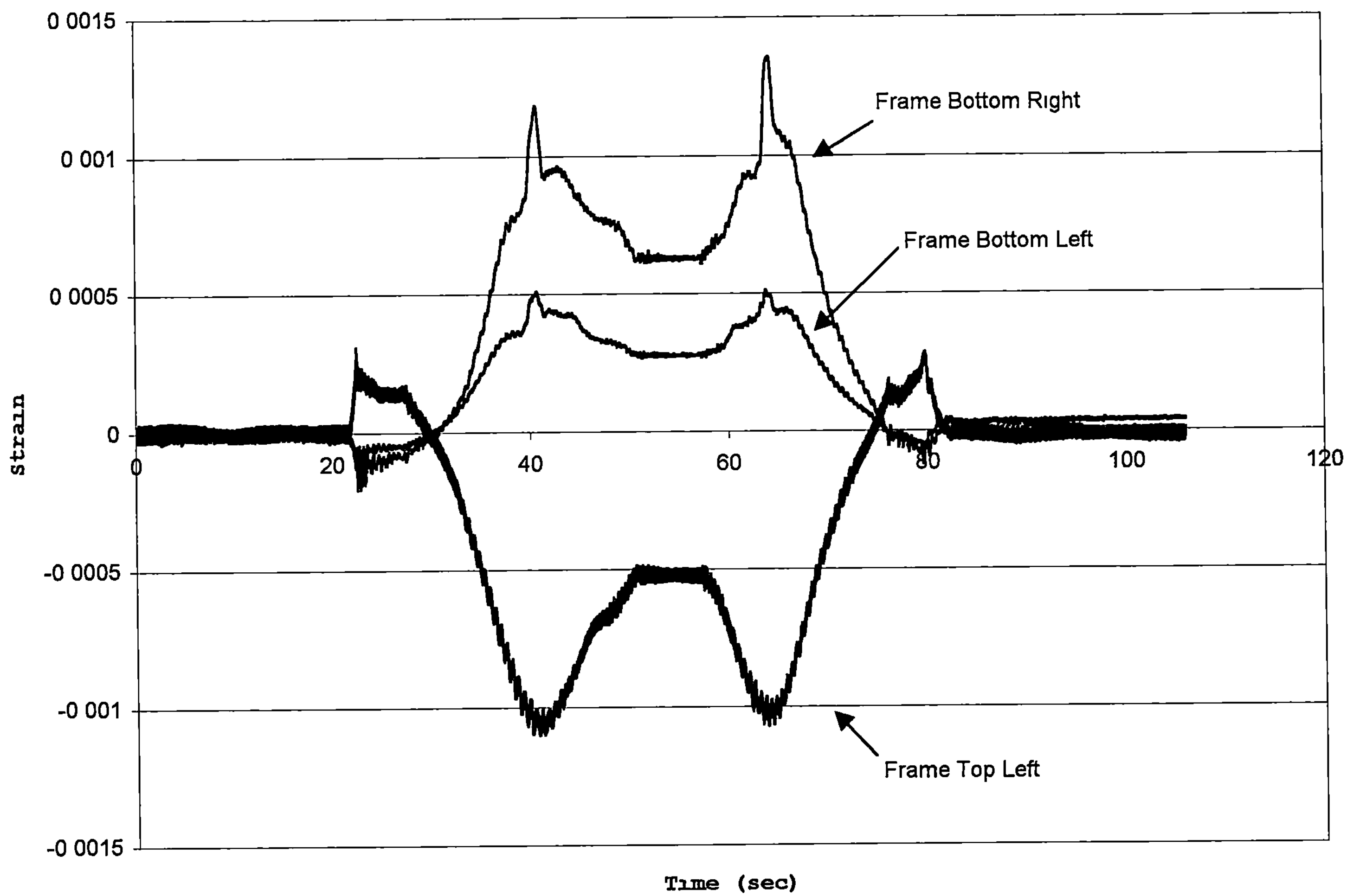


Figure A-10. Measured Strains, Load Test 1, Trailer 2, Frame

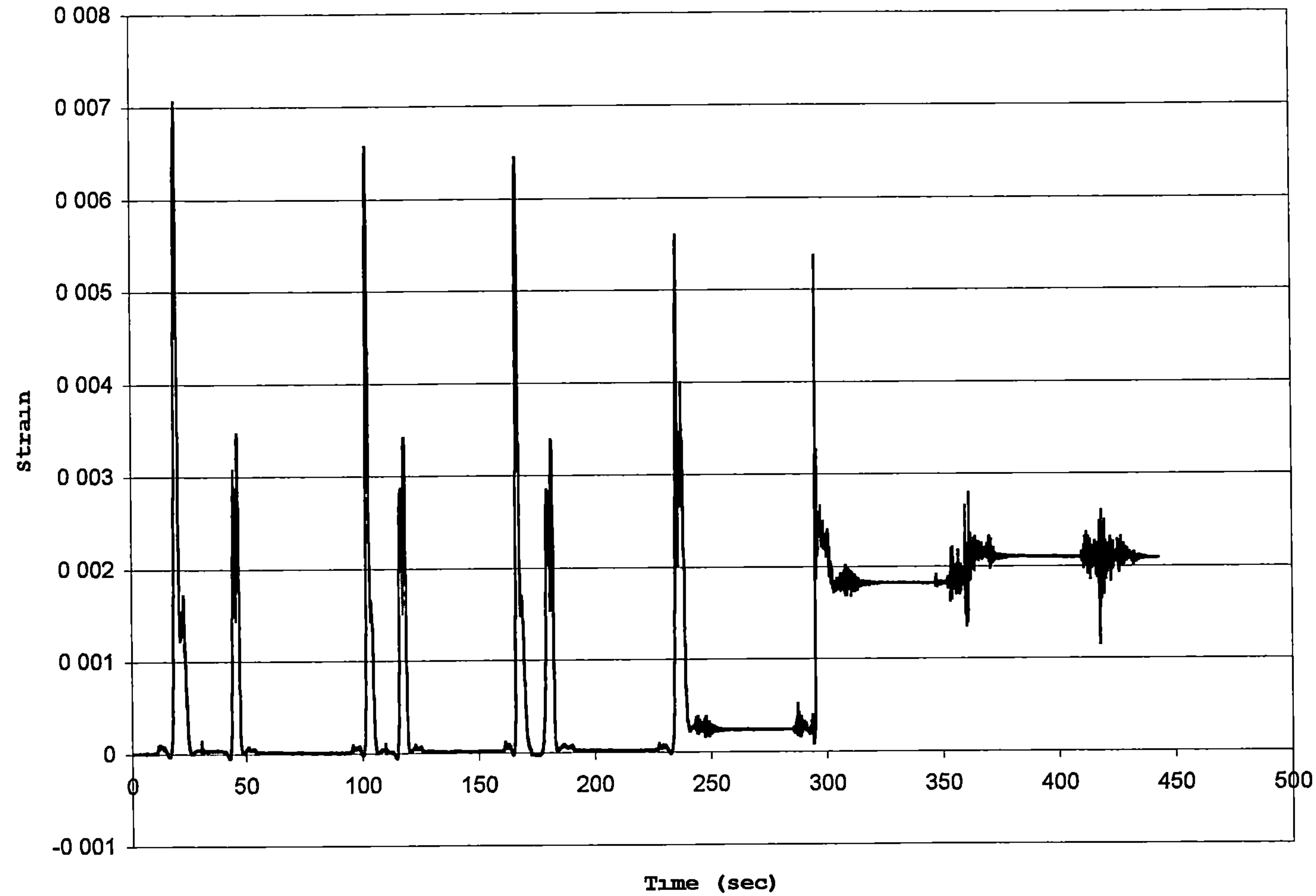


Figure A-11. Measured Strains, Load Test 2, Trailer2, Beam 23

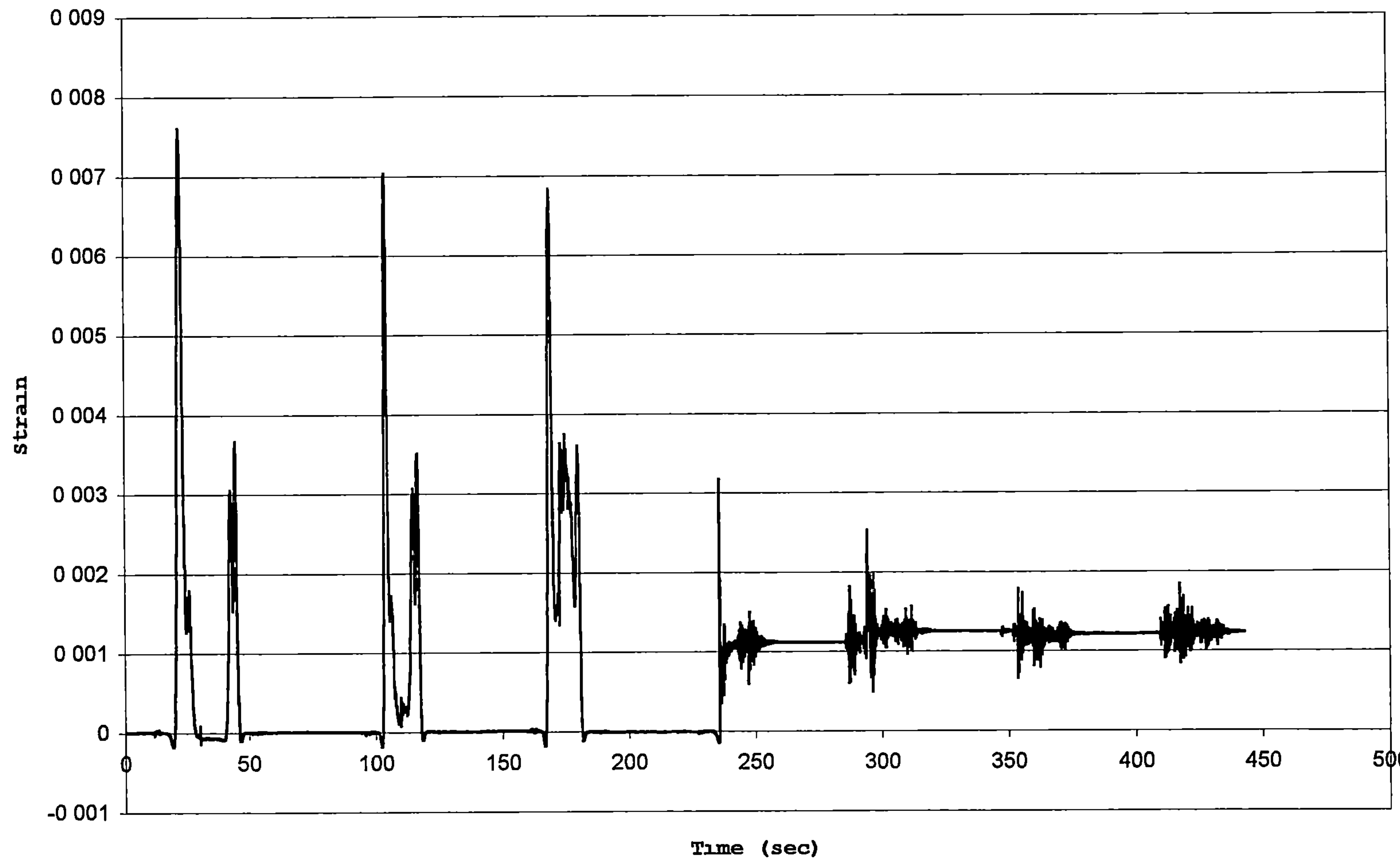


Figure A-12. Measured Strains, Load Test 2, Trailer 2, Beam 28

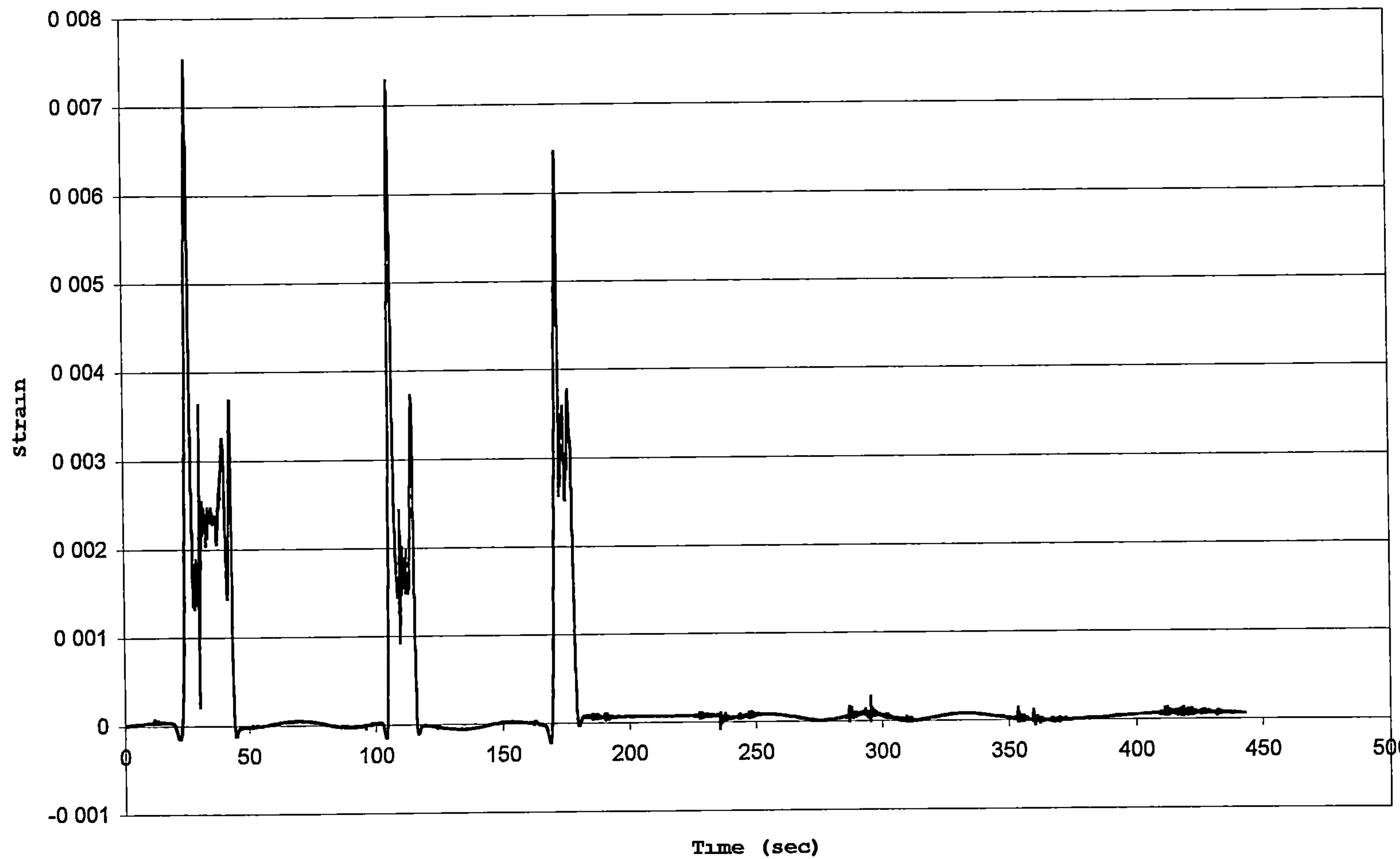


Figure A-13. Measured Strains, Load Test 2, Trailer 2, Beam 34

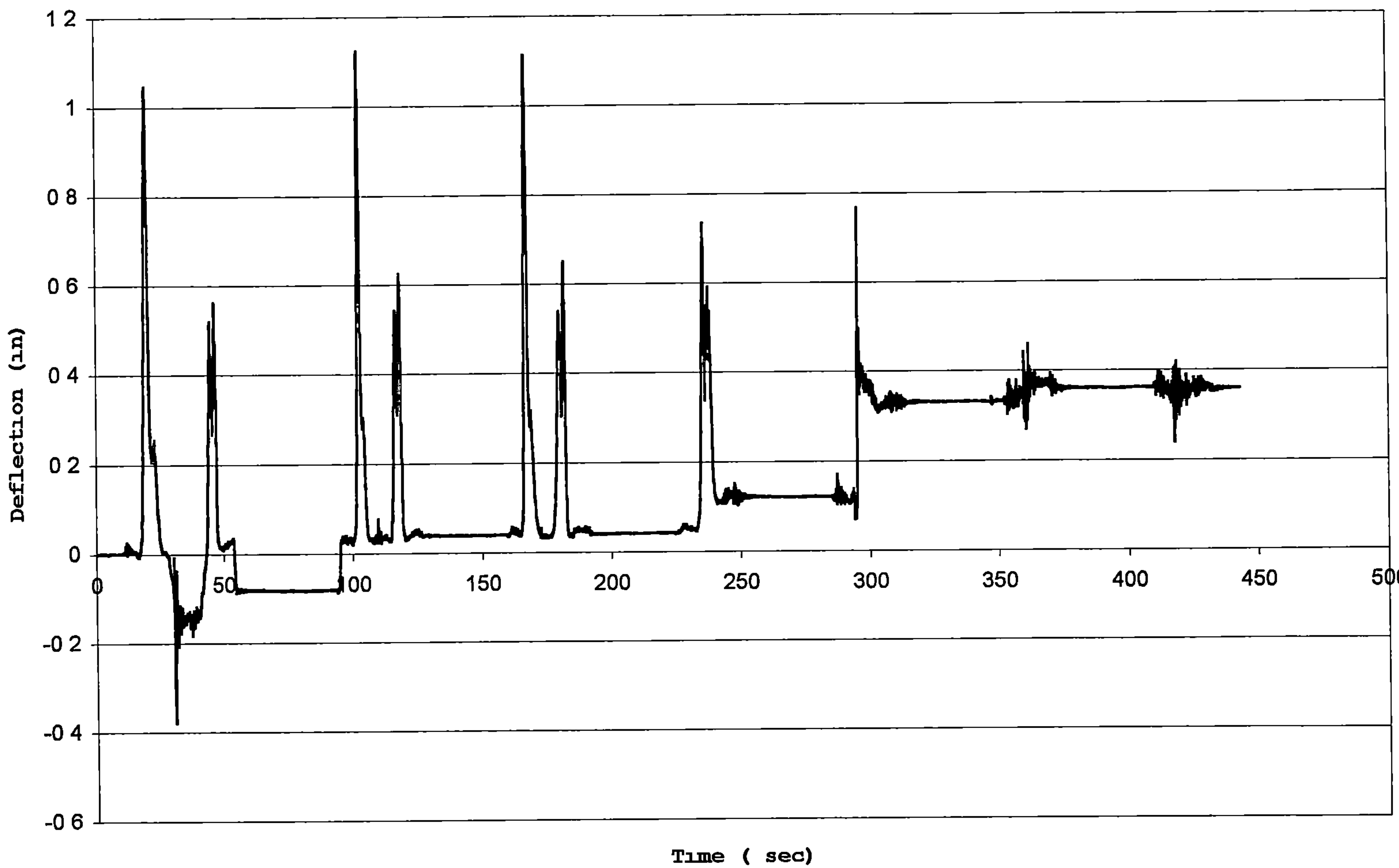


Figure A-14. Measured Deflections, Load test 2, Trailer 2, Beam 23

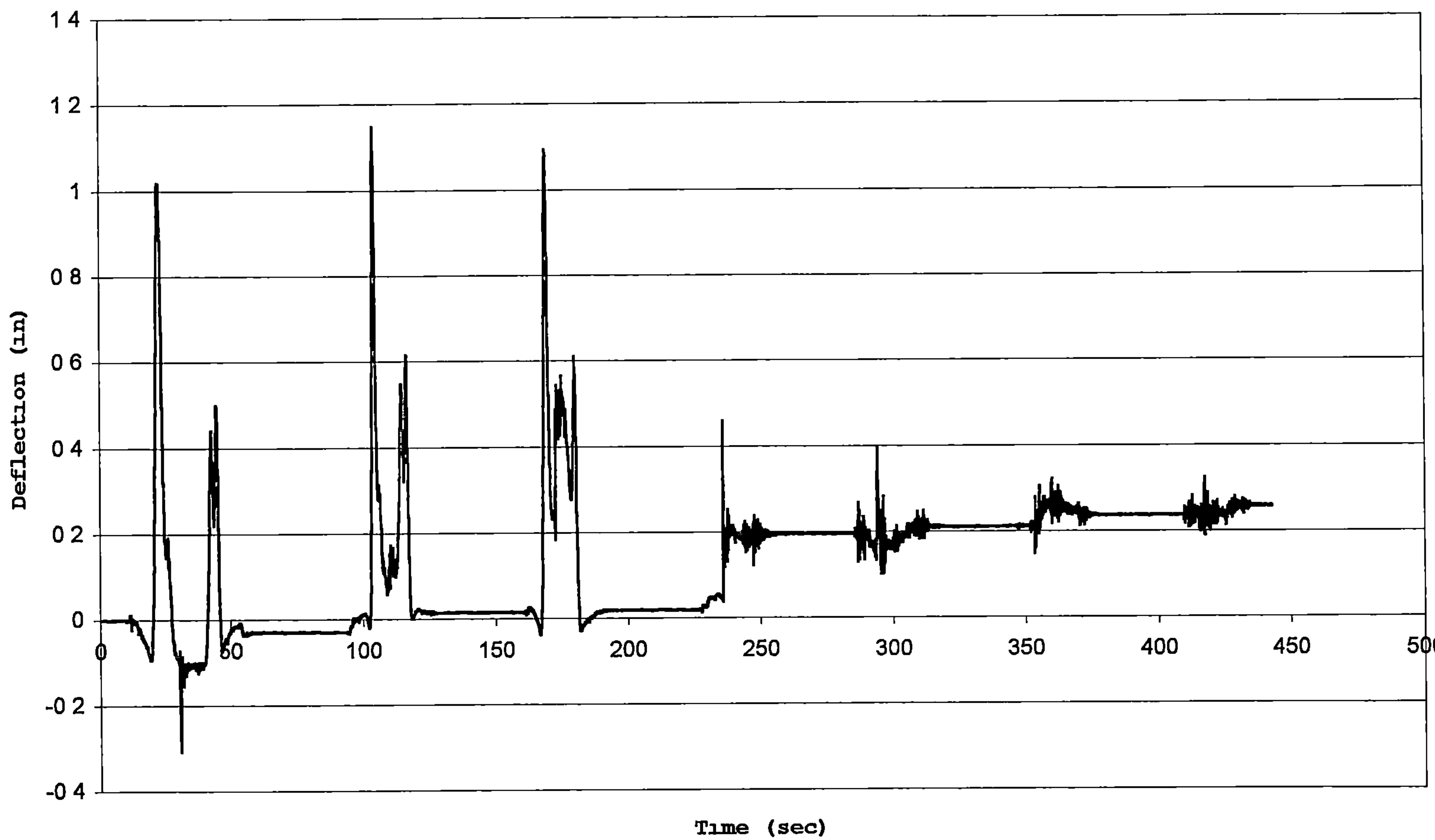


Figure A-15. Measured Deflections, Load Test 2, Trailer 2, Beam 28

