U.S. Department of Housing and Urban Development
Office of Policy Development and Research

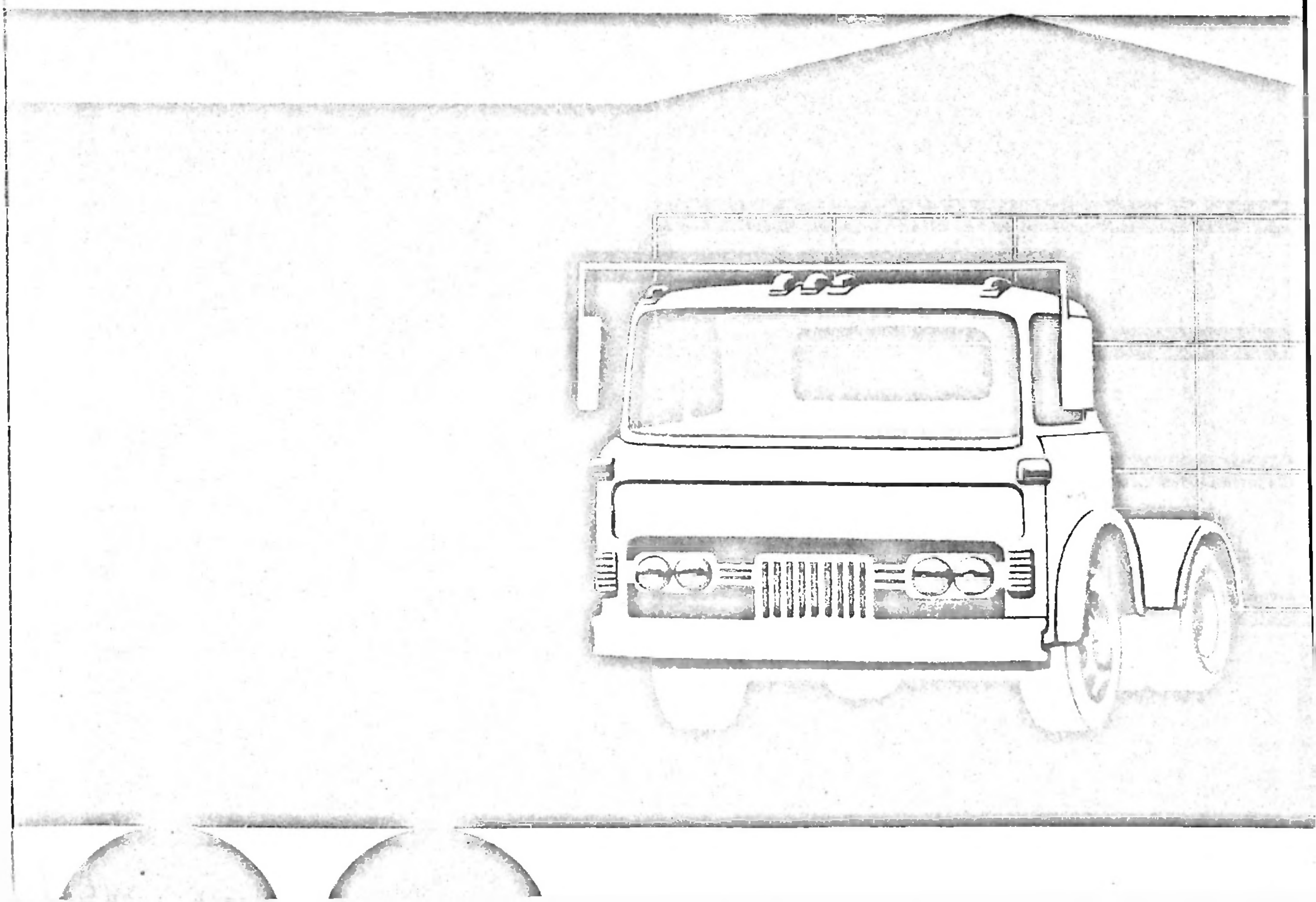
Mobile Home Research

Transportation Test Program and Evaluation/Analyses of Test Data

Transportation and Site-Installation

Volume 2

Final Report



MOBILE HOME RESEARCH

TRANSPORTATION AND SITE-INSTALLATION

TRANSPORTATION TEST PROGRAM AND EVALUATION/ANALYS
OF TEST DATA

VOLUME 2
FINAL REPORT

By

Southwest Research Institute

Prepared for

U.S. Development of Housing and Urban Development
Office of Policy Development and Research

Contract Number H-2411

March 1979

FOREWORD

At the present time, 10 million Americans live in mobile homes. For them, and for the increasing numbers of people who will come to live in such homes in the future, HUD, at the request of the Congress, has undertaken research to improve mobile home safety and durability. Out of that research, HUD is to develop, promulgate, and enforce one nation-wide construction standard for the industry.

The six volumes that constitute this report should prove invaluable to those who develop standards as well as those architects and engineers who design both manufactured housing and mobile homes. That some of the research may be controversial is only to be expected. It is pioneering work that offers a new approach to resolving difficult problems.

The Division of Energy, Building Standards and Technology of HUD's Office of Policy Development and Research should be recognized for its contribution to this worthwhile project.

Moon Landrieu

Moon Landrieu
Secretary

TABLE OF CONTENTS

NOTE: Since each part was originally written as a separate volume, each contains its own Table of Contents, List of Figures and Tables and pagination.

SUMMARY

The research contained herein was undertaken to provide a basis for determining the adequacy of the Mobile Home Construction and Safety Standards, effective June 15, 1976. "Adequate" is defined as Standards that result in mobile homes with sufficient durability to provide the homeowner with an acceptable useful life; currently defined for purposes of this Study as a minimum of 15 years for a single-wide and as a minimum of 20 years for a double-wide unit. The research methodology to evaluate the standard included: (1) the development of analytical methods to determine transportation and site-installation induced loads and the resulting member stresses, joint-loads and deflections; (2) the development of a means to predict degradation caused by the aforementioned forces; (3) the conduct of a test program that compares analytically determined input loads and predicted degradation with actual physical test measurements and observations; (4) if required, proposed changes to the Standards; and (5) analytical or test methodology that could be used by enforcement agencies to evaluate proposed mobile home designs.

To determine mobile home structural member loads caused by in-transit conditions, computer modeling techniques were used. Critical in-transit conditions (i.e., road roughness and towing velocity) were analytically related to critical structural parameters (i.e., torsional stiffness, flexural stiffness, and damping) in order to calculate estimated

member loads. This analysis also related analytically predicted changes in structural parameters to degradation of the mobile home. Equations were developed that, in part, statistically compare structural parameters of any given mobile home to a home that is considered to be 100 percent degraded. Solution of these equations result in an estimation of mobile home degradation. These equations were modified as required to provide "best fit" estimates consistent with test data and are subject to further modification as additional data becomes available. This research activity is described in Volumes 1 and 4. A detailed rationale for analytical equations is not presented since emphasis was put on the "best fit" relationship of analytical computer simulations and test data.

Volumes 1 and 4 also includes a computer oriented methodology for the analysis of mobile home structures. This data provides a basis for future research oriented to the rapid analysis of mobile home member stresses, joint loads and structural deflections.

A test program was conducted to obtain data that could be compared to analytically derived data. Emphasis was placed on measured test data which resulted in equation modifications as necessary to "best fit" experimental data. Test data was obtained from single-wide and double-wide homes built per the current standard and from homes built prior to implementation of the current standard. Test homes were subjected to transportation and site-installation conditions to simulate years of actual use. Volume 2 describes the test program with supportive data sheets included in Volume 3.

The objective of proposed revisions to the Standards is to reduce the incremental degradation of mobile homes where current design practices result in predicted and observed degradation that exceeds acceptable levels. Volume 5 contains proposed changes to the current standard based on an analysis of data contained in Volumes 1 through 4. The proposed changes include increased design loads to resist in-transit and on-site forces; increased design criteria for attachment of joints as required to minimize loosening of joints during transportation; and a requirement for a minimum integrated structure stiffness criteria to ensure that degradation with respect to time is consistent with a reasonable useful life. Recommended design loads were based on actual measured test data multiplied by a factor selected to account for rough roads and highway speeds greater than 45 MPH. Minimum stiffness criteria were based on values obtained from the single-wide home built to the current standards.

Volume 6 contains a proposed field test method that could be used to measure the stiffness parameters of new or used mobile homes. These parameters are required to verify adherence to the proposed standard, and to perform calculations necessary to predict the remaining useful life of the mobile home.

Volume 7 (yet to be printed) will summarize the major results of the other six volumes and will provide a cohesive evaluation for the reader interested primarily in understanding the broader aspects rather than becoming technically involved in the specific technical aspects of the study.

The Southwest Research Institute's Study offers an innovative approach in terms of a concept and a model upon which to assess mobile home structural durability, or conversely, structural degradation. The Study's findings should offer a base upon which to develop proposed Standards.

The rationale of using degradation of torsional and flexural rigidity as a measure of mobile home durability is innovative for mobile home design and would appear to be basically sound. Changes in stiffness (torsional and flexural) and damping, have been used for several years in engineering practice as a measure of structural degradation in other applications. The concept of seeking a measurable parameter that is sensitive to degradation appears to have merit.

This Study's findings should therefore be considered in the whole context of the research effort rather than narrowly disected. Certain assumption's made upon the best available information from data, may later be modified as experience is gained in the use and application of the Study's results.

RELATED DOCUMENTATION

The research program, from which this volume and six others were derived, was originally organized into eight project tasks under each of which a varying number of reports were written; e.g., Task I consisted of Volumes I, II, III, and IV. In order to reduce the number of separate volumes produced from this research, certain reports that were considered related were combined into one volume.

Volume 1 consists of Task I, Vols I, II, III, IV;
Volume 2 consists of Task II and Task III, Vol I, Parts I & II;
Volume 3 consists of Task III, Vol I, Part II Raw Data;
Volume 4 consists of Task III, Vols II & III;
Volume 5 consists of Task IV, Vols I, II, & III;
Volume 6 consists of Tasks V, VI, & VII; and
Volume 7 consists of Task VIII.

The reader is made aware of this in order to understand the cross-references that occur throughout these documents as they were originally written. Thus, for example, references to Task I, Vols I and II can be found in the first two parts of what is now Volume 1. It is hoped that any confusion created by this compilation will be offset by the convenience of having fewer volumes of analogous material.

NOTE: Volume 3 is available through the National Technical Information Service; 5282 Port Royal Road, Springfield, Va. 22161. To order by phone call (703) 557-4610. This volume was not printed by the Government Printing Office since it is believed that the demand for Raw Data will be relatively small.

ACKNOWLEDGMENTS

The authors are indebted to many professionals for contributions and guidance that made this study possible. Our thanks include:

- Battelle Memorial Institute - for their earlier research study into mobile home flexural rigidity;
- U.S. National Bureau of Standards - for Dr. Robert Crist's evaluation of the predictive analysis theory;
- U.S. Department of Transportation - for their Federal Highway Administration and the Bureau of Motor Carrier Safety organizations for providing transportation insights;
- State of Texas Department of Labor and Standards; for the valuable assistance of Mr. Michael Alexander (Manufactured Housing Division) in evaluating the structural dynamics portions of the study;
- State of Texas Department of Public Safety; for Colonel Wilson Spear's assistance during the highway testing phase;
- Boeing Aerospace Company - for the quality of Mr. John Stevens penetrating assessments during the development of each of the several products of the research;
- American Association of State and Highway Transportation Officials - for the coordination of the highway safety survey;
- Manufactured Housing Institute - for coordinating the attendance of key engineering personnel at the several project status reviews and demonstrations conducted during the research.

INTRODUCTION

INTRODUCTION AND PURPOSE

(Task II Abridgement*)

In accordance with Task II of the contract, Southwest Research Institute developed a proposed program to conduct various tests on new and used mobile homes in order to measure the degradation occurring from typical transportation and setup/takedown effects. The test program included the definition of each test article and the instrumentation used for data collection. The proposed test program also included the routes and road conditions over which the mobile homes were transported along with the method of data recording, trip records, and test matrix for the entire fleet of mobile homes tested. In addition to this, the indicators of degradation were defined by various simple tests such as torsion, deflection, and water-soak tests, followed by detailed inspection to determine the degree of degradation after each trip.

Following completion of the test program on each individual mobile home and component, the data were correlated with theoretical data developed in Task I to determine whether or not the predictive analysis of a mobile home can be made by the simplified measurements of torsional and vertical deflection.

---

* The specifics of the test program can be found in Task III, Part I, "Implementation of Test Program." This abridged material from Task II serves only to present a synopsis of the general intent of the testing.

BACKGROUND DISCUSSION

The degradation of mobile homes is a factor that has been known for some time. The data inputs and simplified test methodology that are required to determine the cause for the degradation have not been sufficiently defined to date. Within the terms of this contract, Southwest Research Institute recommended that the mobile homes be towed over actual highways rather than simulating conditions, such as vibration or other input effects, loads, road factors, setups or takedowns because of the questions that can always be raised concerning simulating various types of tests. Southwest Research Institute recommended on-the-road testing with adequate instrumentation to produce actual results of both single- and double-wide mobile homes and, thereby, measure the degree of degradation associated with various transportation and setup and takedown effects. The data review supported the notion that the general indicator of degradation is deflection of some type; vertical deflection tests are used as an indicator by some testing laboratories and mobile home manufacturers. Southwest Research agreed that increasing deflections or a "softening" of the mobile home structure was a good indicator of degradation. However, other factors could be more significant than vertical deflections. Thus, the Institute instrumented the mobile homes in order to measure vertical and torsional deflections. This instrumentation measured inputs from the wheel, tire, and axle combinations and the deflections of the shock absorbing spring axle. The instrumentation on the undercarriage system provided a factor indicating the degree of damping that is associated with mobile home design and construction, and the inputs from the springs and shackles into the mobile home structure furnished a significant input to the analysis. Also, the load and accelerometer inputs from the tractor or towing unit to the hitch and A-frame at the other end of the mobile home provided data. Inspection by qualified engineering and technical personnel produced valuable results.

All of these factors were considered, analyzed, and instrumented where possible and data recorded in critical areas in order that the data derived from the mobile home tests could be correlated with the theoretical analysis of Task I.

Several highway routes were selected over which the mobile homes were tested, and the different routes had different inputs; for example, the hill country run included steep inclines and downhill runs with sharp turns and switchbacks. The high speed run could be made around Loop 1604 which provided an entrance and exit ramp system as well as two-lane passing traffic rather than expressway type traffic. Another run used maximum road roughness to develop maximum accelerations in the vertical mode. Farm to market roads were utilized for rough and gravel road operation as well as roads with shoulders provided for slower traffic that have a tilt angle and road edge roughness for the right hand wheels of the mobile home. After discussions with mobile home transporters, the Institute is of the opinion that these various routes provide a typical cross-section of road conditions that are encountered during the delivery or transporting of the mobile home during a normal life expectancy.

From this test program, the methodology for determining the remaining useful life of a mobile home (developed in Task I, Volumes I and II) was validated.

TEST PROGRAM

TEST PROGRAM

Prepared By

C.R. Ursell, II

W.W. Raine

TABLE OF CONTENTS

LIST OF FIGURES

I. OBJECTIVES

Task III included the implementation of the test program approved in Task II as well as presentation of the test data gathered in the program. These empirical data were then compared to the theoretical data developed in Task I. The Task III effort had four main objectives:

(1) Conduct the test program on new and used mobile homes in accordance with the test plan presented and approved in Task II.

(2) Correlate the resultant dynamic data with the predictive dynamic data from Task I.

(3) Correlate the degradation existing in the test mobile homes with the predicted Remaining Useful Life (RUL) from Task I.

(4) Correlate the results of the program with Task I's finite element analysis.

II. INTRODUCTION

In order to achieve the stated objectives, this Task III effort was divided into three specific areas of endeavor:

1. Implementation of the Test Program

   This area included the basic test program as approved in Task II. Volume I, Part I of this task describes the field testing of the mobile homes including an abridgment of the Task II approved program.

   Volume I, Part II presents the test data from the program derived from the critical test parameters and summarized in tabulated form reflecting the flexural and torsional stiffnesses. These presentations do not include the total tape-recorded data, but only significant excerpts from these data as needed for correlation and verification.