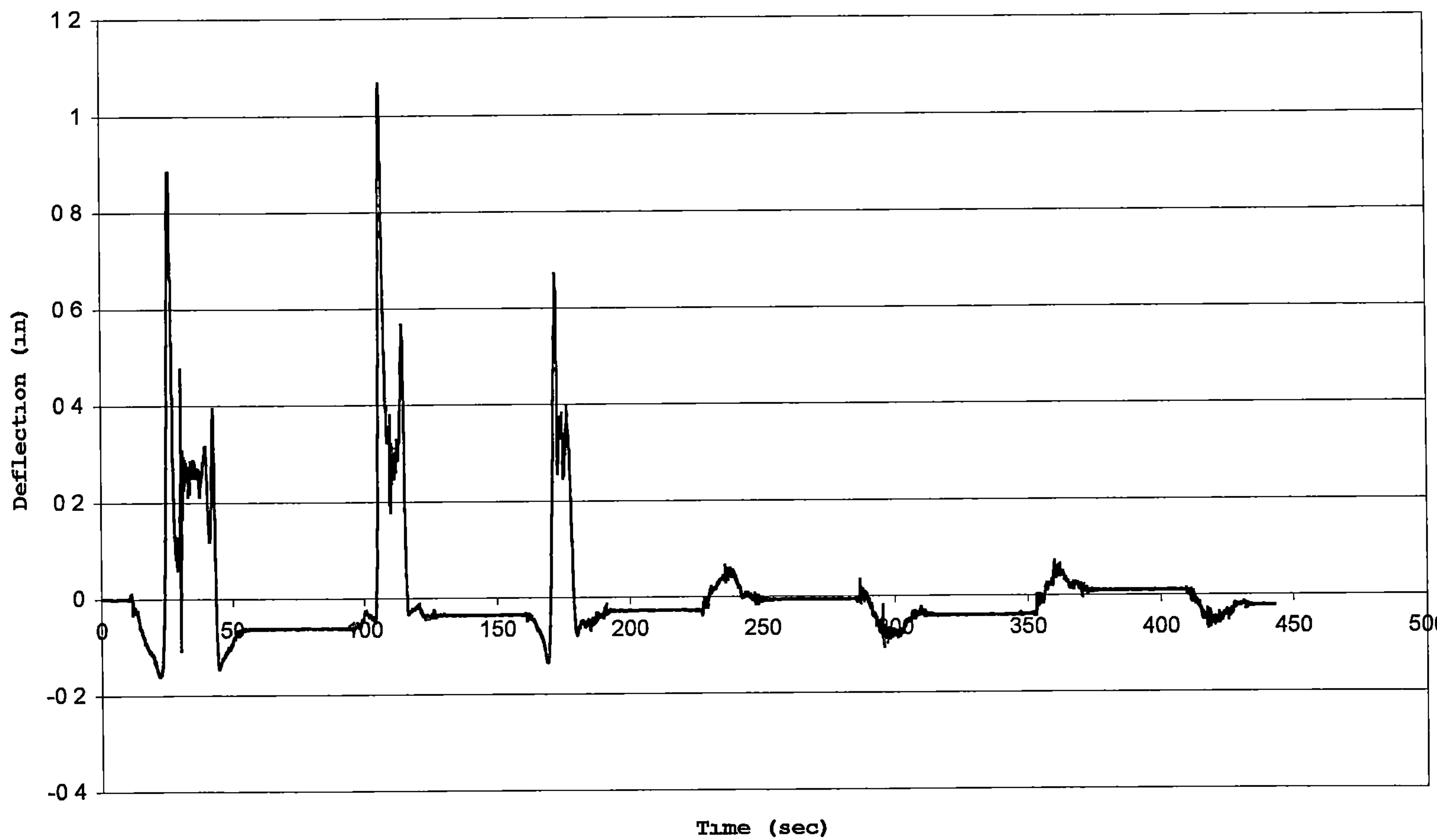


Figure A-16. Measured Deflections, Load test 2, Trailer 2, Beam 34

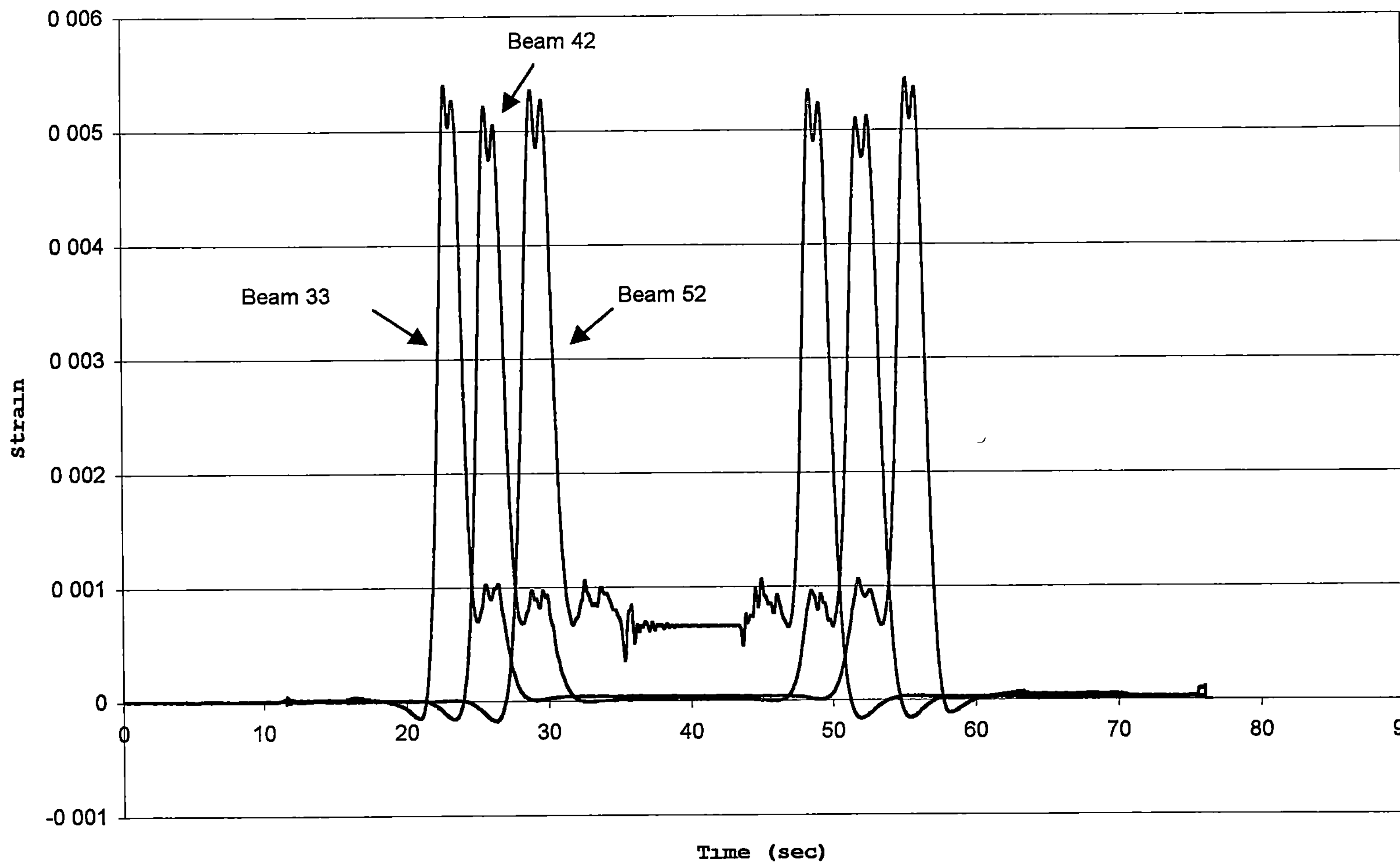


Figure A-17. Measure Strains, Load Test 1, Trailer 3, Beams

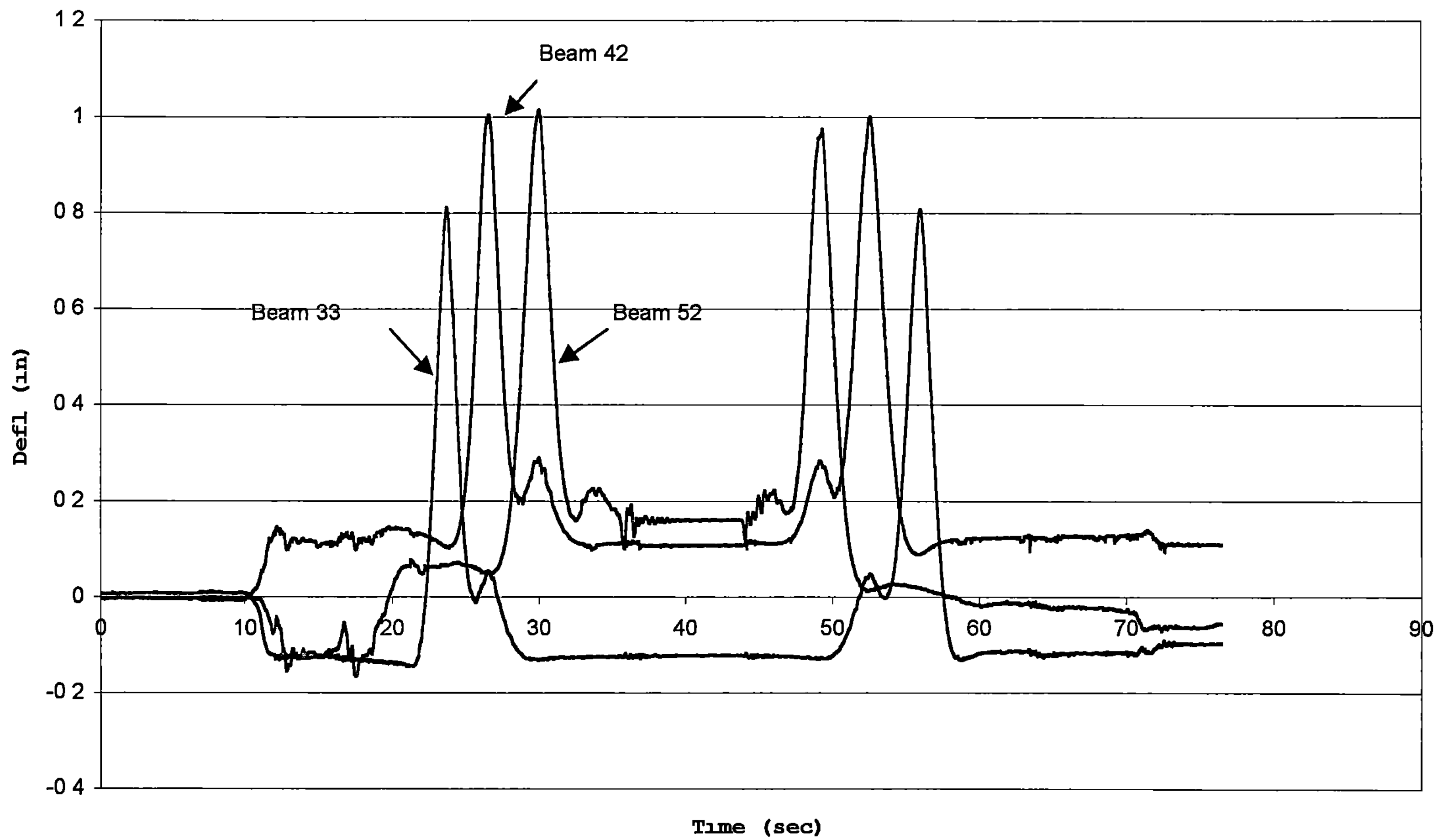


Figure A-18. Measured Deflections, Load Test 1, Trailer 3, Beams

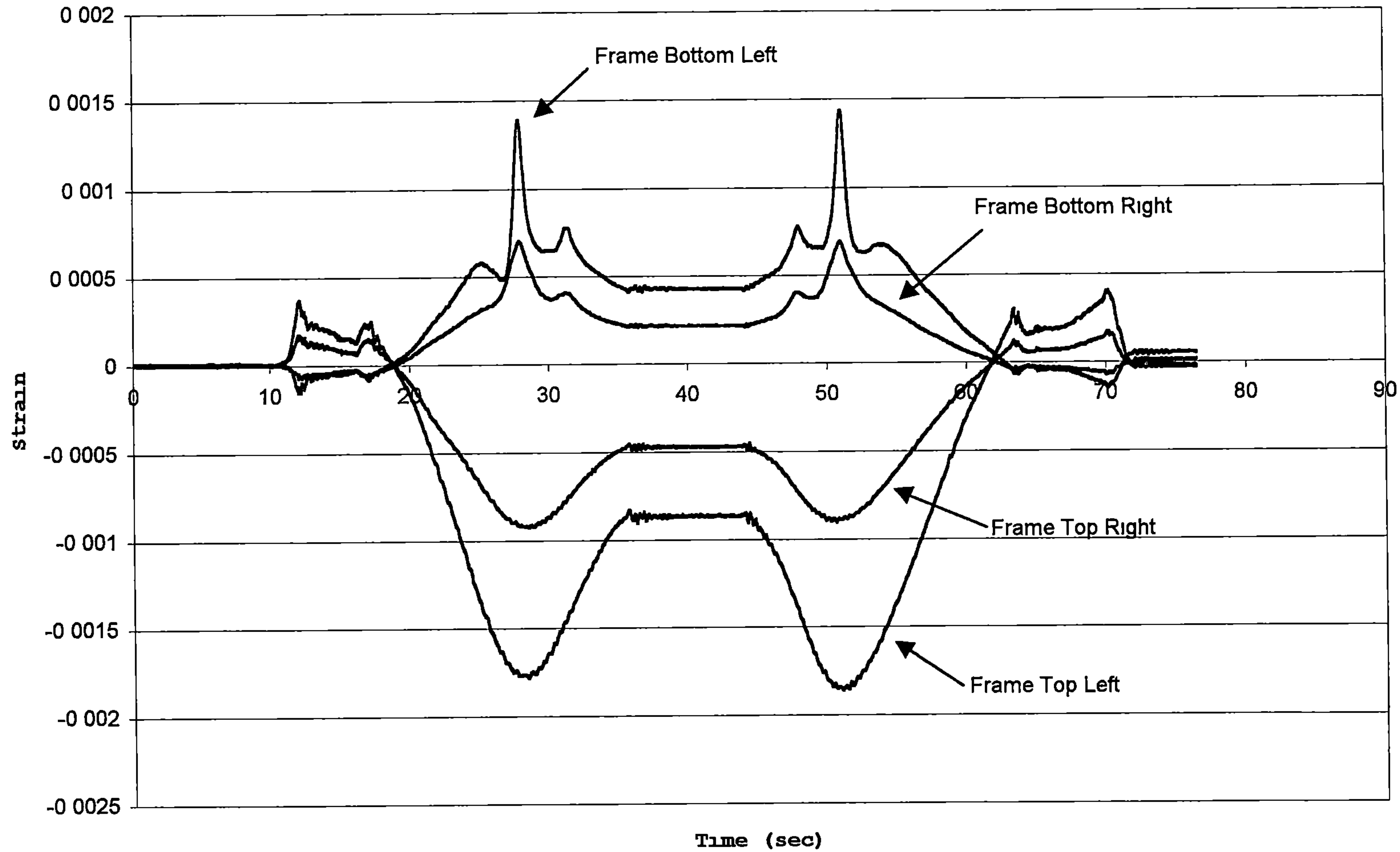


Figure A-19. Measured Strains, Load Test 1, Trailer 3, Frame

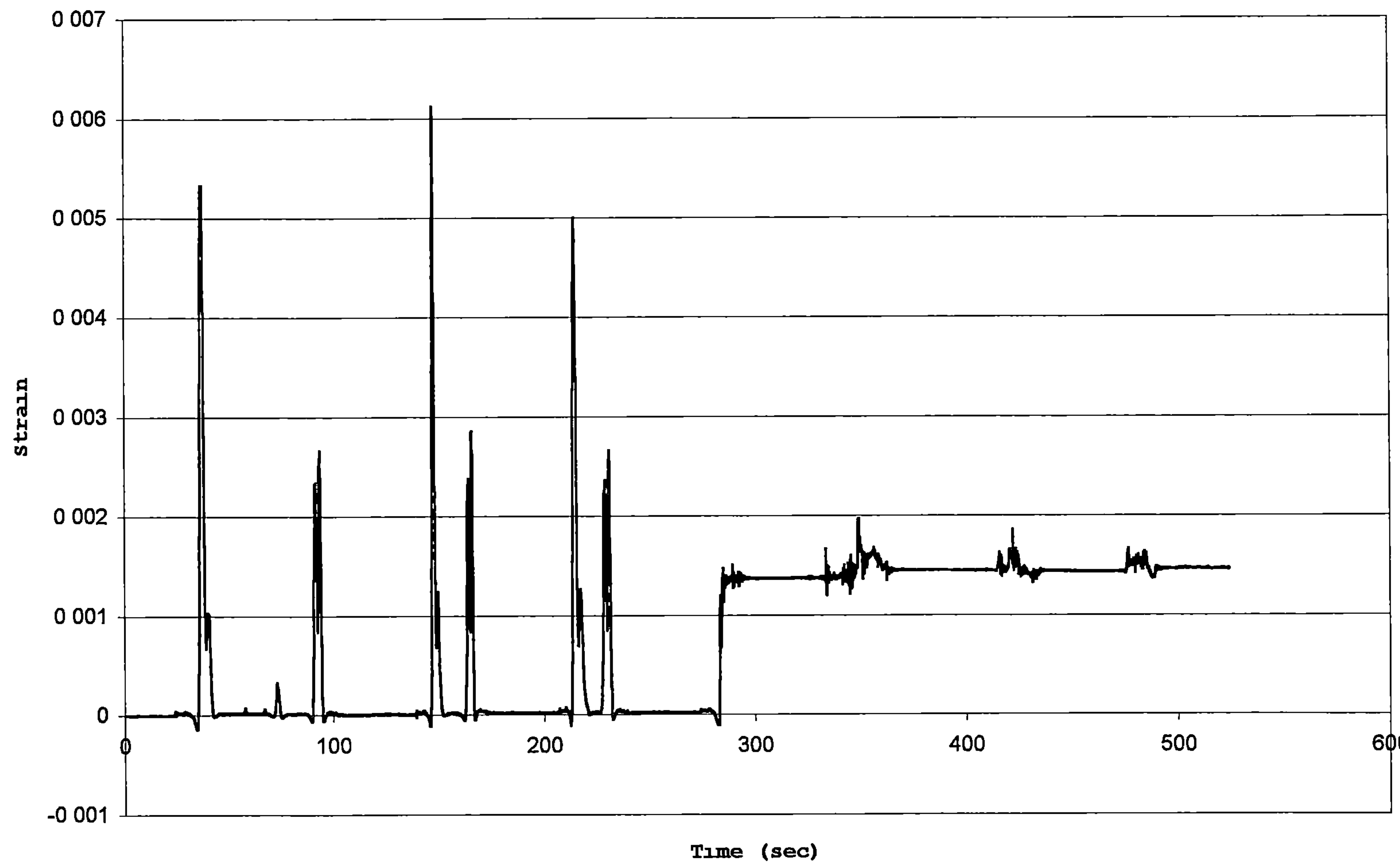


Figure A-20. Measured Strains, Load Test 2, Trailer 3, Beam 33

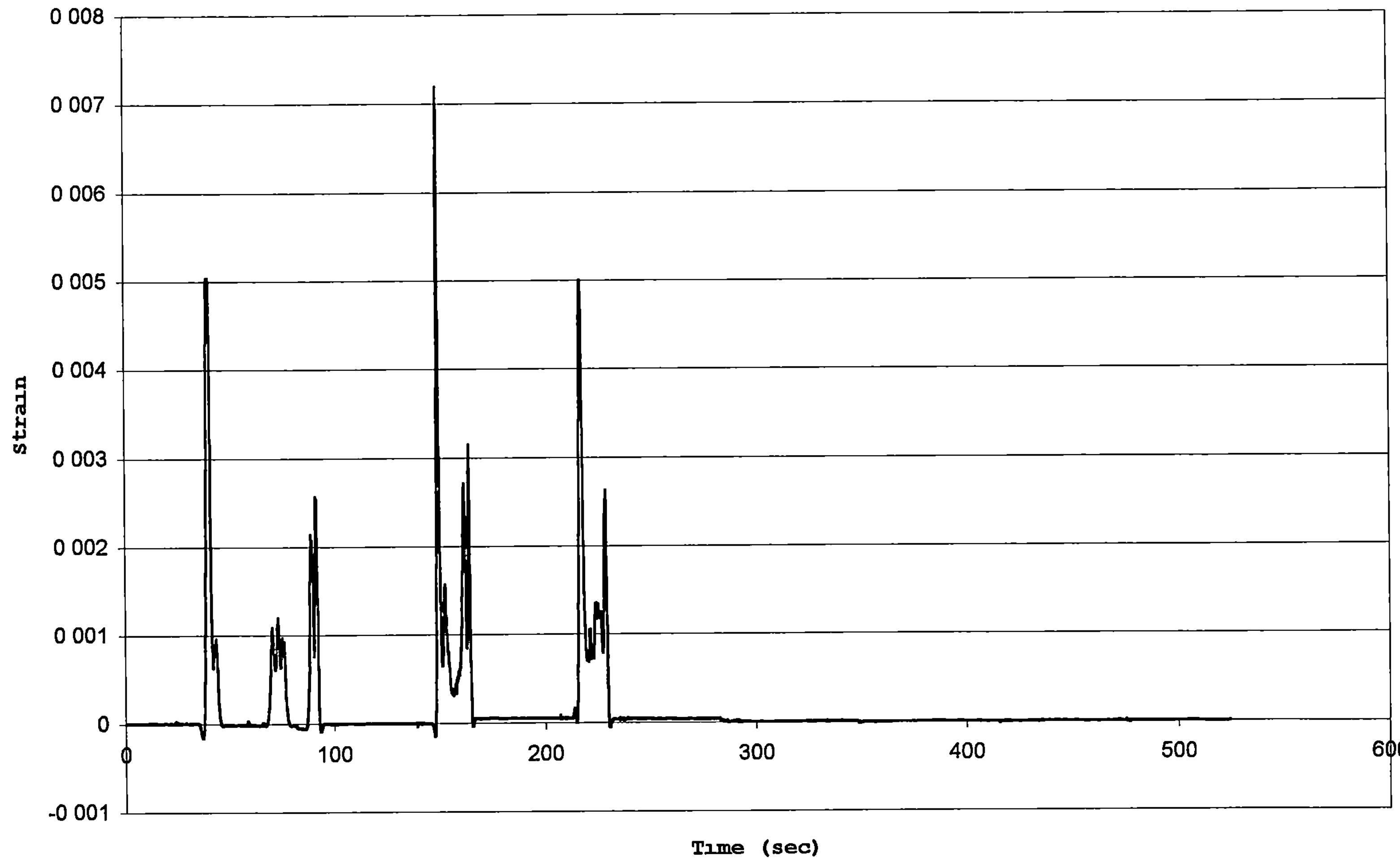


Figure A-21. Measured Strains, Load Test 2, Trailer 3, Beam 42

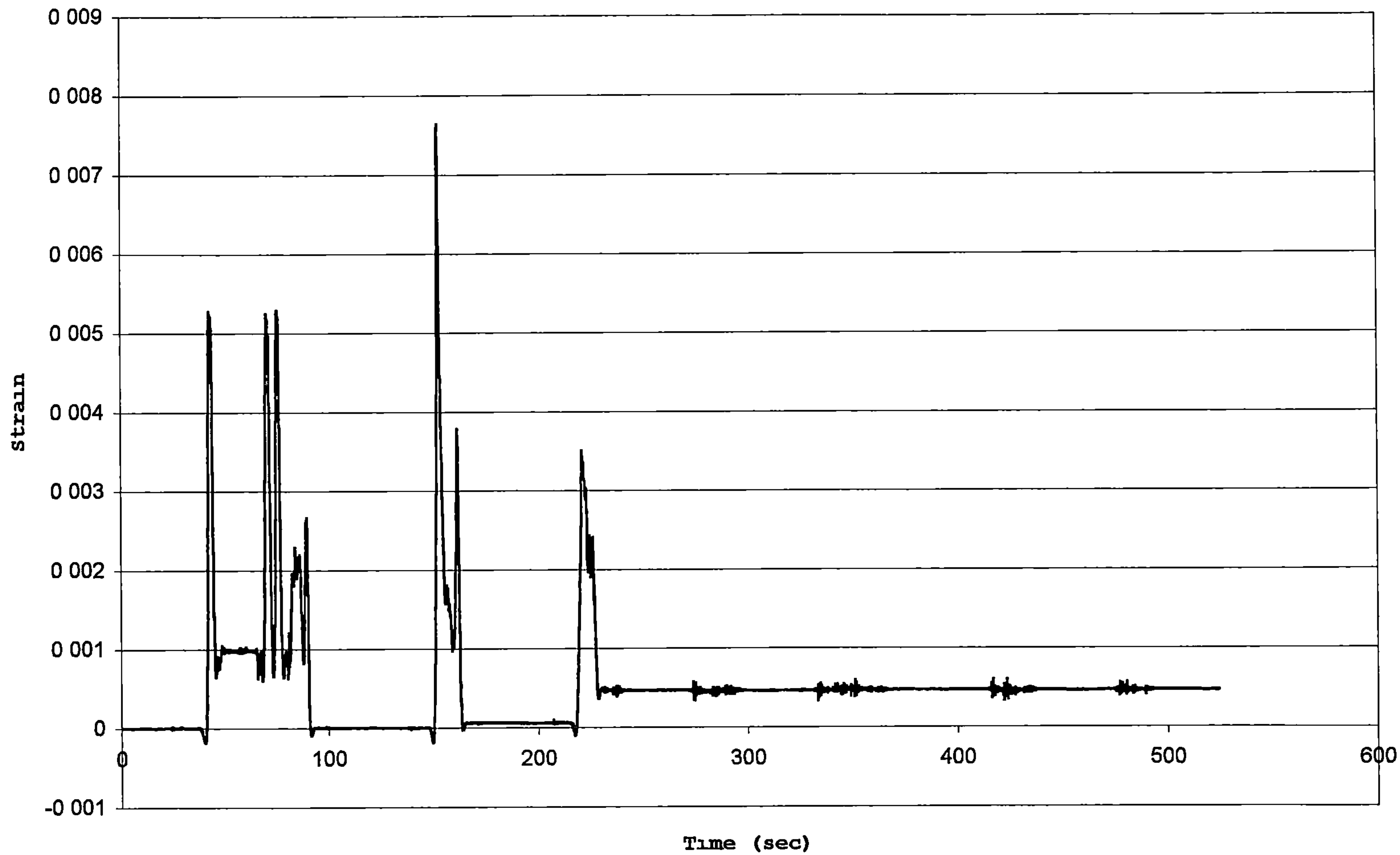


Figure A-23. Measured Strains, Load Test 2, Trailer 3, Beam 52

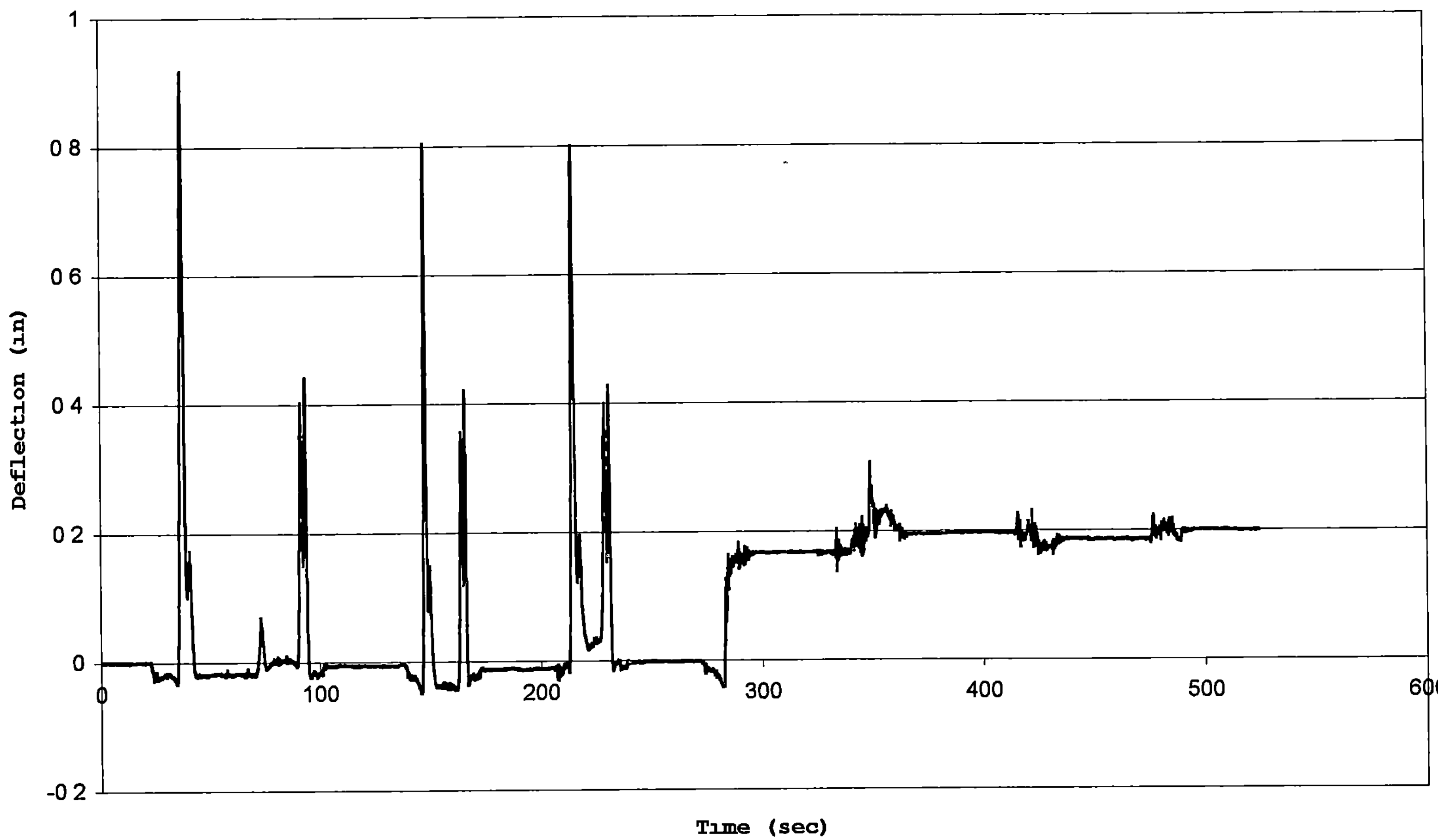


Figure A-24. Measured Deflections, Load Test 2, Trailer 3, Beam 33

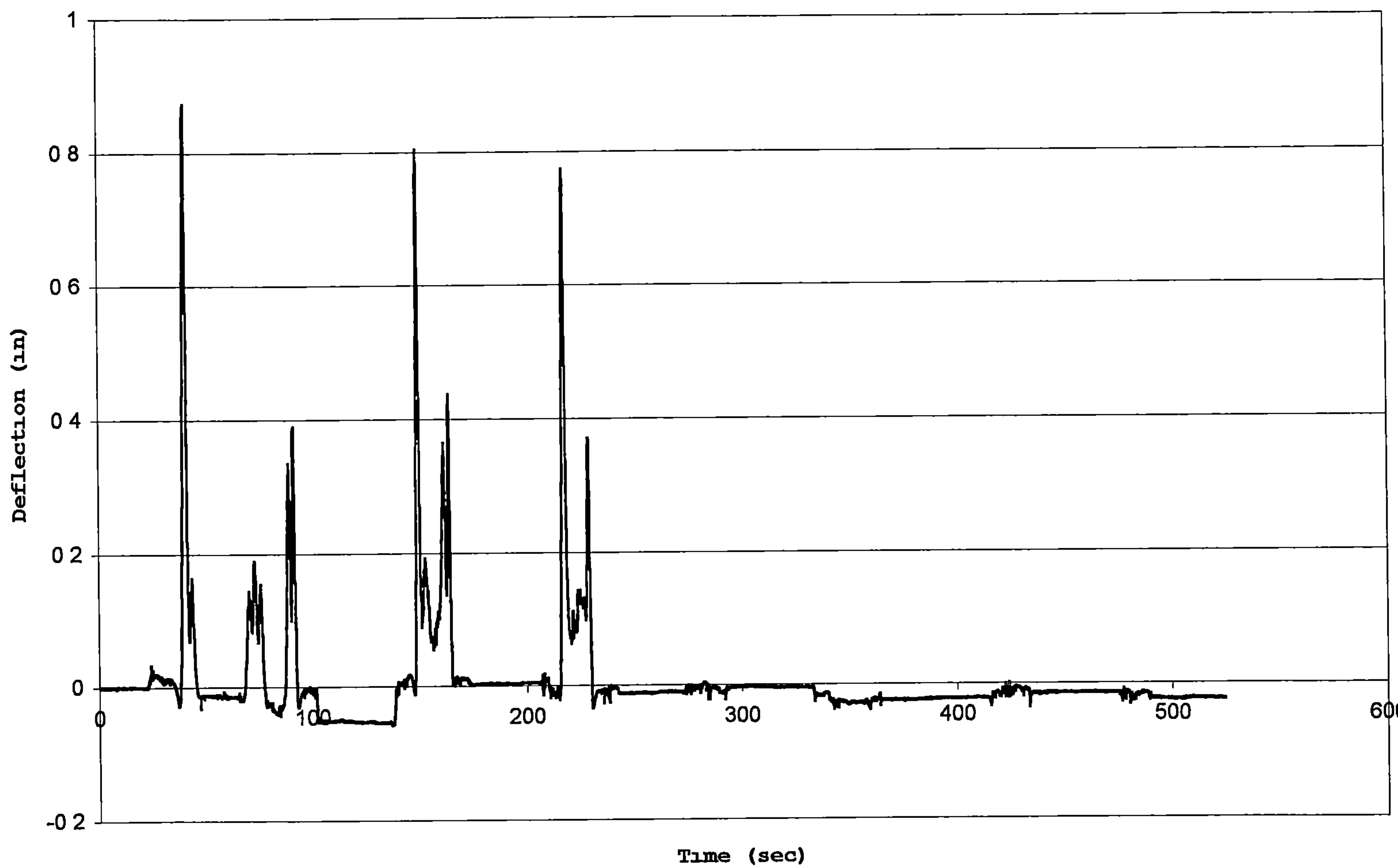


Figure A-25. Measured Deflections, Load Test 2, Trailer 3, Beam 42

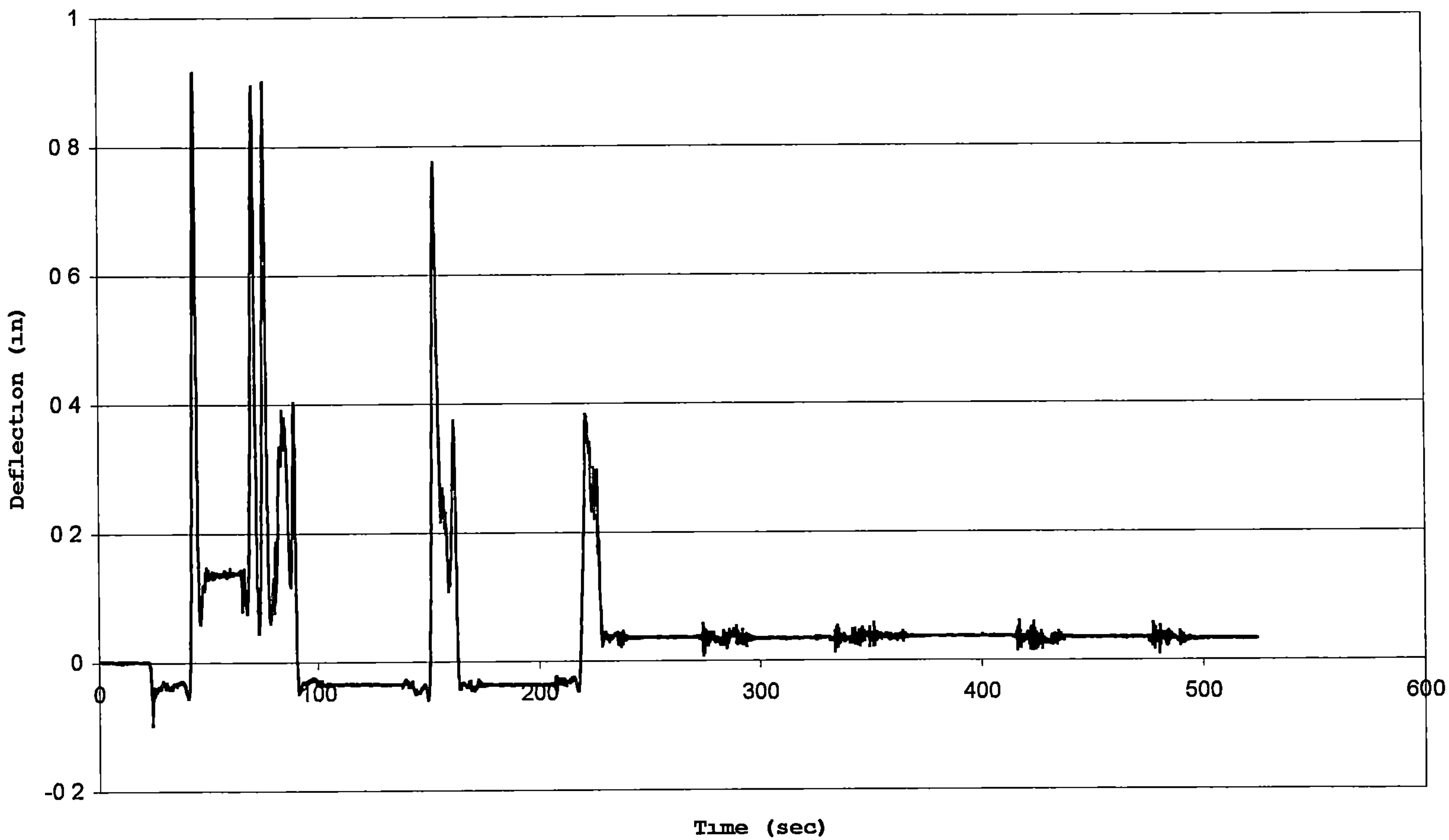


Figure A-26. Measured Deflections, Load Test 2, Trailer 3, Beam 52

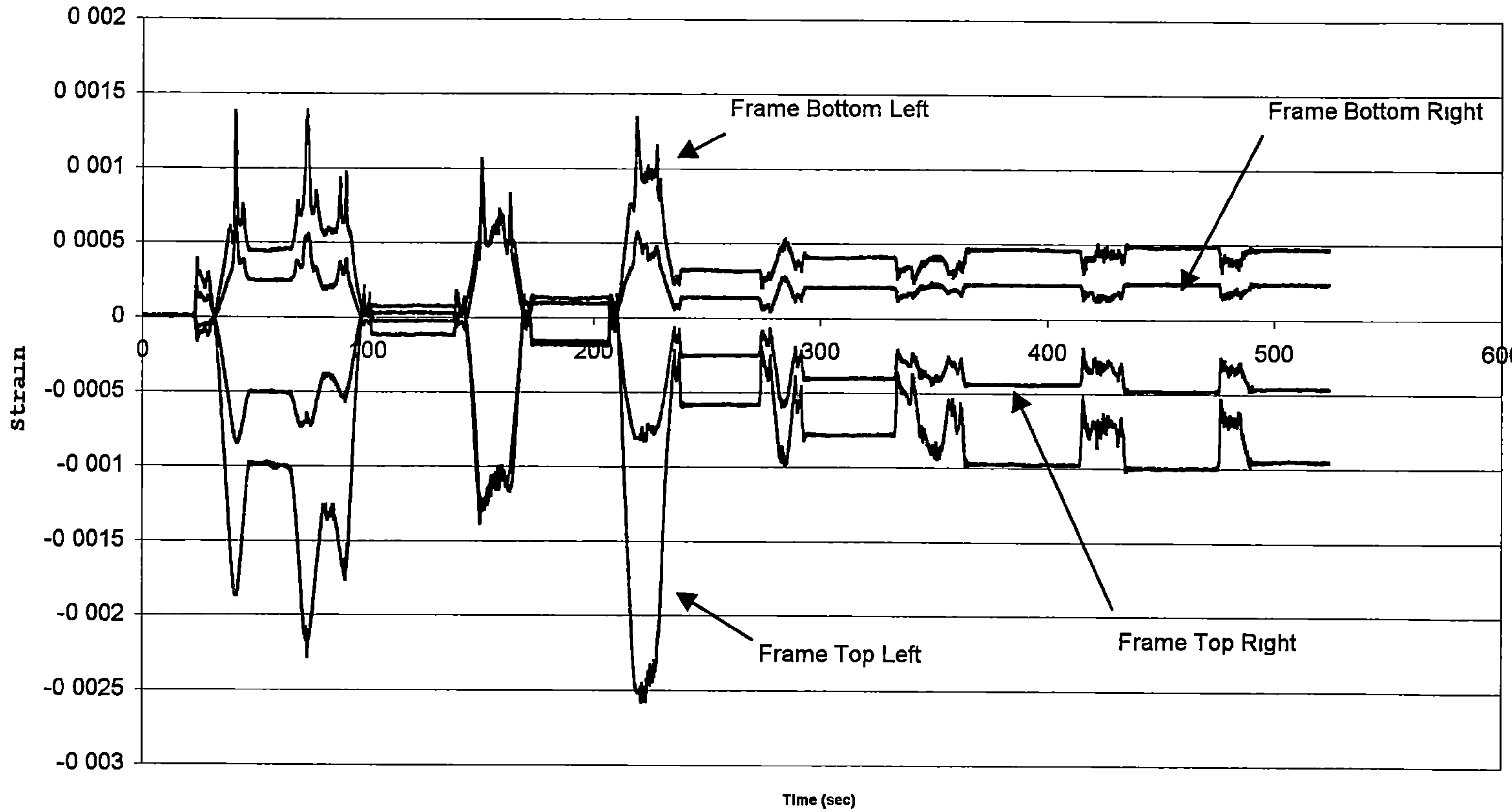
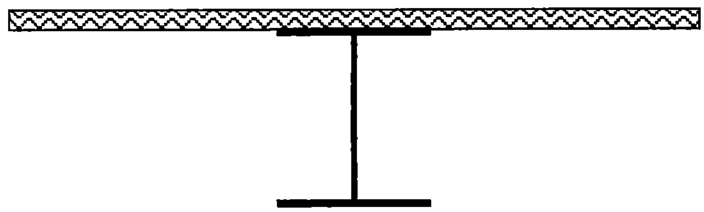


Figure A-27. Measured Strains, Load Test 2, Trailer 3, Frame

Appendix B

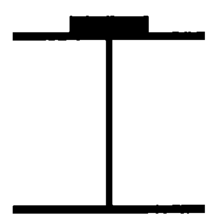