2. Correlation of Test Data With Predictive Data

   After the basic test data were summarized, an analysis was made and correlated to the data of the dynamic predictive analysis of Task I. (Refer to Volume II of this Task).

3. Correlation of Test Results With Finite Element Analysis

   The finite element analysis was applied to the test mobile homes utilizing the static weight and the static equivalent loads generated by the transportation dynamic factors to evaluate resulting outputs of stress and deflection. These data were then correlated with visual inspections of mobile home damage. (Refer to Volume III of this Task.)

III. TEST SPECIMENS

The test specimens for this program were selected by the GTR as representative single- and double-wide mobile homes to be used in the test program as instrumented/controlled test articles. Comparable new and used units were to be purchased with known history (and records, if possible, on the used units). They are listed as follows:

New Single-Wide

Test Designation: T-1

1976 (14 x 65) Two-Bedroom, Two-Bath and Kitchen over Axles

Used Single-Wide

Test Designation: T-3

1971 (14 x 65) Two-Bedroom, Two-Bath and Kitchen over Axles

New Double-Wide

Test Designation: T-2 (24 x 60) 1976

T-2A: 12 x 60 Wet Side; Kitchen, Two-Bath, Bedroom, Den and Service Room

T-2B: 12 x 60 Dry Side; Living Room, Dining Room, Two-Bedroom

Used Double-Wide

Test Designation: T-4 (24 x 60) 1974

T-4A: 12 x 60 Wet Side; Kitchen, Two-Bath, Bedroom, Den and Service Room

T-4B: 12 x 60 Dry Side; Living Room, Dining Room, Two-Bedroom

A. Selection of Used Mobile Homes

Through the use of the instrumentation discussed later in this volume, and current testing methodology, actual mobile home conditions could be experienced. The only condition that could not be simulated in the test program within the project's time frame was degradation resulting from weathering or aging.* The aging factor could neither be accelerated nor simulated with any degree of accuracy. Yet, inspection of numerous used mobile homes in mobile home lots and parks clearly revealed that weathering significantly affects the structural integrity of a unit. Air infiltration and wavering and vibrations caused by buffetting winds and normal family through-traffic were noted frequently in the used units. If the mobile home supports were loose, the vibrations were more severe. Moreover, the periodic settling aspects of the foundation under a mobile home chassis causes the structural box of the unit to deform; thus requiring the unit to be releveled and setup repeatedly during the life of an average mobile home. Particularly noted was the common occurrence of water leakage and resultant damage in used units especially around vents that project through the roof and around the windows.

Hence, used mobile homes were also selected in an attempt to introduce the 'age' or 'weathering' factor and illuminate the difference in structure between the new and used units due to age alone at the end of equivalent mileage and setup/takedowns. To this end, both the new and used, single- and double-wide units were selected such that the floor plan layouts matched as nearly as possible to ensure correlation of test data and overall results.

At this point, it should be kept in mind that mobile home manufacturers frequently change floor plan designs, and recently, changes have been made in compliance with the 1976 HUD regulations. This renders an exact congruency between a 1972 (14 x 65) used mobile home and a 1976 (14 x 65) new mobile home supposedly of the same model practically

---

* Predictive methodology described in Task I does include the effects of use and aging.

impossible. However, for purposes of this research project, a realistic match was effectively achieved.

B. Pre-Test Specimen

At the initiation of this program, procurement of the aforementioned test units was delayed. In the interim, a 12 x 65-ft two-bedroom mobile home was borrowed from the HUD strategic storage center in Palo Pinto, Texas for use in the development of the pre-test concept, i.e., instrumentation, testing methodology and associated equipment. This unit was fully instrumented by SwRI and towed over the various routes that were selected for road conditions and configurations (hills, shoulder conditions, sharp turns, dips, clearance problems) to ensure the effects of representative transportation conditions experienced by each of the test specimens.

C. Specifications on Test Units

The following pages present the mileage history for each of the four test units (T-1 through 4) and the pre-test Palo Pinto unit, designated as T-5.

T-1
1976 SINGLE-WIDE (NEW)
14 x 64
(Box length 60-ft)
Two-Bedroom; Two-Bath; Centerline Kitchen

HISTORY

Delivered to: Walton Mobile Homes Sales, Seguin, Texas, August 1976

Sold to SwRI: October 21, 1976

SwRI DATA

C. R. Ursell and Harry Christensen (HUD/Austin)
Inspected on lot: October 1976

Purchased by SwRI: October 21, 1976 (P.O. 26075 SW)

Moved by SwRI, Seguin to SwRI, San Antonio: October 26, 1976

Mileage:	Factory to Seguin, Texas (no setup)	487 miles
	Seguin to SwRI, San Antonio, Texas (setup)	77 miles
	Total miles to date 11/15/76	564 miles

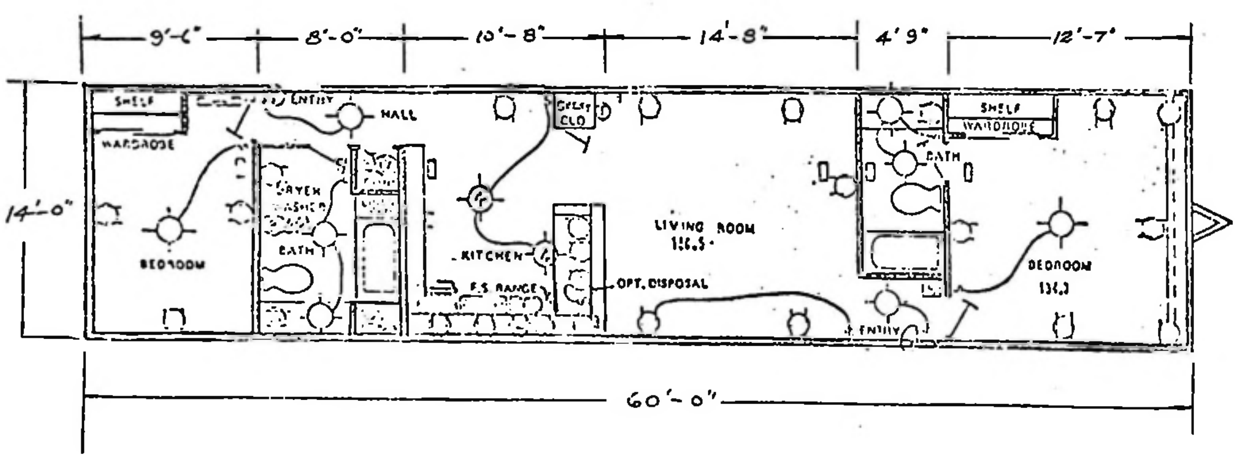


FIGURE 1. T-1 FLOOR PLAN

1976 THREE-BEDROOM DOUBLE-WIDE (NEW)
(24 x 56)
Centerline Kitchen

HISTORY

Purchased by: Walton Mobile Home Sales, Seguin, Texas	October 28, 1976
Purchased by SwRI, San Antonio, Texas (P.O. 26076 SW)	October 21, 1976
Picked up by SwRI Tractor at Grand Prairie, Texas and November 5, 1976, two separate trips	November 8, 1976
Delivered to SwRI, San Antonio, Texas	November 10, 1976

SwRI DATA

Purchased by SwRI from Walton Mobile Home Sales (P.O. 26076 SW)	October 21, 1976
Picked up at Grand Prairie, Texas by SwRI	November 8, 1976 November 10, 1976
Mileage: Grand Prairie to SwRI, San Antonio	315 miles
Total miles	315 miles

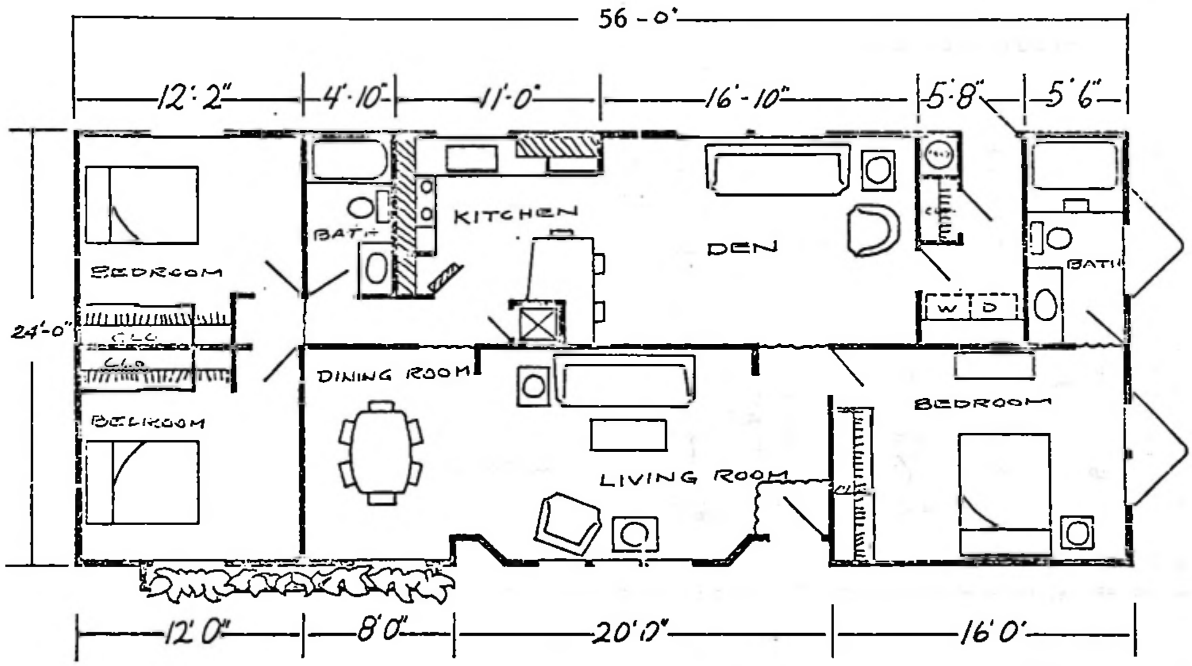


FIGURE 2. T-2A AND T-2B FLOOR PLANS (24 x 56)

T-3
1971 SINGLE-WIDE (USED)
(14 x 64)
(Box length 60-ft)
Two-Bedroom; Two-Bath; Centerline Kitchen

HISTORY

Delivered to:	Walton Mobile Home Sales; Seguin, Texas	July 1971

Sold to Mr. D. Bundick: August 1971

SwRI Purchased from Mr. Bundick: October 1976

SwRI DATA

C. R. Ursell and Harry Christensen (HUD/Austin) Inspected on site:	October 1976

Purchased by SwRI: October 1976

Moved from Seguin to San Antonio: November 1, 1976

Mileage:	Factory to Seguin, Texas	291 miles
	Seguin to ranch	13 miles
	Ranch to SwRI	90 miles
	Total miles to date 11/10/76	394 miles

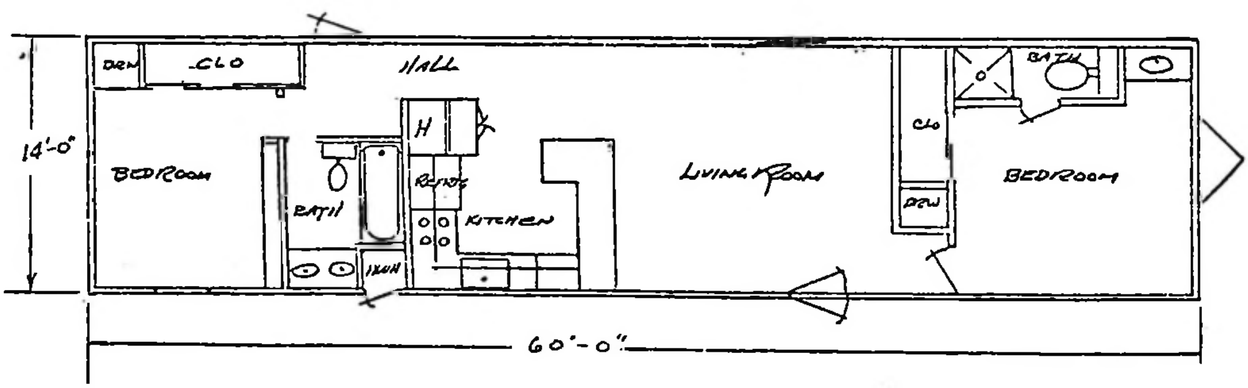


FIGURE 3. T-3 (USED) SINGLE-WIDE 1971 (14 x 64)

T-4
1974 DOUBLE-WIDE (USED)
(Box length 24 x 60)
Three-Bedroom; Two-Bath; Centerline Kitchen

HISTORY

Delivered to dealer at: Seguin, Texas (357 miles)
(Dealer out of business)

Sold to: Mr. & Mrs. Fitzgerald of Seguin, Texas (2 miles) — April 1974

SwRI DATA

Selected at Seguin, Texas by J. McCollom and C. R. Ursell — October 2, 1976

Purchased by SwRI for HUD: September 29, 1976 (P.O. 24858 SW)

Moved to SwRI, by SwRI, October 11, 1976 (77 miles)

Mileage:	Factory to Seguin	357 miles
	Seguin to Fitzgerald site	2 miles
	Fitzgerald site to SwRI, San Antonio, Texas	77 miles
	Total miles	436 miles

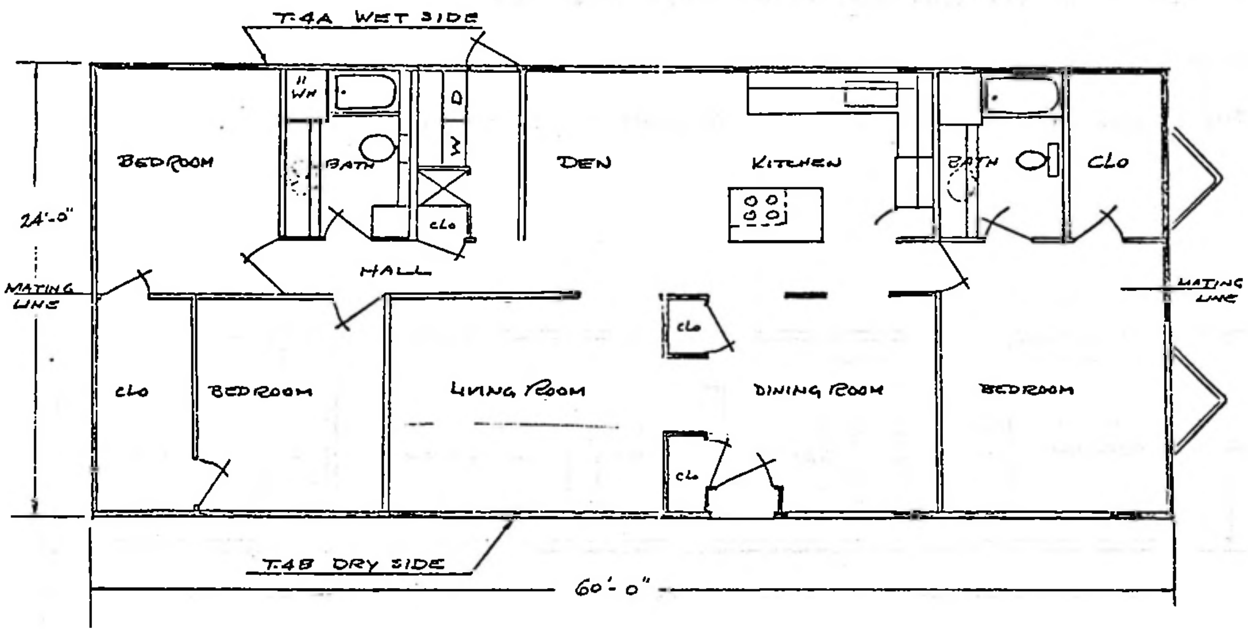


FIGURE 4. T-4 USED DOUBLE-WIDE (24 x 60)

T-5
1972 PALO PINTO SINGLE-WIDE
12 x 64
(Box length 60-ft) S/N 3931
Three-Bedroom; One and a half Bath; Centerline Kitchen

HISTORY

Manufactured at: Unknown

Delivered to Wilkes Barre, Pennsylvania: Unknown

Transferred from Wilkes Barre, Pennsylvania to Palo Pinto: May 22, 1974
(1550 miles) by Sentry Transportation

SwRI DATA

Selected at Palo Pinto by C. R. Ursell and Juan Gill (HUD) 1976

Picked up by SwRI crew at Palo Pinto 1976
(Inspection report attached)

Delivered to SwRI, San Antonio, Texas 8/19/76, 294 miles

Instrumented and highway tested by SwRI (total test miles) 557 miles
1976 September/October

Torsional and vertical deflection tests conducted by SwRI

Number of setups and takedowns at SwRI: 4 each

Total known miles on mobile home to date: 1550 + 557 = 2107

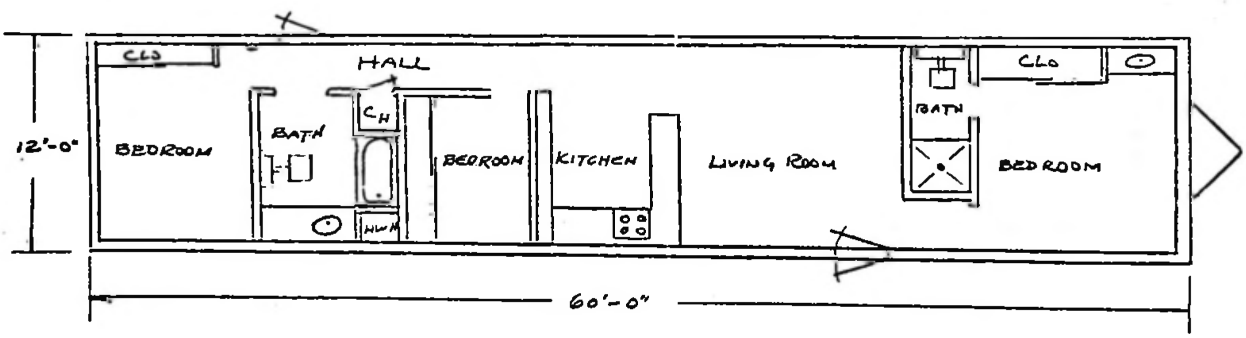


FIGURE 5. T-5 HUD PALO PINTO STRATEGIC STORAGE CENTER UNIT
(12 x 64)

IV. TEST PREPARATION AND SETUP

A. Conditions I and II

In order to comply with the contractual requirements, two "conditions" were established for testing the mobile homes.