Transformed Section Calculations
(With Floor Beams at 12" on centers)



$N = E_{steel} / E_{wood}$

$= 29000 \text{ ksi} / 1600 \text{ ksi}$

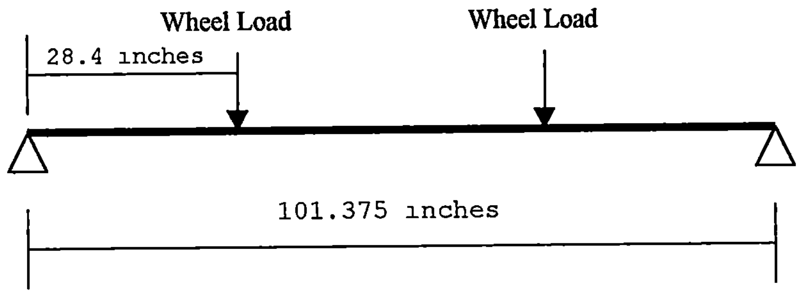
$= 18.125$



Shape	Area	d	A(d)	A(d^2)	I
wood	0 91	4 688	4 27	1 7	0 14
beam	0 94	2	1 88	1 64	2 63
	1 85		6.15	3.34	2 77

centroid = 3 32
I transformed = 6 114 in^4

Yield Moment Calculations
(Floor Beams at 12" on centers)



Maximum Moment = 28.4 inches (Wheel Load)

Wheel Load = Axle Load / 2

Axle Load = 23.495 kips (Figure 1)

Wheel Load = 11.75 kips

Yield Moment = σ_y (Section Modulus)

σ_y = 80 ksi

Section Modulus = 1.84 in^3