Condition I:

Testing of newly purchased mobile homes transported between 250 to 500 miles from the manufacturer's plant and installed upon the purchaser's site (initial transportation);

Condition II:

Testing of the same mobile homes after the following time-related activities:

T1: Simulated 15 years of use including three occupancy periods and two secondary transportation movements ranging between 300 to 600 miles; an additional distributed weight of 4,000 lb of occupants' personal effects were included in the transportation calculations.

T2: Simulated 20 years of use including two occupancy periods and one secondary transportation movement ranging between 300 to 600 miles. An additional distributed weight of 8,000 lb of occupants' personal effects were included in the transportation calculations.

Because of the necessity for using only "standard production items" for the tests, new mobile homes were purchased through or from dealers. The new single-wide mobile home (T-1) was transported a distance of 487 miles from the factory to Seguin, Texas, plus another 77 miles from Seguin to SwRI. Since the delivery mileage had already been imposed upon the unit, the "original-condition tests" could not be conducted.

Both halves of the new double-wide test mobile home (T-2) were towed to SwRI from the dealer's lot in Grand Prairie, Texas--a distance of 315 miles. Vertical deflection and torsional tests were conducted in Grand Prairie on T-2 in order to measure and record initial stiffness. In essence, the test program was initiated without the detailed information required for a "Condition I" data retrieval on both the T-1 and the T-2; only stiffness values on T-2 were measured for the initial delivery mode.

B. Test Matrix

Prior to in-transit and static testing of the units, a matrix was used to program each of the mobile homes through the scheduled tests. Table 1 presents this matrix indicating the sequence of the testing and the routes to be traveled by each mobile home. As shown in Table 1, 12-ft wide mobile homes traverse some highways that 14-ft wide units cannot because of state regulations.

C. Loading Schedule

Each test mobile home assembly was weighed as a unit to determine the delivered gross weight. This was accomplished by first recording the static weight resting on the axles, wheels and tires. Then, the hitch was uncoupled from the tractor, and the hitch or tongue weight was recorded. The units were weighed as delivered by the manufacturer and received by the dealer including the normal lightweight manufacturer-supplied furniture. The total recorded weight was the gross weight recorded for the Condition I tests (initial transportation moves). The furniture in the area where instrumentation was installed was displaced by equipment of equivalent weight. The used single- and double-wide units were purchased with existing furniture. Each previous owner had replaced the original lightweight furniture of the manufacturer with heavier household furniture. Because of the problems associated with purchasing and handling furniture from mobile home to mobile home, sandbags were substituted as equivalent weights of the furniture.

TABLE 1
TEST MATRIX AND CODES

TEST	T-1	(wet) T-2A	(dry) T-2B	T-3	(wet) T-4A	(dry) T-4B	T-5
Setup	X	X	X	X	X	X	X
Instrument	X	X	X	X	X	X	X
Weigh	X	X	X	X	X	X	X
Torsion Test	X	X	X	X	X	X	X
Vert. Deflection Test	X	X	X	X	X	X	X
Furniture Load	X	X	X	X	X	X	
Takedown	X	X	X	X	X	X	X
Inspection	X	X	X	X	X	X	X
Water Test	X	X	X	X	X	X	
Trip - Route No. 1	X	X	X				X
Water Test	X	X	X				X
Inspection	X	X	X				X
Data Deflection Test	X	X	X				X
Torsion Test	X	X	X				X
Setup & Takedown	X	X	X				X
Trip - Route No. 2					X	X	X
Water Test					X	X	X
Torsion Test					X	X	X
Deflection Test					X	X	X
Inspection					X	X	X
Setup & Takedown					X	X	X
Trip - Route No. 3							
Water Test							
Torsion Test							
Deflection Test							
Inspection							
Trip - Route No. 4	X	X	X	X	X	X	
Water Test	X	X	X	X	X	X	
Torsion Test	X	X	X	X	X	X	
Deflection Test	X	X	X	X	X	X	
Inspection	X	X	X	X	X	X	
Setup & Takedown	X	X	X	X	X	X	
Trip - Route No. 5	X	X	X	X	X	X	
Water Test	X	X	X	X	X	X	
Torsion Test	X	X	X	X	X	X	
Vert. Deflection Test	X	X	X	X	X	X	
Inspection	X	X	X	X	X	X	
Setup	X	X	X	X	X	X	
MEAS. FLOOR PLAN	X	X	X	X	X	X	X
MEAS. SEC. PROP.	X	X	X	X	X	X	X

During Condition II testing (i.e., secondary transportation movements), an additional distributed weight of 4000 lb was carried in each test unit to simulate the weight of typical household furniture added by homeowners. Standard household furniture tends to be heavier than the manufacturer-supplied mobile home furniture. The weight schedule for each mobile home is noted in Task III, Volume I, Part II.

D. Test Setup

The test setup for each mobile home unit consisted of two areas of work:

(1) Setup for in-transit testing consisting of installation of instrumentation and data retrieval systems in the mobile home to measure the en-route dynamic factors (e.g., vertical, lateral and longitudinal accelerations and stresses in various steel members) associated with degradation.

(2) Setup for post-trip static testing to measure the static factors considered indicators of degradation from road trips and setups and takedowns.

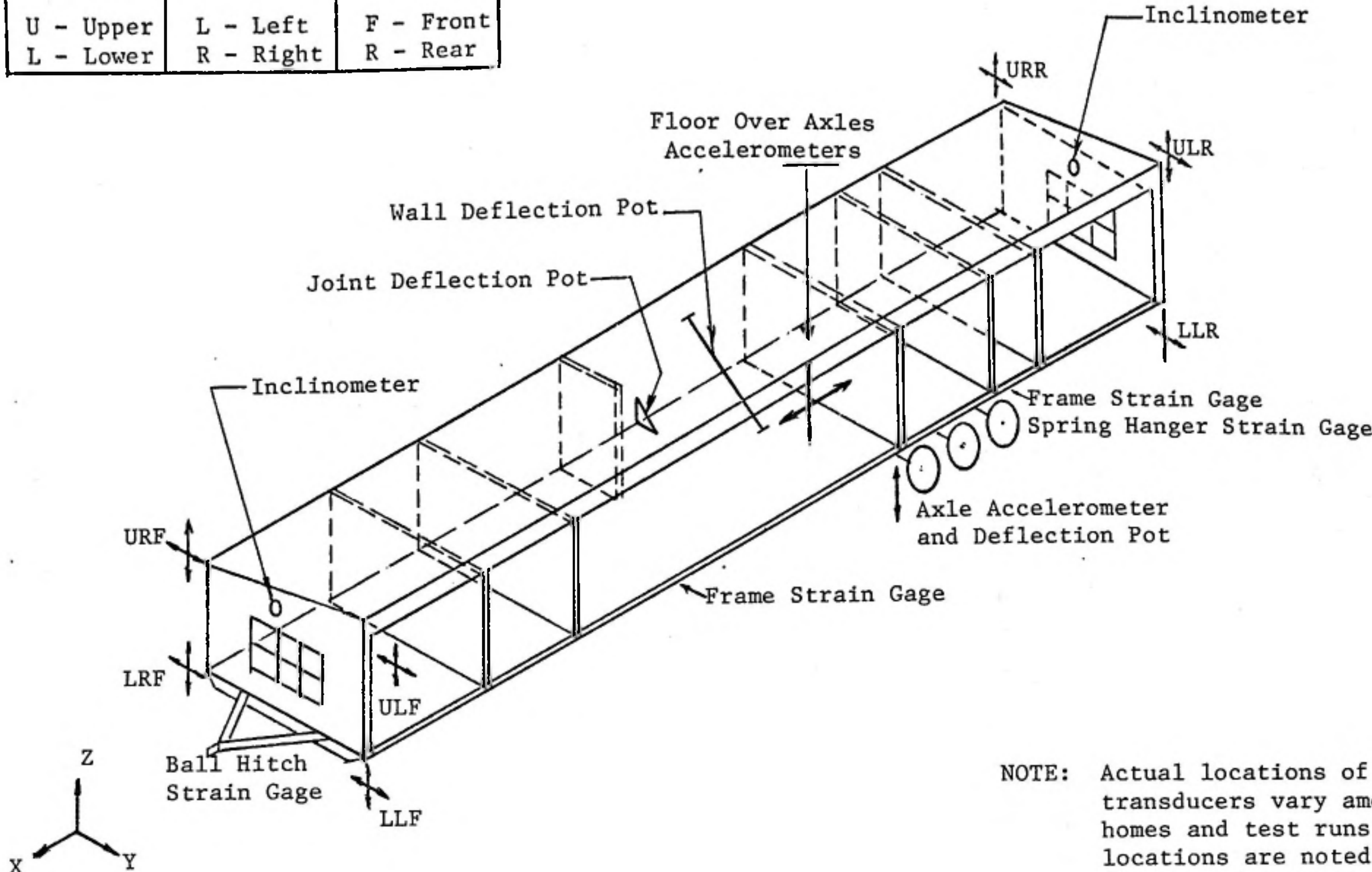
1. Instrumentation

Testing of the mobile homes during the transportation mode required a unique instrumentation system in order to measure the vertical, lateral and longitudinal accelerations and stresses in the steel members. Strain gages were installed in critical locations as well as accelerometers.

The accelerometers were located on the axle, the floor over the axle and at the c.g. in the front and rear, upper and lower corners. In these locations, the vertical and lateral accelerations were recorded indicating torsion, vertical bending, frequency accelerations and damping. Strain gages were located on the spring/shackel hangers, the A-frame and the tow hitch/coupler to record stresses under all loading conditions. It must be noted that the strain gages on the longitudinal I-beams were installed with the pre-camber, but with the mobile home in a level position. The degree of residual stresses due to pre-camber and static structural loading is not known. Only the "added" loads or stresses were measured. Diagonal wall deflection indicators were installed between the side walls and floor in the long open areas devoid of partitions or shear walls to measure the wall deflections resulting from torsion. Deflection pots were also installed on the front axle to measure the deflection associated with the vertical accelerations measured on the same axle. The instrumentation system depicted in Figure 6 is a block diagram of each major component within the system.

ACCELEROMETER LABELING CODE

1st Letter	2nd Letter	3rd Letter
U - Upper L - Lower	L - Left R - Right	F - Front R - Rear



NOTE: Actual locations of the transducers vary among the homes and test runs. Specific locations are noted in the figures of Appendix A.

FIGURE 6. TYPICAL TEST INSTRUMENTATION

The installation and location of the various transducers and data pickup points may have varied from one mobile home to another in the test because of the width, length, shape, size, and type of construction. However, the general layout remained the same, as was required for correlating data with the predictive data of the dynamic and finite element analyses.

Because of the large volumes of data that were generated from the latter equipment, a magnetic tape recording system was chosen to record displacements, accelerations and forces along with a descriptive voice channel to identify events and the various channels of data that were required for the analysis. These test data channels were recorded on the FM multiplex system. Data traces were played back at significant events on light beam oscillographs for detailed measurements. The dynamic data were used for correlation with Task I predictive analysis (Task III, Volume II), and the static, or 1 "g " and strain gage data were used to verify and correlate with the finite element analysis. (See Task III, Volume I, Part II and Task III, Volume III.)

2. Data Recording

The typical data input system takes low-level inputs from transducers, conditions them and modulates voltage controlled oscillators and mixes them for tape recording. The retrieval system demodulates the carriers off the tape, amplifies the analog signal and displays this signal on a strip recorder or routes it to an analog-to-digital converter for digitizing and processing by a computer.

Signal Conditioner -- The typical signal conditioner adjusts the voltage applied to transducer, balances the bridge, amplifies the output, and drives the following voltage controlled oscillator. The strain gage plug-in cards contain the voltage regulator, the plus and minus calibration relays and components and any bridge completion components as required.

Voltage Controlled Oscillators -- The oscillators are selected to fit within the pass band of the tape recorder with the deviations of the individual voltage controlled oscillators selected to reproduce the desired data band. All of the measurements taken on these mobile homes fit within the SAE class GC frequencies which have a flat response to 60 Hz.

The VCO input/output definitions indicate the lower band edge (LBE), center frequency (CF), upper band edge (UBE), and full band width (FBW).

An additional oscillator is utilized as a reference oscillator when the data is recorded on magnetic tape. This signal is used to reduce the effects of tape speed variations.

Voltage Controlled Oscillator Calibration -- A voltage calibrator is built into the system which can apply from two to nine levels of voltage to the inputs of the voltage controlled oscillators for calibration purposes. This is done manually for pre-test check out. An automatic calibration sequencer is built into the equipment for calibration during a test. The sequencer first does a plus calibrate on all measurement devices, then has a slight zero condition period before going into the minus calibrate mode for all measurement devices. After a second slight zero condition period, the sequencer steps to the automatic calibration of all the voltage controlled oscillators. When that function is completed, the equipment goes to a data collect mode of operation for about 15 minutes. The complete calibrate sequence is then repeated.

The use of this automatic calibration sequencer injects numerous calibration points on the lengthy tests. This allows a continuous verification of proper operation of measurement devices and their associated electronics. It also allows the verification of exactly what part of the test any measurement device was damaged or failed.

Mixer Amplifier -- The multiplexed output of the voltage controlled oscillators of a designated group are combined with the reference oscillator and the combined signal amplified with the mixer amplifier.

Subcarrier Discrimination -- The multiplexed output of a tape channel is applied to the inputs of a group of matching discriminators. Here the signal is filtered, limited, amplified, and detected. The detected signal is filtered and amplified to reconstruct the original input signal. The reference signal is detected by the reference discriminator, and the compensation signal is routed to all other discriminators to correct for tape speed variations.

3. Data Retrieval

A decision was made not to operate the tape recorder continuously during the entire course of the mobile home highway testing phase because this would generate an excessive volume of repetitious data which would be of little value except when some dynamics were occurring. For this reason, a technician was located in the cab with the driver in order to keep records and monitor the communication system between the tractor and the mobile home unit. Additionally, the technician alerted the tape operator before a highway event occurred. An aircraft type seat was installed in the mobile home that could withstand high "G" loads and thereby protect the operator in the event of an accident, including rollover of the unit. All of the test instrumentation was securely fastened to the floor and wall structure of the mobile home to prevent the introduction of errors due to impacts caused by relative motion between the structure and instruments.

In practice, the observer, riding in the tractor watched the road and advised the equipment operator of approaching road sections that might trigger an event. Items that the observer looked for were:

- High road crowns,
- Chuck holes or rough spots,
- Dips,
- Heavy traffic,
- Rough shoulders,
- High wind conditions,
- Panic stop,
- Sharp or gradual turn right or left,
- Change in road conditions or terrain,
- Inclines or downgrades.

With such advance knowledge during the course of the trip, the instrumentation operator would activate the tape recorder and verbally identify the type of event. Thus, it was very easy to locate any discrete event on any section of road at any one time for each mobile home. Consequently, the trip log and event location have been very useful in the data retrieval process.

The data retrieval system recorded the signals from the various transducers on the magnetic tape. Calibration signals were a necessary function of the data package in order to properly measure and analyze the tracer. Therefore, two calibration signals were placed on each data trace: one at the beginning of the setup and before the start of the trip and one automatic calibration signal at prescribed intervals during the course of the trip and the recording of data. The reason for using the automatic calibration was to provide backup in the event a data channel malfunctioned. If a malfunction occurred, the last calibration would be used as an indicator to determine the point at which it happened.

Copies of the various forms used throughout the test program and the applicable instructions are included in Appendix A at the end of this volume. These forms include trip reports, inspections, tests and general records. The test data/record books for each mobile home test unit are on file at SwRI. Each significant event is recorded including inspections, activities, data logs, tire blowouts, routes and all pertinent information and data relating to each test mode.

E. Tests and Inspections

In order to measure any observable degradation in durability performance, records were maintained of the following activities for each mobile home.*

(1) Receiving inspection,
(2) Weight,
(3) Instrumentation layout,
(4) MUX channel assignment,
(5) Trip activities,
(6) Inspection,
(7) Tire failure,
(8) Setup test activities,
(9) Water testing,
(10) Electrical testing,
(11) Plumbing testing,
(12) Gas system testing,
(13) Vertical deflection testing,
(14) Torsional deflection front (left and right) testing,
(15) Takedown testing.

*See Appendix B for the basic test sequence for the test specimens.

V. IN-TRANSIT TESTS

The overall purpose for in-transit and static testing of the mobile homes, rather than simulation testing, was to replicate routine transportation and site installation practices in order to measure their effect on actual full-scale units. To that end, each mobile home was towed over the same highway routes--designated by the Texas Department of Public Safety as routes for mobile home transporters--and fitted with identical instrumentation in order that identical inputs be generated for each mobile home for correlative and comparative purposes. The road inputs, as well as the setups and takedowns, were patterned after typical operations of contract transporters and setup/takedown crews so that degradation would be applicable to the average mobile home.

A. Towing of Test Units

The same SwRI tow tractor was used for towing the mobile homes. The tow tractor was equipped with an instrumented ball hitch and a stabilized electrical power generator for the instrumentation utilized within the mobile home. The 1970 tow tractor had a 454 cubic-inch engine and a ten-speed gear box and rear axle combination. The tractor was equipped with tool boxes, electrical generator, a flashing yellow running light, and extended rear view mirrors.

A "Wide Load" sign was installed on the front bumper with extra running lights, all indicating "SwRI Test Unit." On the rear of the mobile home (in addition to the normal tail and running lights), "Wide Load" and "SwRI Test Unit" signs with rotating or flashing yellow lights were installed as a precaution for all motorists either trailing, passing, or meeting the unit on the highway.

The driver was an experienced professional and was instructed to conform with mobile home transportation regulations, as well as accepted practice, in order to simulate typical operating conditions. A nominal speed, used for the majority of the trips, was an average of 45 mph. Other speeds up to 55 and 60 mph were infrequently used; and, in the hill country areas, the speeds were as low as 10 to 20 mph depending on the road configuration and the weight of the unit.

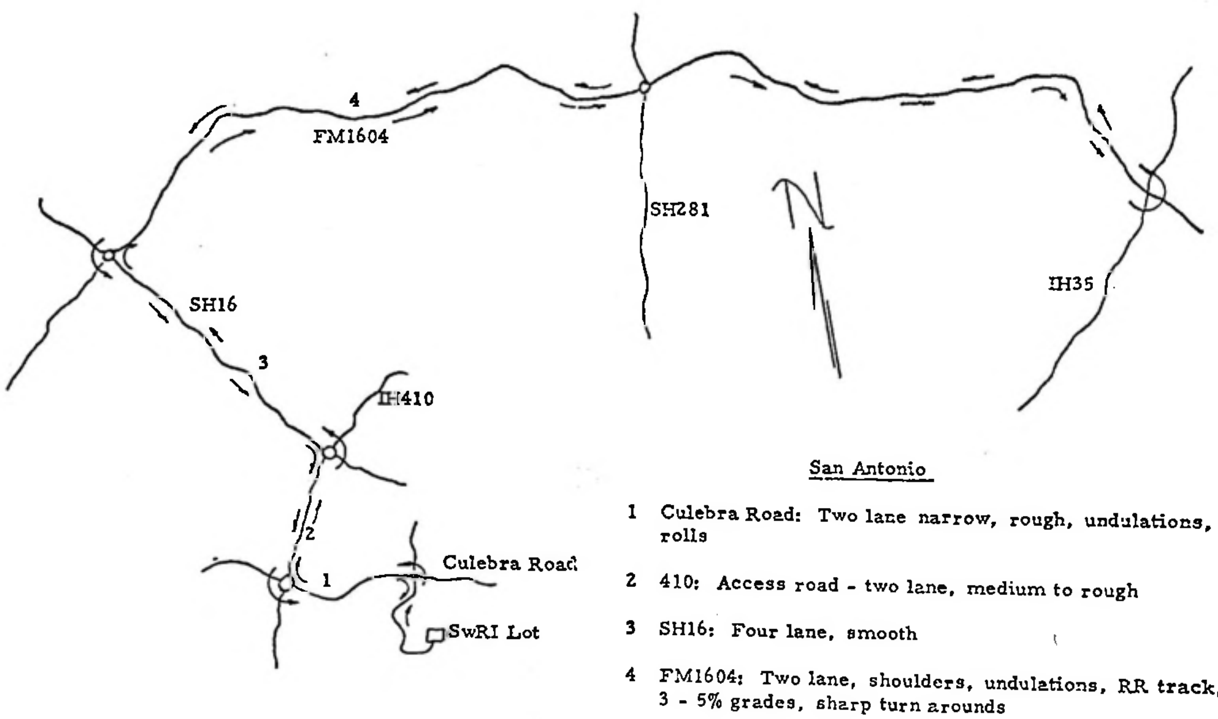
B. Highway Test Routes

The following pages delineate the highways that were used as the five test routes for the mobile home test trips. All of these routes are within the South Texas area. The Texas State Highway and Farm to Market road numbers and U.S. Interstate numbers are noted on the route delineation with a description of the route, mileage, road surface conditions and other significant factors comprising the inputs to transportation effects encountered on these runs. The test routes included smooth paved roads, rough or undulating paved roads, paved roads with sharp shoulders and chuck holes, hills, inclines, downgrades, sharp turns, turnarounds, entrance and exit ramps to highways, dips and expressway smooth roads.

The routes were selected after discussion with (1) the Texas Department of Public Safety which routes the mobile homes, and (2) numerous mobile home transport operators who gave their opinions on what they considered the average road surface encountered when delivering a mobile home. From the latter discussions, it appears the average route for a 14-ft wide mobile home consists of Class 2 paved roads with chuck holes, undulating waves or patches and rough shoulders. The roads tend to be narrow, often

ROUTE No. 1

The FM1604 road constitutes an "outer loop" around the city of San Antonio. All of the mobile homes were delivered to the Institute along this route. Also, the test runs with the Palo Pinto 12 x 65 were initially conducted along this route. FM1604 provides a smooth two-lane road with exit/entrance ramps, railroad crossings, shoulders and curves with on-coming traffic.

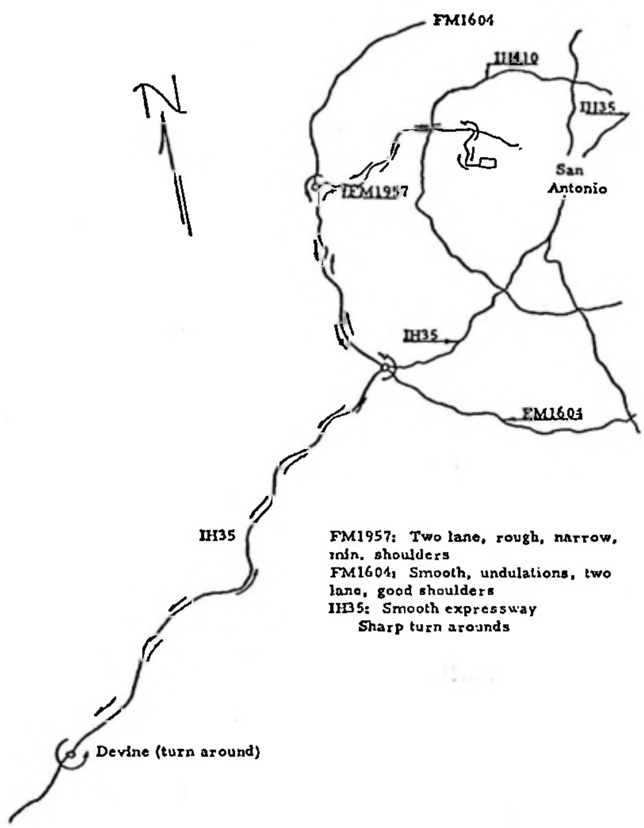


ROUTE NO. 1: HIGH-SPEED RUN: TOTAL MILES = 65.2

ROUTE NO. 2

This route can be run with 12-ft wide units only. If 14-ft wide units need high speed or expressway runs, they will be conducted on Route No. 1, FM 1604. The restricted portion of this route is IH35 from FM1604 to Devine and return.

The FM1957 is a narrow two-lane rough asphalt road with minimum shoulders from the Institute to FM1604. On this run the mobile home receives a combination of both rough roads, smooth roads, high-speed smooth expressways and sharp turnarounds. This route is predominantly through flat country with minimum inclines.

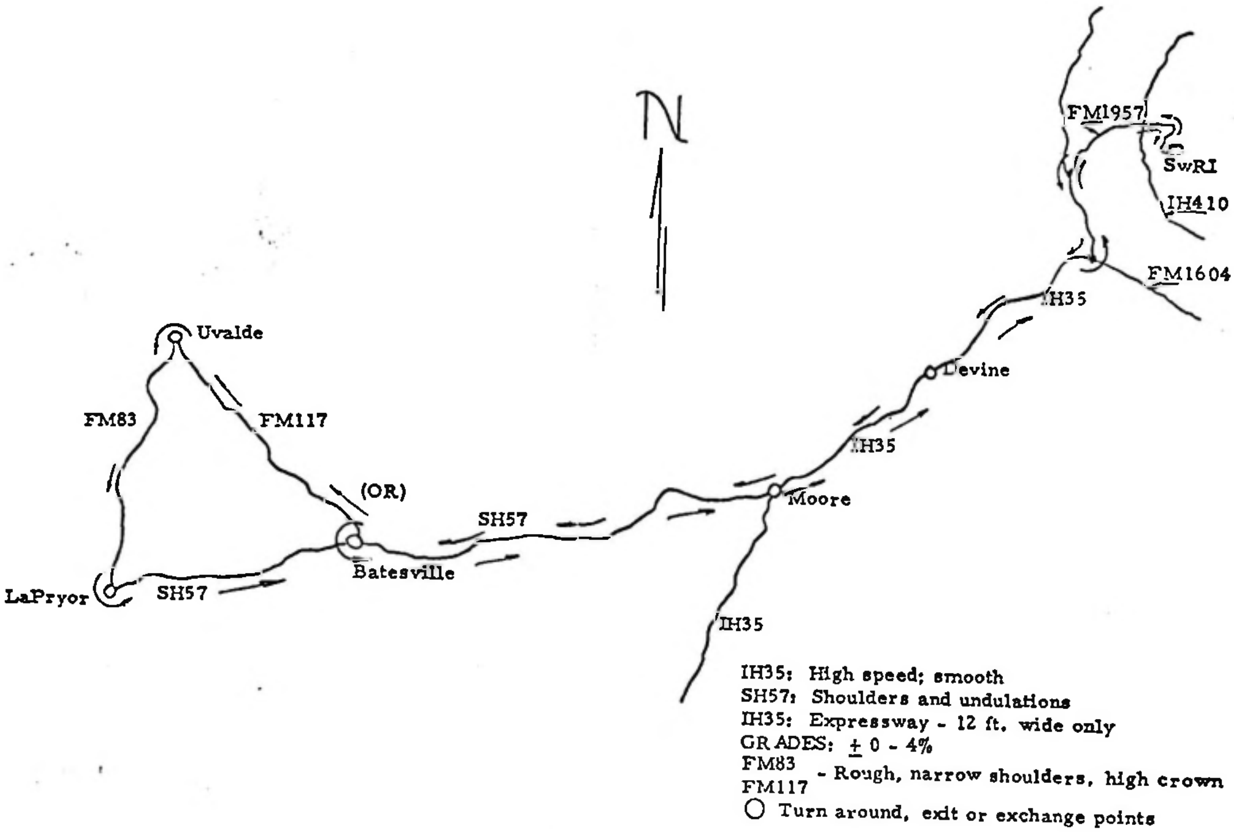


ROUTE NO. 2: HIGH-SPEED RUNS: TOTAL MILES = 60, SMOOTH
(12-ft WIDES ONLY ON IH35)

ROUTE NO. 3

This route was picked for the SH57 road conditions because of the undulating nature of the asphalt road. However, approximately halfway through the test program the Texas Highway Department re-surfaced the road, and the alternate rough road route was taken as indicated by Route No. 5.

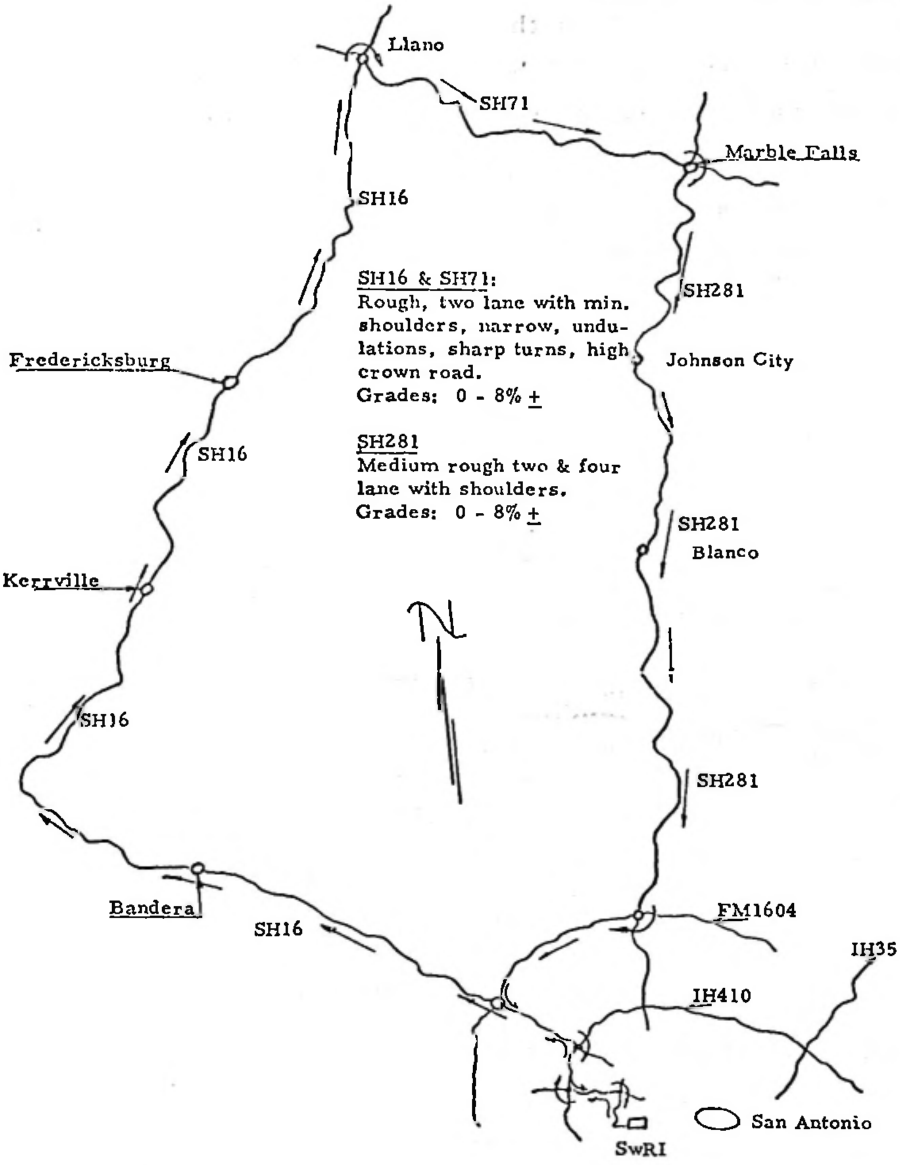
Also, a 14-ft wide mobile home had to travel the access road from FM1604 to Moore and the same thing on the way back. The FM83 and FM117 roads were considered rough. The triangle formed by FM83, FM117, and SH57 provided opportunities to turn around at any time to obtain the correct mileage for the trip. The routes are predominantly through flat country with minimum grades. With the exception of IH35, the roads are two-lane, somewhat narrow, paved asphalt providing a cross-section of the average type roads traveled in mobile home transportation.