Yield Moment = 80 ksi (1.84 in^3)

= 147.3 kip inches

Yield Wheel Load = 147.3 kip inches / 28.4 inches

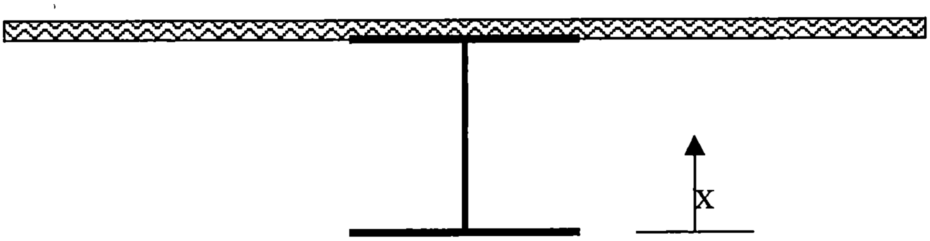
= 5.19 kips

Yield Axle Load = 2 (5.19)

= 10.38 kips

Plastic Moment Calculations

(Floor Beams At 12″ on centers)



4″ Junior I Beam
    Height = 4″
    Flange Width = 2.25″
    Flange Thickness = 0.126″
    Web Thickness = 0.105″

Wood
    Width = 12″
    Thickness = 1.375″

σ_{steel} = 80 ksi

σ_{wood} = 1.9 ksi

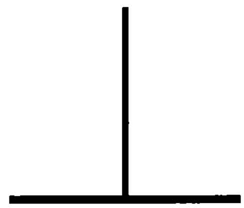
Area Wood (σ_{wood}) + Area of Top Flange (σ_{steel}) + (Web Height − X) (Web Thickness) (σ_{steel}) = X (Web Thickness) (σ_{steel}) + Area of Bottom Flange (σ_{steel})