ROUTE NO. 3: ROUGH ROAD WITH UNDULATIONS: TOTAL MILES = 215

ROUTE NO. 4

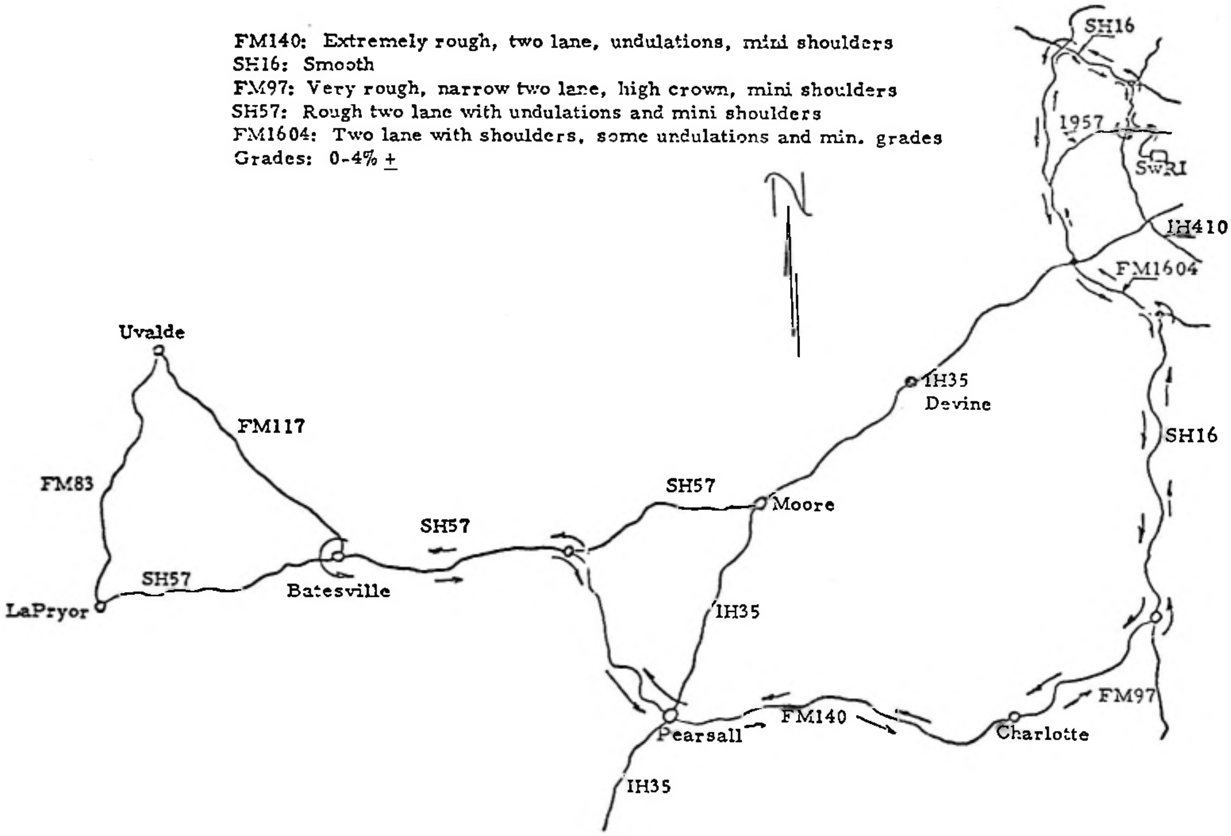
This route is referred to as the "Hill Country Run." The sections from Bandera, to Kerrville, Fredericksburg and Marble Falls are in the rough hill country with inclines and downgrades up to 8 percent. All of the roads are in the hills and are two-lane rough roads with minimum shoulders. SH16 from IH410 to Bandera is a four-lane expressway. The SH281 from Marble Falls to FM 1604 is a two-lane smooth road with grades up to 4 percent. The high winds and blowover of T-2A occurred 8 miles south of Johnson City. Highway 281 is heavily travelled by mobile homes, travel and tractor trailers, trucks, and passenger vehicles.



ROUTE NO. 4: HILLS AND ROUGH TWO-LANE: TOTAL MILES = 200

ROUTE NO. 5

The FM140 road is the second or alternate rough road picked because SH57 was re-surfaced. This route was used during the last half of the program since it provided smooth roads on FM1604 and SH16 with rough roads on FM97, SM140 and SH57. Incidents such as tire blowouts and spring and hanger failures occurred on this route, predominantly in the rough sections. Truck and tractor trailer traffic is heavy, and the test units had to run with the right wheels off the shoulder several times because of the narrow road.



ROUTE NO. 5: TYPICAL ROUGH NARROW FM ROADS: TOTAL MILES = 350 causing difficulties for vehicles passing the 14-ft wide units.

The trip distance during the day was scheduled for an average of 250 miles, equal to a normal 1-day run for a transporter conducting a long move. The test units were returned to the SwRI lot at night in order to maintain progressive inspections and incremental measurements.

C. Significant Events During Towing Operation

During the routine towing of the mobile homes over the various routes, several significant events occurred. These events included such items as frequent tire failures, suspension system failures, weak brakes, spring hanger failures, spring failures, wind blowovers, cracks in interior walls, loss of complete window assemblies, loss of screen doors, loss of roof vents, loosening of exterior aluminum covering, loosening of locks on exterior doors, and loosening of interior walls at the attachments.

These items have been depicted on color slides and some have also been depicted on 16-mm motion picture film for flexibility in presentation. Because of the apparently routine problems associated with the transportation of both new and used mobile homes, the final report in this program will contain recommendations for highway safety as well as durability pertaining to the overall transportation structure of the mobile home units. For example, the State of Texas does not have a wind restriction for towing mobile homes on interstates, state highways, farm-to-market or any other type of road within the state. Also, the double-wide units, towed in half units, are more susceptible to blowovers than are the single-wide units that have a totally different profile. The potential of a blowover, however, is always prevalent depending on a ratio of length to width as well as height to width with the span of the undercarriage a significant factor.

D. Trip Records

All trip data were recorded on Form No. 1, "Trip Report" which consisted of:

- Preparation check list,
- Trip/action report,
- Trip report basic data.

Data contained on this form provided the as-inspected condition of the mobile home and associated items and systems ensuring a systematic inspection of key items and a record of notable events during the test trip such as tire failures, spring hanger failures, exterior siding damage, etc. Refer to Appendix A for a sample of the trip report form.

VI. STATIC TESTING

A. Natural Frequency Test

Measurements were taken of each mobile home or section thereof to determine the natural frequency. As an example, Figure 7 presents a typical test on one mobile home.

Scope:

1. Determination of the natural frequency of the mobile home in question for use in analysis and (RUL) determination.

Procedure:

(a) Weight distribution inside mobile home is to be the same as used during road tests.

(b) Use vertical accelerometer located in one of the aft or rear corners for recording purposes.

(c) Install "pull-away" prop under A-frame or hitch. Height of drop is equal to length of "pull-away" prop. Three inches is the recommended drop height.

(d) Attach the tow tractor to "pull-away" prop.

(e) Turn on recorder.

(f) Pull prop out from under hitch or A-Frame with a swift jerk, allowing the hitch to drop on a solid plate.

(g) Record oscillations and playback via oscillographic recorder.

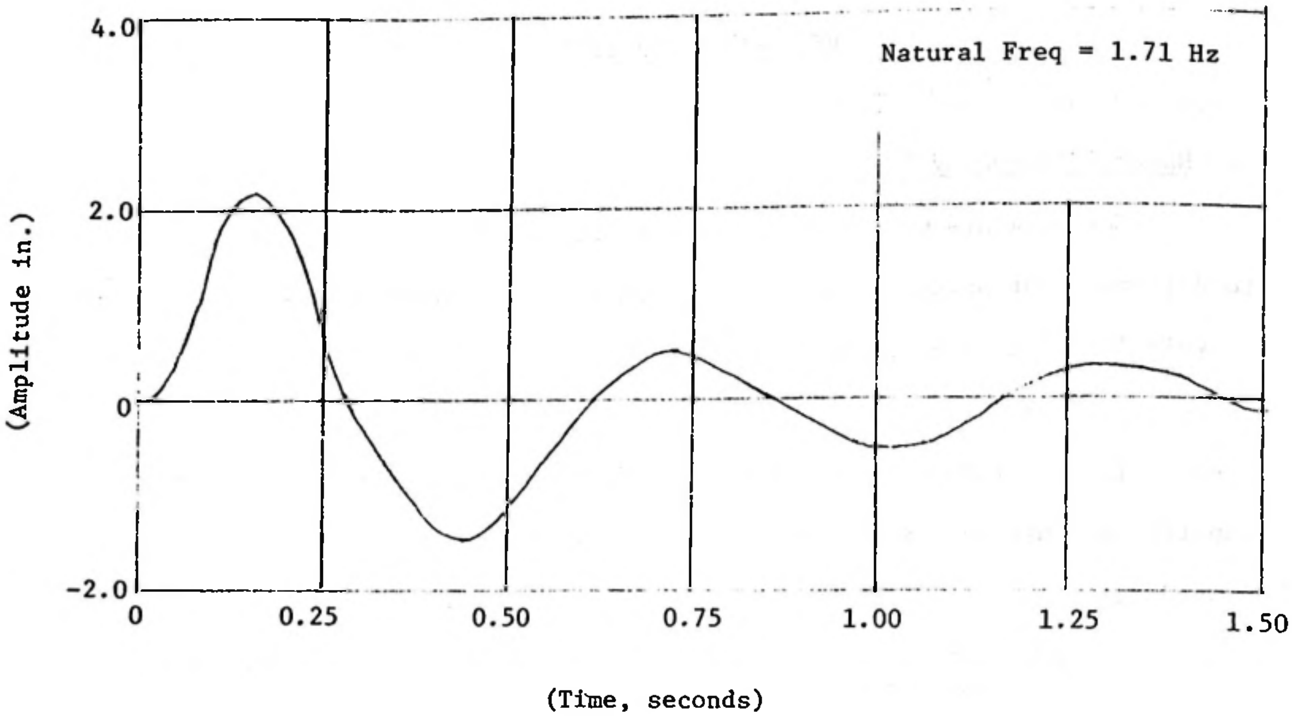
(h) Compute natural frequency by taking the reciprocal of the average period of oscillation.

B. Torsion Test

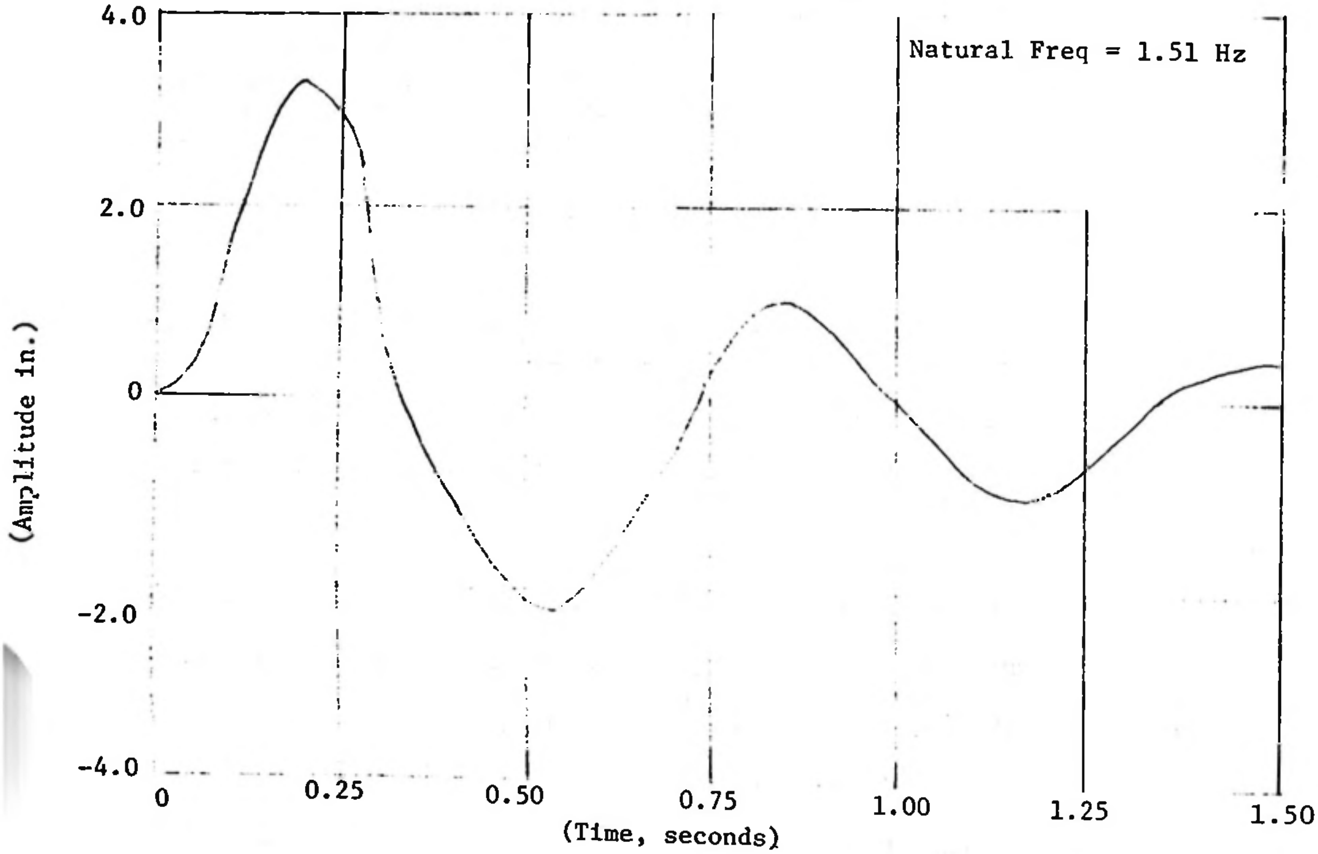
The torsion test on the mobile home was conducted following each trip in order to determine the degree of degradation in the box structure. The data were recorded on the applicable Form No. 9 (Appendix A).

Scope:

1. This method of test outlines a procedure for determining the degradation of a mobile home box structure and its reduction of torsional



(a) Drop Height = 3 in.



(b) Drop Height = 6 in.

Film Analysis Test Results - Drop Tests
Mobile Home No. 1
(Palo Pinto 12 ft x 60 ft)

Figure 7. Sample of Natural Frequency Test

rigidity due to degradation. Results of this test can be reduced to an effective torsional stiffness J.