31.4 + 22.5 + 31.5 − 8.4X = 8.4X + 22.5

X = 3.74

Force in Wood = 31.4 kips

Force in Steel = 22.5



Force in Web = 31.5 kips

Force in Flange = 22.5 kips
Sum Moments About Centroid

Plastic Moment = 0.0625(22.5) + 0.8125(31.4) + 1.875(31.5) + 3.812(22.5)

= 172 kip inches

Plastic Axle Load = (172/28.4)(2) = 12.1 kips

Bolted Connections (Single and Double Shear)							
Project:	Thesis						
Input Parameters							
t_m	1.375		$F_{e\parallel}$	7616			
G_m	0.68		$F_{e\perp}$	6237.962			
			$F_{e\theta}$	7616			
t_s	0.125		$F_{e\parallel}$	n/a			
$^*G_s$			$F_{e\perp}$	n/a			
			$F_{e\theta}$	n/a			
*If side member is steel, leave G_s blank.							
F_{yb}	45000						
D	0.3125						
θ	0						
Calculated Parameters							
			Enter in Boxes				
1			Enter 1 for	$F_{e\parallel}$			
F_{em}	7616		Enter 2 for	$F_{e\perp}$			
			Enter 3 for	$F_{e(steel)}$			
F_{es}	80000		Enter 4 for	$F_{e\theta}$			
R_e	0.0952						
R_t	11						
K_θ	1						
K_1	0.432125						
K_2	0.559681						
K_3	7.636585						
Results							
Single Shear			Double Shear				
Z_{1m}	818.125		Z_{1m}	818.125			
Z_{1s}	781.25		Z_{1s}	781.25			
Z_2	375.1084		Z_{3s}	677.705			
Z_{3m}	480.8141		Z_4	881.5713			
Z_{3s}	338.8525						
Z_4	440.7856						
Capacity per screw to wood connection is 338.9 pounds.							

Vita

Todd Phillips was born in Knoxville, Tennessee on May 30, 1976. He graduated from Anderson County High School in June, 1994. He entered Pellissippi State Community College in August, 1994 which he attended for two years before transferring to the University of Tennessee at Knoxville. After three years at the University of Tennessee he earned his Bachelor of Science degree in Civil Engineering in December, 1999. With the completion of his undergraduate degree he entered the Master's program in Civil Engineering. One year later he received his Master's degree in Civil Engineering in December, 2000.