Apparatus:

2. In addition to a mobile home, the apparatus shall consist of the following:

(a) Six jacks or mobile home piers;

(b) One "load cell" jack calibrated to read as a minimum 0-5000 lb in 500-lb increments;

(c) 48 to 52-in. plumb line pendulum with plumb bob;

(d) Steel rule - at least 6-in. long, in 0.01-in. increments;

(e) Paper, pencil, masking tape, and data sheet, or equivalents;

(f) Spirit and/or optical level.

Procedure:

3. This method of the test involves jacking up (and permitting the weight to sag) each corner of a leveled mobile home in prescribed weight increments. At each load, the corner deflection and the horizontal displacement of an end wall mounted pendulum are recorded. The test procedure steps and suggested data recording sheet are as follows:

(a) Position six jacks, or support piers, beneath mobile home: three under each of the two longitudinal I-beams, two forward, two aft and two immediately in front of the forward axle. (Refer to Appendix A for data sheet and figure)

(b) Jack up the home until load is off wheels and home is level using spirit level or optical level.

(c) Using optical level, level bottom of I-beams front-to-rear and side-to-side to further level home.

(d) Hang 50-in. plumb line and bob on front inside wall at center line of mobile home.

(e) Secure blank sheet of paper flat under plumb bob, almost touching. (Paper can be on floor or raised platform).

(f) Place the load cell jack under the front cross beam or I-beam, 48-in. off center.

(g) Jack up using load cell jack to just relieve the force on the corner's supporting jack without disturbing level conditions of mobile home.

(h) Mark plumb bob position on blank sheet as "zero pendulum displacement" and record weight on jack (or jack pressure and indicate as "PSI").

(i) Jack up load cell jack increasing load in 500-lb increments.

(j) At each incremental load, record load on load cell jack and corner deflection reading. Also mark pendulum displacement on data sheet.

(k) Continue lifting until mobile home is lifted clear of the other supporting jack at that end. Record data at that "clear" load.

(l) Reduce load on load cell jack back to original level load and record data. Mechanical set is normal such that mobile home may not return to original level condition.

(m) Continue to reduce load downward in 500-lb increments, recording corresponding data until zero load is attained and jack is free or clear of load.

(n) Increase load to original load, record data, set and replace original jack.

(o) Repeat Steps e through n for the other side of this end of the mobile home.

(p) Repeat Steps d through o for the rear end. Load cell jack is placed under longitudinal I-beam in rear if no cross beam is present.

(q) Calculate GJ's or J's front and rear (example in Appendix A). Use the appropriate formulas of the following:

$$\overline{GJ} = Phy/\tan^{-1}(W/\ell)$$

Single-wide:

$$\text{Front} - \bar{J}_F = 9.21(10^{-4})P_F h_F y_F \ell_F W_F{}^{-0.277}$$

$$\text{Rear} - \bar{J}_R = 4.48(10^{-4})P_R h_R y_R \ell_R W_R{}^{-0.391}$$

Wet Double-wide Half:

$$\text{Front} - \bar{J}_F = 1.48(10^{-5})P_F h_F y_F \ell_F W_F{}^{-0.654}$$

$$\text{Rear} - \bar{J}_R = 2.47(10^{-4})P_R h_R y_R \ell_R e^{-3.062 W_R}$$

Dry Double-wide Half:

Front - $\overline{J}_F = 2.76(10^{-4})P_F h_F y_F \ell_F e^{-0.405W_F}$

Rear - $\overline{J}_R = 5.15(10^{-5})P_R h_R y_R \ell_R (1 - 1.32W_R)$

where, subscripts F and R denote front and rear;

P is the applied vertical force which twists the unit;

h is the distance from the unit's centerline to the force P (the moment arm length);

y is the length of the twisted member;

ℓ is the length of a pendulum used to measure the unit's angular deflection; and

W is the linear deflection of the pendulum.

All units are in inches or pounds.

(These formulas were developed during the program for RUL analysis and new stiffness criteria. Due to complications in their use, a simplified formula applicable to all mobile homes is presented in Volume 6.)

Notes:

4. (a) Record other information required on data sheet, such as lengths from front to middle and middle to rear support jacks, width between rear support jacks, length of pendulum (48 to 52-in.), date, project No. and mobile home identification.

   (b) Proper execution of this test requires preferably three technicians but can be accomplished by two. One technician records all data and marks the pendulum displacement inside. The others jack up the corner, measure the corner deflections, and monitor the "clear/not clear" status of the other support jack (Part 3k).

Alternate Procedure:

5. This method of the test involves releasing the load on each corner of a leveled mobile home in prescribed weight increments. At each load, the corner deflection and the horizontal displacement of an end wall mounted pendulum are recorded. The data sheet suggested for the previous procedure is applicable here. The procedural steps are as follows:

(g) Jack up using load cell jack to just relieve the force on the corner's supporting jack without disturbing level conditions of mobile home.

(h) Mark plumb bob position on blank sheet as "zero pendulum displacement" and record weight on jack (or jack pressure and indicate as "PSI").

(i) Jack up load cell jack increasing load in 500-lb increments.

(j) At each incremental load, record load on load cell jack and corner deflection reading. Also mark pendulum displacement on data sheet.

(k) Continue lifting until mobile home is lifted clear of the other supporting jack at that end. Record data at that "clear" load.

(l) Reduce load on load cell jack back to original level load and record data. Mechanical set is normal such that mobile home may not return to original level condition.

(m) Continue to reduce load downward in 500-lb increments, recording corresponding data until zero load is attained and jack is free or clear of load.

(n) Increase load to original load, record data, set and replace original jack.

(o) Repeat Steps e through n for the other side of this end of the mobile home.

(p) Repeat Steps d through o for the rear end. Load cell jack is placed under longitudinal I-beam in rear if no cross beam is present.

(q) Calculate GJ's or J's front and rear (example in Appendix A). Use the appropriate formulas of the following:

$$\overline{GJ} = Phy/\tan^{-1}(W/\ell)$$

Single-wide:

$$\text{Front} - \bar{J}_F = 9.21(10^{-4})P_F h_F y_F \ell_F W_F^{-0.277}$$

$$\text{Rear} - \bar{J}_R = 4.48(10^{-4})P_R h_R y_R \ell_R W_R^{-0.391}$$

Wet Double-wide Half:

$$\text{Front} - \bar{J}_F = 1.48(10^{-5})P_F h_F y_F \ell_F W_F^{-0.654}$$

$$\text{Rear} - \bar{J}_R = 2.47(10^{-4})P_R h_R y_R \ell_R e^{-3.062 W_R}$$

Dry Double-wide Half:

Front - $\bar{J}_F = 2.76(10^{-4})P_F h_F y_F \ell_F e^{-0.405W_F}$

Rear - $\bar{J}_R = 5.15(10^{-5})P_R h_R y_R \ell_R (1 - 1.32W_R)$

where, subscripts F and R denote front and rear;

P is the applied vertical force which twists the unit;

h is the distance from the unit's centerline to the force P (the moment arm length);

y is the length of the twisted member;

ℓ is the length of a pendulum used to measure the unit's angular deflection; and

W is the linear deflection of the pendulum.

All units are in inches or pounds.

(These formulas were developed during the program for RUL analysis and new stiffness criteria. Due to complications in their use, a simplified formula applicable to all mobile homes is presented in Volume 6.)

Notes:

4. (a) Record other information required on data sheet, such as lengths from front to middle and middle to rear support jacks, width between rear support jacks, length of pendulum (48 to 52-in.), date, project No. and mobile home identification.

   (b) Proper execution of this test requires preferably three technicians but can be accomplished by two. One technician records all data and marks the pendulum displacement inside. The others jack up the corner, measure the corner deflections, and monitor the "clear/not clear" status of the other support jack (Part 3k).

Alternate Procedure:

5. This method of the test involves releasing the load on each corner of a leveled mobile home in prescribed weight increments. At each load, the corner deflection and the horizontal displacement of an end wall mounted pendulum are recorded. The data sheet suggested for the previous procedure is applicable here. The procedural steps are as follows:

(a) Position six jacks or piers beneath mobile home; three under each of the two longitudinal I-beams; two forward, two aft, and two immediately in front of the forward axle.

(b) Jack up the mobile home until the load is off the wheels and the home is level using spirit level or transit.

(c) Using transit, level bottom of I-beams front-to-rear and side-to-side to further level home.

(d) Install plumb line pendulum on front inside wall at center line of mobile home. Secure blank sheet of paper flat under plumb bob, almost toughing. (Paper can be on floor or raised platform.)

(e) Place the load cell jack under the front cross beam or I-beam, 48-in. off center.

(f) Jack up load cell jack to just relieve the force on the corner's supporting jack without disturbing level conditions of the mobile home. Remove this jack.

(g) Mark plumb bob position on blank sheet as "zero displacement" and record weight (or pressure) on load cell jack.

(h) Reduce the load on the jack in 500-lb increments by relieving the jack pressure.

(i) At each incremental load, record load on load cell jack and corner deflection reading. Also mark pendulum displacement to be measured later.

(j) Continue lowering the jack until it is free of the mobile home. Record load and corner deflections and mark pendulum displacement at this zero load condition.

(k) Raise the jack until its load equals the original level condition load (Step g above). Record load and corner deflection and mark pendulum displacement. Mechanical set of permanent set is normal such that the mobile home structure may not return to original level position.

(l) If set is evident, jack up corner approximately an inch above level and return to level position.

(m) Replace the load cell jack with the original support.

(n) Repeat Steps e through m for the other side of this end of mobile home.

(o) Repeat Steps d through n for the rear end of the mobile home. Load cell jack is placed under longitudinal I-beams in rear if no cross beam is present.

Alternate Procedure Notes:

6. See Note 4.

C. Deflection Test

The vertical deflection test on the mobile home units was conducted following each trip in order to determine the degree of degradation in the box structure. The test was conducted in accordance with the procedure outlined below (see Form No. 10 in Appendix A). Results of this test can be reduced to an effective bending stiffness EI.

Scope:

1. This method of test outlines a procedure for determining the degradation of a mobile home box structure and its reduction of bending stiffness.

Apparatus:

2. In addition to a mobile home, the apparatus shall consist of the following:

(a) Six jacks or mobile home support piers;

(b) Two load jacks;

(c) One dial indicator, at least 1-in. maximum deflection reading in 0.01-in. increments;

(d) 1000-lb of portable weights to be installed in mobile homes, such as two each calibrated 66-gal. drums to be filled with water;

(e) Data sheet and pencil, or equivalents;

(f) Spirit and/or optical level.

Procedure:

3. This test method involves leveling the home on six points,

removing disignated supports, adding weight to that area, and all the while measuring the vertical deflection. The procedure steps and suggested data recording sheet are as follows:

(a) Position six jacks, or support piers, beneath mobile home; three under each of the two longitudinal I-beams, two jacks forward, two aft, and two immediately in front of the forward axle. (See Appendix A for data sheet and figure).

(b) Jack up home until load is off wheels and home is level using spirit or optical level.

(c) Using optical level, level bottom of I-beams front-to-rear and side-to-side to further level home.

(d) Install the dial deflection indicator along the mobile home centerline under a cross member located approximately half-way between the front cross beam and the two supports located in front of the forward axle.

(e) Check the two longitudinal I-beams at this point for level. If the I-beams are sagging, use load jacks to raise them to level and record load. With this pre-load set the dial indicator at zero.

(f) Remove the two pre-loaded support jacks and measure the sag at this point using the dial indicator. Record this measurement.

(g) Add weight inside mobile home over this point in equal increments up to 1000 lb of added weight. Measure and record deflection at each incremental acculated weight. Weight of technician must be considered.

(h) Let the final total weight set for 30 minutes. Measure and record any added deflection due to creep.

(i) Remove all added weight. Measure and record new no-load deflection. Mechanical set is normal such that mobile home may not return to original unloaded deflection.

(j) Relocate the dial indicator along the centerline at the rear of mobile home (or longitudinal I-beams). Where a deflection reading can be taken on the mobile home structure, preferably on the rear-most steel member.

(k) With the mobile home level use the load jack to measure the weight on the two rear supports. Zero the dial indicator. Remove the two rear supports and measure the sag without adding any weight. Record these data.

(l) As in Step g, add weight in mobile home above dial indicator in equal increments up to 1000 lb of added weight. Measure and record deflection at each incremental accumulated weight, considering weight of technician.

(m) Let the final total weight set for 30 minutes. Measure and record any added deflection due to creep.

(n) Remove all added weight. Measure and record new no-load deflection. Mechanical set is normal.

(o) Calculate apparent EI's front and rear (example in Appendisx A).

Notes:

4. (a) Record all information required on data sheets, such as lengths between supports, mobile home identification, and date.

(b) One convenient method of adding the required weight is to install a pair of 55-gal. drums at the proper location in the mobile home. Adding water to the empty drums accomplishes the incremental loading.

(c) This test can be executed properly with only two technicians; one adding the weights inside, one measuring the deflections and either recording the data. Though not as convenient, it is possible for one technician to perform all duties.

D. Water Soak Test

Water leaks around windows, vents, roof seams, doors and side wall seams/joints are a good indication of degradation. Therefore, the mobile homes were slowly passed through a water spray rack by first backing through and then pulling forward -- the total cycle required approximately 4 minutes. During this period, water was spraying on both sides and roof under 40-60-psi nozzle pressure with output of 5.0 gal/ft^2 hr. That particular nozzle pressure and total volume of water is reasonably equivalent to ASTM 547. Following the water test, an inspection was made to look for leaks and the results recorded on Form No. 5. (Appendix A).

Scope: 1. To measure degradation by using water leaks as an indicator.

Procedure:

2. (a) Following each test run/trip, process mobile home through water spray/flood test rig to flood top, sides and end walls

with sufficient water to indicate areas that have "opened-up" through degradation and results in a water leak.

(b) Back the unit slowly through the spray rig and then slowly pull forward to permit adequate "flooding" of all parts.

(c) Inspect the unit for water leaks around vents, seams, windows, doors, joints and pipes. Record data on Form No. 5. During the water spray test, the inspector must be inside the mobile home to view any water leakage that may not leave a trace.

E. Setup and Takedown Operations

Scope:

1. Conduct setup and takedown operation on the single- and double-wide units in accordance with the following procedures. Details may vary from unit to unit, but the basic procedure remains about the same. This test is not necessary if Torsion and Vertical Deflection Test are performed, since they induce equivalent structural degradation.

Procedure:

2. Single-Wide -- Takedown

(a) Disconnect electrical service - store cables.

(b) Disconnect water and gas service - store equipment.

(c) Disconnect sewer drain lines - flush - store equipment.

(d) Disconnect air conditioner - store equipment.

(e) Removed skirting and store equipment.

(f) Remove wheels and pack bearings with grease.

(g) Reinstall wheels and check tire pressure.

(h) Open faucets - drain water: drain water heater.

(i) Tie-back refrigerator and secure to floor.

(j) Remove toilet bowl lid - lay on floor - flush toilet(s).

(k) Secure washer/dryer units.

(l) Pull furniture away from wall.

(m) Remove storm windows - store in closets.

(n) Tape closet and cabinet doors closed.

(o) Remove loose light fixture components and store.

(p) Tape sliding glass doors closed.

(q) Remove control heater panels and store.

(r) Install wide load signs.

(s) Using six jacks, lower unit after removing blocking. Lower unit as evenly as possible and onto tractor hitch.

(t) Hook up lights, brakes, safety chains, hitch and signs. Check out.

(u) Lock doors, secure windows and vents.

(v) Check towing/tracking operation.

(w) Obtain trip permits.

(x) Conduct trip.

3. Single-Wide -- Setup

(a) Back mobile home into position.

(b) Un-hitch tractor, lights, brakes, check wheels.

(c) Locate blocking points, and place pads and blocks in place.

(d) Using six jacks, jack up mobile home as evenly and level as possible. Check chassis for lateral and longitudinal level. Shim blocking points as requred for level.

(e) Install toilet bowl lid and heater panels.

(f) Remove signs.

(g) Remove tape on doors, windows and vents.

(h) Install or assemble removed light fixtures.

(i) Install storm windows.

(j) Place furniture in correct position.

(k) Remove securing straps on refrigerator, washer and dryer.

(l) Install skirting.

(m) Hook-up water and gas

(n) Hook-up sewer - drain.

(o) Install and hook up air conditioner.

(p) Hook-up electrical and air conditioner power.

(q) Check doors and windows for operation and locking.

(r) Check water/plumbing system for leaks.

(s) Light water heater.

(t) Check for leaks.

(u) Check heater blower/ducts for operation and leaks.

(v) Check operation of electrical circuits.

(w) Re-level as required.

(x) Check roof for buckler or ripples.

4. Double-Wide -- Takedown

(a) Disconnect electrical service - store cables.

(b) Disconnect water and gas service - store equipment.

(c) Disconnect sewer drain lines - flush - seal - store equipment.

(d) Disconnect air conditioner - store equipment.

(e) Remove skirting and store equipment.

(f) Provide sideways greased skid boards under whells of dry side.

(g) Open faucets and drain water; drain water heater and pipes.

(h) Secure refrigerator, washer and dryer.

(i) Pull furniture away from wall.

(j) Remove toilet bowl lids and place on rug floor; flush toilets.

(k) Remove storm windows and store in closet.

(l) Tape closet doors and cabinet doors closed.

(m) Remove loose light fixtures or components and store.

(n) Tape sliding glass doors closed.

(o) Remove panels on central heater and lay on rug floor.

(p) Using twelve jacks, lower entire home to ground level. Leave jacks for support in level position.

(q) Remove roof ridge and upper beam cross ties.

(r) Remove end panel seal strips.

(s) Remove floor and subfloor connections between units.

(t) Remove electrical connections between units.

(u) Remove jacks from dry side.

(v) Skid dry side on greased boads, sideways minimum of 6-8-in.

(w) Check A-fram and hitch before hook-up to dry side.

(x) Move dry side to location for sealing open areas.

(y) Install plastic tarp over mating opening on dry and wet side.

(z) Install battens and diagonal 1 x 4's as required to seal sides.

(aa) Install lights, signs and safety chains.

(bb) Lower wet side to ground.

(cc) Hook-up electric brakes and check out operation.

(dd) Check tire pressure.

(ee) Grease wheel bearings as required.

(ff) Obtain trip permits.

(gg) Check towing and training operation.

(hh) Conduct trip(s)

5. Double-Wide -- Setup

(a) Back both units into position, side by side, with the mating walls as close together as possible and aligned fore and aft.

(b) Place blocking units in designated positions.

(c) Prepare greased slide plates and remove plastic tarp on mating surfaces.

(d) Using axle jacks, jack up dry side wheels and place greased plates under each. Remove jacks and skid two units together.

(e) Align two units so that they mate properly.

(f) Fasten two units together structurally.

(g) Install roof seal cap.

(h) Install end seal strips.

(i) Install floor seal strips and interior wall/floor seal strips.

(j) Hook-up electrical between two units.

(k) Jack up entire assembly using twelve jacks.

(l) Level unit.

(m) Skim and block units in level position.

(n) Check roof line/surface for buckles.

(o) Check doors and windows for operation and alignment.

(p) Hook-up water system and check plumbing for leaks.

(q) Hook-up sewer system and check for leaks.

(r) Hook-up gas system and check for leaks.

(s) Hook-up electrical and check out system.

(t) Install air conditioner and hook-up electrical.

(u) Check heater ducts for leaks - turn on blower.

(v) Install skirting.

(w) Remove tape on cabinet doors and closet doors.

(x) Install panels on heater.

(y) Install toilet bowl lids.

(z) Install light fixtures or components.

(aa) Seal all exterior seams as required.

(bb) Install storm windows and check doors for security.

VII. DATA ANALYSIS AND APPLICATION

The data retrieved from these tests were in three formats:

- Tape-recorded data from instrumentation modules; tape-recorded descriptive voice channel depicting events during test run;
- Written inspection test reports; (Refer to Part II for a summary of these inspections for each unit.)
- Photographs. (See Appendix C.)

All of these data were tabulated, cross-checked, verified and analyzed in Volume I, Part II of this task for use in the correlation and verification of the dynamic and static predictive data of Task I. The degree or type of data removed from the tape and reports was dependent on the critical test parameters for analysis of the in-transit test data and the theoretical predictions. Items of interest or use from the data were:

- The cyclic data related to frequency of input loads.
- The cyclic data related to the magnitude of the loads.
- The cyclic data related to accelerations in the torsional mode and vertical bending mode.
- Random excitation from road conditions.
- Damping characteristics of the spring mass.

The static tests for torsional and vertical bending deflection and water leaks offered "proof of the results" regarding the degradation of the mobile homes.

APPENDIX A
INSPECTION FORMS

INSPECTION FORMS

At periodic intervals throughout the mobile home testing, inspections were made and data recorded on various appropriate forms.* The SwRI forms used in the testing are presented in this appendix as follows:

Form No. 1 -- Trip Report

Form No. 2 -- After Trip Inspection Report

Form No. 3 -- Tire Failure Report

Form No. 4 -- Receiving Inspection

Form No. 5 -- Water Test

Form No. 6 -- Electrical Test

Form No. 7 -- Plumbing Test

Form No. 8 -- Gas System Test

Form No. 9 -- Torsion Deflection Test

Form No.10 -- Vertical Bending Deflection Test

Form No.11 -- Vertical Bending Stiffness Calculations

Form No.12 -- Mobile Weight Record

Each form served as a means to record any degradation occurring in the mobile home throughout the testing program.

*Refer to Appendix B for test inspection sequence schedule.

Form No. 1

TRIP REPORT

Manufacturer	Trip No.	SwRI Mobile Home No.	Model	Date
	#2	T-1	2602 B	10/26/76

Mileage:	Instrumentation Package No.	Weight	Serial Number
IN: 65699 OUT 35522		16,000	0013

Driver	Observer	Instrumentation Tech.	Highway Route No.
Bush	Collins	Johnson	Time out: Time in:

Weather	Permit	Camera Installed	Total Mileage to date
Clear, warm Wind: light	Yes	No	564

PREPARATION CHECK LIST

Tire Inspection	yes	Toilet lid removed	yes
Tire Pressure	70-80 psi	Furniture in place	yes
Hitch Security	yes	Side plastic tight	N/A
Hitch strain gages	yes	Generator power check	yes
Tongue Jack retracted	yes	Instrumentation operating	yes
M.B. brakes working	yes	Calibration	yes
No. axles with brakes	2	Truck fuel	yes
No. axles	3	Truck mirrors	yes
Doors & windows secure	yes	Spare tires and jacks	yes
Rear sign and lights	yes	C. B. operating	yes
Beacons operating	yes	Truck serviced	yes
Egress for Technician	yes	Truck brakes	yes
Deflection measurements	yes	Truck front sign	yes

TRIP/ACTION REPORT

(Tape Play Back Verification) Date: 10/26/76

MILEAGE	SPEED	CAMERA	CODE	REMARKS
77	45	No	A/B	Blowout on LR (3rd axle)
				at RR tracks on
				1604, 1 mile north
				of IH-10

T = Turns E = Exits BU = Backups TBO = Tire Blowout S = Shoulder

S = Stops C = Concrete G = Gravel PS = Panic Stop A = Asphalt

AFTER TRIP INSPECTION REPORT

MB Mfg.________ Inspector Bush Date 10/26/76

MB. Model________ Following Trip No. 2 Date________

SwRI MB. No. T-1

1. Steel frame damage or buckling ✓
2. Hitch and "A" frame damage or buckling ✓
3. Roof buckling No
4. Side wall buckling yes (see photos)
5. Interior paneling and trim OK
6. Interior ceiling OK
7. Rigidity of toilet and refrigerator Refrig Loose; Toilet ok
8. List or tilt of box (lateral) No
9. Deflection measurements (per test) see test data
10. Window cracks Front door glass
11. Doors binding Front door slightly
12. Water test Front door leaks
13. Water leaks yes
14. Vents leaking exhaust fan
15. Windows leaking No
16. Roof leaking Vent
17. Condition of tires fair
18. Electrical system checkout ✓
19. Water system checkout ✓
20. Air duct system checkout ✓
21. Heater system stove oven checkout ✓
22. Loose screws along left side and rear
23. Loose nails No
24. Loose staples No
25. Exterior panels working see 22

FORM NO. 3

TIRE FAILURE REPORT

Trip No.: 2 Route No.: Direct Date: 10/26/76

Mobile Home Mfg.: ______

Mobile Home Model: F-1

Weight (axle): 16,140 lbs

Number of axles: 3

Tire size: 7 x 14.5

Tire pressure at blowout: 80 psi

Tire rating: ______

Tire Mfg.: ______

DOT load range: None

Tire plys: Not indicated

Ply rating: 10

Type failure: Blow out

Depth of tread: ______

Condition of tire: old used

Condition of wheel: good

Reaction of mobile home from tire failure: Not noticeable

Outside ambient air temp: 90 °F

Type of road surface: asphalt & RR track

Did you run on shoulder: No

Tight turns for scrubbing: Yes ___ No X

Driver Bush

RECEIVING INSPECTION

SwRI Mobile Home No.: T-1 Date 11/1/76

S/N: 0013 Single Wide ✓ Double Wide ____ "A" ____ "B" ____

Manufacturer: ____ Model ____ Year mfg. 1976

Size (include hitch) 14 X 64 Registered Weight 16000

Furnished ✓ Unfurnished ____ Color white Trim Brown - yellow

Number Axles 3 Number Bedroom 2 Number Baths 2

Picked up from: Seguin, Texas Date 11/1/76

Attach Form No. 1 - Trip Report

Attach Form No. 2 - After Trip Inspection Report

Attach Form No. 3 - Tire Failure Report (as required)

Conduct Inspection per Form No. 2 "After Trip Inspection Report in Section XV".

D. Bush
Inspector

WATER TEST

Manufacturer: ____________ Model: 2602 B ____ Date: 11/6/76

SwRI No.: T- 1 ____ Following Trip No.: 2 ____

Time to pass through: 5 min. ____ Water Pressure: Blowing rain ____ psi Temp.: 65 °F

Preparation and Test of Mobile Home:

- Close all windows and lock ✓
- Close stove/oven vent ✓ (Leaks in Vents)
- Close all doors ✓
- Close heater door ✓
- Close external electrical plugs ✓
- Leave electric brakes hooked up ✓
- Perform inspection for water leaks ✓

Leaks: around front door due to mobile home twist
around vents
in stove exhaust fan

Bush / Johnson
Inspector

Form No. 6

ELECTRICAL TEST

Manufacturer:__________ Model: 2602 B Date 11/23/78

SwRI No.: T-1 Following Trip No.: 2

Electrical Appliances Check:

Oven - Yes ✓ No____

Stove - Yes ✓ No____ Gas

Central heater blower - Yes ✓ No____

Dishwasher - Yes____ No X N/A

Garbage disposal - Yes____ No X N/A

Refrigerator - Yes ✓ No____

Washer, clothes - Yes____ No ✓ N/A outlet: yes ✓

Dryer, clothes - Yes____ No ✓ N/A outlet: yes ✓

Air conditioner - Yes____ No X N/A

Electric heater-bath - Yes ✓ No____

TEST:

1. Turn all circuit breakers to OFF position ✓
2. Plug in electric outlet ✓
3. Turn on main circuit breaker ✓
4. Turn on each circuit breaker, one by one ✓
5. Turn on heater fan, refrigerator, ceiling lights, ~~garbage disposal~~, ~~dishwasher~~ and ~~clothes dryer~~ or ~~clothes washer~~____
6. Using 150 watt bulb, plug into each wall socket ✓
7. Report any circuit breaker that trips under load ✓
8. Check for any shorts or damage. None

Bush / Smith

Inspector

Form No. 7

PLUMBING TEST

Manufacturer: ______________________ Model: 2602 B ______________ Date 11/23/76

SwRI No.: T- 1 ______________ Following Trip No.: 2 ______________

Water Pressure: 100 ________ psi Temp.: 65 ________ °F

Preparation Test of Mobile Home:

Turn off all faucets (including toilet bowl, dishwasher, clothes dryer, water heater, washer and external faucets) ✓

Connect water hose to supply ✓

Record water pressure 100 ✓ psi

Open each faucet to fill lines (use hoses on clothes washer) ✓

Close all faucets ✓

Inspect all plumbing for leaks ✓

Record location of all leaks None

Shut off water inlet supply ✓

Drain all lines and traps to prevent freezing ✓

System held pressure for 1 1/2 hours

Bush / Smith
Inspector

Form No. 8

GAS SYSTEM TEST

SwRI Mobile Home No.: T- 1 Model: 2602 B Date: 11/23/76

Manufacturer: ______ Following Trip No.: 2

Butane: ✓ Natural Gas: ______ Check jets: ✓

Preparation Test of Mobile Home:

Inspect all gas lines and valves for integrity ✓

Close to OFF position all gas valves ✓

Turn on Gas Supply Valve ✓ Pressure: ______ psi

Check for leaks via odor or sound ✓

Open each gas valve and ignite unit ✓

- N/A ~~Water heater~~ (leave on not more than one minute) Electric
- ✓ Control heater
- ✓ Stove - all burners
- ✓ Oven
- N/A Heater (bath) if gas fired - Central

Turn off each ignited source ✓

Check for leaks via odor or sound ✓

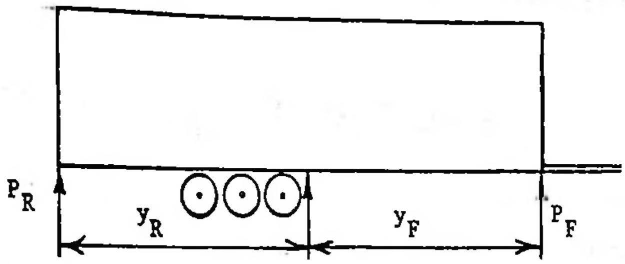
Turn off gas supply valve ✓

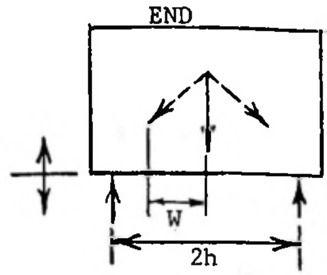
Open all gas valves for 10 minutes to vent lines ✓

Close all gas valves ✓

Bush / Smith
Inspector

TORSION TEST DATA SHEET





Mobile Home________________

Date________________

Inspector________________

Support Spacings

h_F=________in.

h_R=________in.

y_F=________in.

y_R=________in.

Pendulum Lengths

ℓ_F=________in.

ℓ_R=________in.

FRONT LEFT CORNER

Jack Pressure (psi)	$P_F + F$ * (lbs)	Corner Deflection (in.)	W_F (in.) Pendulum Deflection
	F=		

FRONT RIGHT CORNER

Jack Pressure (psi)	$P_F + F$* (lbs)	Corner Deflection (in.)	W_F (in.) Pendulum Deflection
	F=		

REAR LEFT CORNER

Jack Pressure (psi)	$P_R + F$ * (lbs)	Corner Deflection (in.)	W_R (in.) Pendulum Deflection
	F=		

REAR RIGHT CORNER

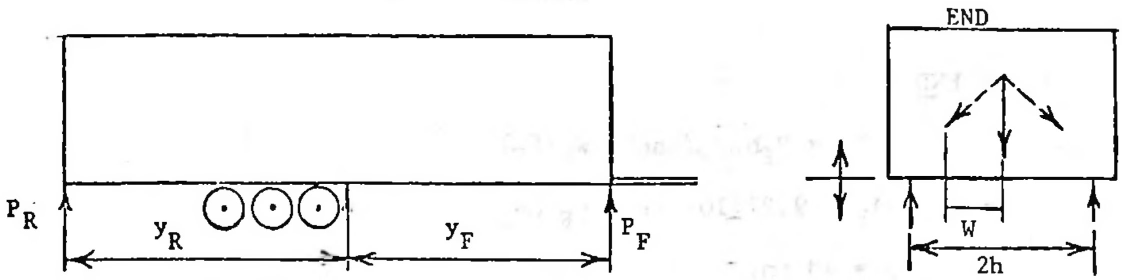
Jack Pressure (psi)	$P_R + F$ * (lbs)	Corner Deflection (in.)	W_R (in.) Pendulum Deflection
	F=		

* F = force required to support leveled corner.

P_F; P_R = force required to raise or lower corner.

Form #9

TORSION TEST DATA SHEET



Mobile Home T-1
Date 1/15/78
Inspector W. Raine

Support Spacings
h_F = 48 in.
h_R = 48 in.
y_F = 396 in.
y_R = 324 in.

Pendulum Lengths
ℓ_F = 50 in.
ℓ_R = 50 in.

FRONT LEFT CORNER

Jack Pressure (psi)	$P_F + F$ * (lbs)	Corner Deflection (in.)	W_F (in.) Pendulum Deflection
1000	F=2330	0	0
1250	2920	0.13	0.16
1500	3500	0.22	0.28
1750	4080	0.35	0.41
1800	4200	0.38	0.44
1000	2330	0	0
750	1750	-0.05	-0.09
500	1150	-0.17	-0.22
250	580	-0.28	-0.34
0	0	-0.41	-0.47

FRONT RIGHT CORNER

Jack Pressure (psi)	$P_F + F$* (lbs)	Corner Deflection (in.)	W_F (in.) Pendulum Deflection
750	F= 1750	0	0
1000	2330	0.12	0.15
1250	2920	0.18	0.22
1500	3500	0.28	0.34
1750	4080	0.45	0.53
750	1750	0	0
500	1170	-0.10	-0.13
250	580	-0.26	-0.29
0	0	-0.34	-0.39

REAR LEFT CORNER

Jack Pressure (psi)	$P_R + F$ * (lbs)	Corner Deflection (in.)	W_R (in.) Pendulum Deflection
650	F=1520	0	0
900	2100	0.04	0.06
1150	2680	0.10	0.13
1250	2920	0.17	0.19
650	1520	0	0
400	930	-0.06	-0.09
150	350	-0.11	-0.16
0	0	-0.18	-0.22

REAR RIGHT CORNER

Jack Pressure (psi)	$P_R + F$ * (lbs)	Corner Deflection (in.)	W_R (in.) Pendulum Deflection
700	F=1630	0	0
950	2220	0.15	0.19
1200	2800	0.28	0.31
1300	3030	0.33	0.37
700	1630	0	0
450	1050	-0.09	-0.13
200	470	-0.14	-0.19
0	0	-0.25	-0.31

* F = force required to support leveled corner.
P_F; P_R = force required to raise or lower corner.

Form #9

FRONT END

$$(\overline{GJ})_F = P_F h_F y_F / \tan^{-1}(W_F/\ell_F)$$

$$(\overline{J})_F = 9.21(10^{-4}) P_F h_F y_F \, {}_F W_F^{-0.277}$$

h_F = 48 in.
${}_F$ = 50 in.
y_F = 396 in.

Jack Pressure (psi)	$P_F + F$ (lb)	P_F (lb)	W_F (in.)	$\overline{GJ}$ (lb - in.^{2})	$\overline{J}_F$ (in.^{4})
Left Corner					
1000	2330	0	0	-	-
1250	2920	590	0.16	6.12×10^7	8.58×10^5
1500	3500	1170	0.28	6.93×10^7	1.46×10^6
1750	4080	1750	0.41	7.08×10^7	1.96×10^6
1800	4200	1870	0.44	7.05×10^7	2.05×10^6
1000	2330	0	0	-	-
750	1750	-580	-0.09	10.7×10^7	9.89×10^5
500	1150	-1180	-0.22	8.90×10^7	1.57×10^6
250	580	-1750	-0.34	8.54×10^7	2.07×10^6
0	0	-2330	-0.47	8.22×10^7	2.51×10^6
			MEAN Left =	7.94×10^7 (lb-in.^{2})	1.68×10^6 (in.^{4})
Right Corner					
750	1750	0	0	-	-
1000	2330	580	0.15	6.41×10^7	8.59×10^5
1250	2920	1170	0.22	8.82×10^7	1.56×10^6
1500	3500	1750	0.34	8.54×10^7	2.14×10^6
1750	4080	2330	0.53	7.29×10^7	2.43×10^6
750	1750	0	0	-	-
500	1170	-580	-0.13	7.40×10^7	8.93×10^5
250	580	-1170	-0.29	6.69×10^7	1.44×10^6
0	0	-1750	-0.39	7.44×10^7	1.99×10^6
			MEAN Right =	7.51×10^7 (lb-in.^{2})	1.62×10^6 (in.^{4})
			MEAN Front =	7.73×10^7 (lb-in.^{2})	1.65×10^6 (in.^{4})

REAR END

$$(\overline{GJ})_R = P_R h_R y_R / \tan^{-1}(W_R/\ell_R)$$

$$J_R = 4.48(10^{-4}) P_R h_R y_R \ell_R W_R^{-0.391}$$

h_R = 48 in.

y_R = 324 in.

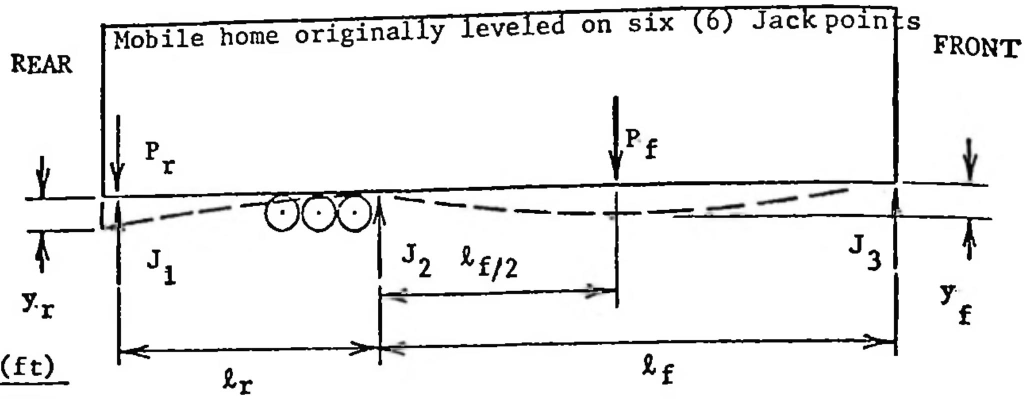
ℓ_R = 50 in.

Jack Pressure (psi)	$P_R + F_R$ (lb)	P_R (lb)	W_R (in.)	$(\overline{GJ})_R$ (lb - in.^{2})	$\overline{J}_R$ (in.^{4})
Left Corner					
650	1520	0	0	-	-
900	2100	580	0.06	13.1×10^7	6.07×10^5
1150	2680	1160	0.13	12.1×10^7	8.97×10^5
1250	2920	1400	0.19	10.0×10^7	9.34×10^5
650	1520	0	0	-	-
400	930	-590	-0.09	8.90×10^7	5.27×10^5
150	350	-1170	-0.16	9.92×10^7	8.34×10^5
0	0	-1520	-0.22	9.38×10^7	9.57×10^5
			MEAN Left =	10.5×10^7 (lb-in.^{2})	7.93×10^5 (in.^{4})
Right Corner					
700	1630	0	0	-	-
950	2220	590	0.19	4.21×10^7	3.93×10^5
1200	2800	1170	0.31	5.12×10^7	6.44×10^5
1300	3030	1400	0.37	5.14×10^7	7.19×10^5
700	1630	0	0	-	-
450	1050	-580	-0.13	6.06×10^7	4.49×10^5
200	470	-1160	-0.19	8.29×10^7	7.74×10^5
0	0	-1630	-0.31	7.14×10^7	8.98×10^5
			MEAN Right =	5.99×10^7 (lb-in.^{2})	6.46×10^5 (in.^{4})
			MEAN Rear =	8.05×10^7 (lb-in.^{2})	7.20×10^5 (in.^{4})

BENDING DEFLECTION TEST

Trip No.: ______________ SwRI No.: ______________ Date: ______________

Manufacturer: ______________ Model No.: ______________



ℓ_r = ______ (ft)

ℓ_f = ______ (ft)

FORWARD LOADING

LOAD P_f (lbs)	DEFLECTION y_f (inches)
0 (level)	0
(dead load weight)	(dead load sag)
+ 250 =	
+ 500 =	
+ 750 =	
+1000 =	

REAR LOADING

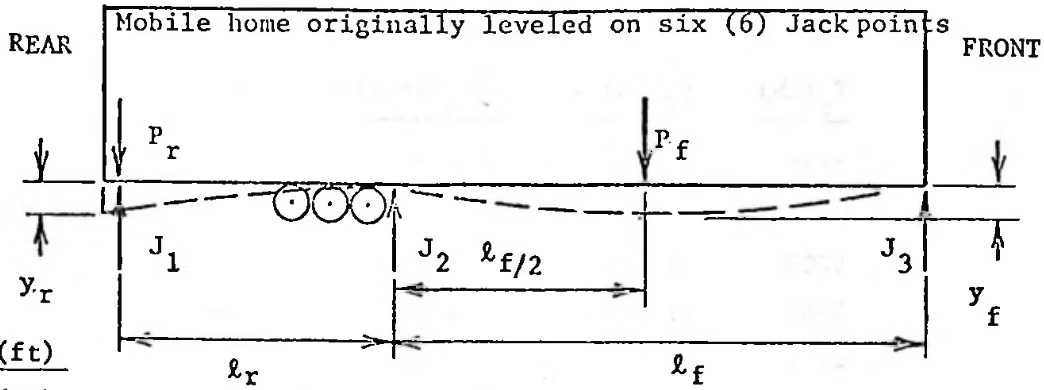
LOAD P_r (lbs)	DEFLECTION y_r (inches)
0 (level)	0
(dead load weight)	(dead load sag)
+ 250 =	
+ 500 =	
+ 750 =	
+1000 =	

FORM # 10

BENDING DEFLECTION TEST

Trip No.: 3 SwRI No.: T-2A Date: 8/11/77

Manufacturer: Double wide Model No.: Wet half



ℓ_r = 21 (ft)

ℓ_f = 35 (ft)

FORWARD LOADING

LOAD P_f (lbs)			DEFLECTION y_f (inches)
	0 (level)		0
(dead load weight)		5200	(dead load sag) .600
5200	+ 250 =	5450	.668
5200	+ 500 =	5700	.728
5200	+ 750 =	5950	.780
5200	+1000 =	6200	.826

REAR LOADING

LOAD P_r (lbs)			DEFLECTION y_r (inches)
	0 (level)		0
(dead load weight)		3100	(dead load sag) 2.690
3100	+ 250 =	3350	2.924
3100	+ 500 =	3600	3.210
3100	+ 750 =	3850	3.515
3100	+1000 =	4100	3.885

FORM # 10

VERTICAL BENDING STIFFNESS CALCULATIONS
(Double-wide, wet half)

From Battelle Memorial Institute Final Report, p. 29

$$(\overline{EI})_f = 36\ell_f^{\,3}\left(\frac{P}{y}\right)_f \;\&\; (\overline{EI})_r = 575\ell_r^{\,3}\left(\frac{P}{y}\right)_r\left[1 + \frac{\ell f}{\ell_r}\right]$$

FORWARD LOADING $\ell_f = 35$ ft

P_f(lb)	y_f(in)	$(\frac{P}{y})_f$(lb/in)	$(\overline{EI})_f$(lb-in^2)
5200	.600	8667	1.34×10^{10}
5450	.668	8159	1.26×10^{10}
5700	.728	7830	1.21×10^{10}
5950	.780	7628	1.18×10^{10}
6200	.826	7506	1.16×10^{10}
		AVG =	1.23×10^{10}(lb-in^2)

REAR LOADING $\ell_r = 21$ ft

P_r(lb)	y_r(in)	$(\frac{P}{y})_r$(lb/in)	$(\overline{EI})_r$(lb-in^2)
3100	2.690	1152	1.64×10^{10}
3350	2.924	1146	1.63×10^{10}
3600	3.210	1121	1.59×10^{10}
3850	3.515	1095	1.56×10^{10}
4100	3.885	1055	1.50×10^{10}
		AVG =	1.58×10^{10}(lb-in^2)

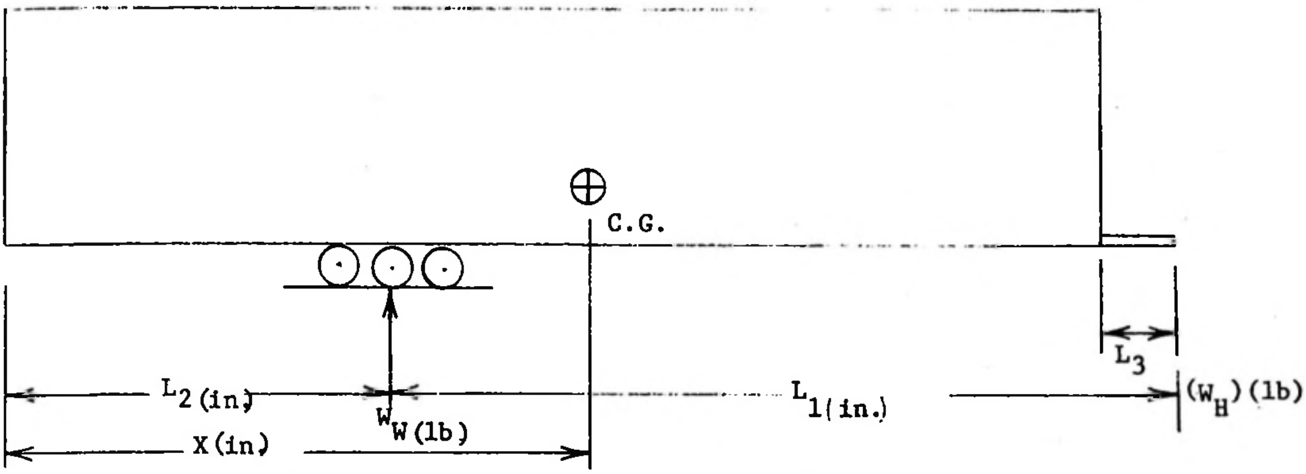
MOBILE WEIGHT RECORD

Date: 10/30/76

Manufacturer: ______ Model: T-1 S/N 0013

Size 14 X 64 Single-Wide ✓ Double-Wide ______ "W" ___ "D" ______

Number of Axles: 3



W_H = 2960 lb L_1 = 36 ft 9 in.

W_W = 13180 lb L_2 = 27 ft 4 in.

W_T = 16140 lb L_3 = 4 ft 0 in.

Compute C.g.:

$$\frac{(L_2)\ (W_W) + (L_2 + L_1)\ (W_H)}{(W_W + W_H)} = X \quad = 34\text{ ft}$$

Furnishings: (on board at weighing)

✓	Stove	✓	Coffee Table
✓	Refrigerator	✓	End Table
✓	Oven		Dishwasher
✓	Living Room Sofa		Garbage Disposal
	Living Room Chairs		Washer, Clothes
	Dinette Set		Dryer, Clothes
	Bed		Den Sofa
	Bed		Den Chair
	Bed		Dining Room Set

Instrumentation: ______ lb

Total furnishings weight: ______ lb

Bush

Inspector/Driver

APPENDIX B

TEST SEQUENCE

TEST SEQUENCE

The basic sequence for testing the mobile homes will be as follows:

(1) Weigh mobile home as received;

(2) Install accelerometers, strain gages and displacement devices;

(3) Install tape recorder, MUX system and signal conditioning;

(4) Install operator's and observer's chairs;

(5) Check out system and calibrate;

(6) Load mobile home with sandbags (4000-lb additional weight);

(7) Take down from setup;

(8) Hook up tow tractor, lights, flashers and signs;

(9) Hook up and check out power generator, running lights and electric brakes;

(10) Check out data recording system using generator;

(11) Zero all systems;

(12) Check tie-down of all loose items in mobile home;

(13) Check weather conditions;

(14) Obtain trip permit and license;

(15) On double wides;

(16) Tow mobile home over route;

(17) Record data and photograph incidents;

(18) Return to SwRI;

(19) Conduct water spray test;

(20) Return mobile home to SwRI parking lot;

(21) Set up mobile home;

(22) Conduct electrical system test;

(23) Conduct plumbing system test;

(24) Conduct gas system test;

(25) Conduct detailed inspection;

(26) Conduct vertical deflection test front and rear;

(27) Conduct torsional test, front and rear, left and right;

(28) Take down mobile home.

APPENDIX C

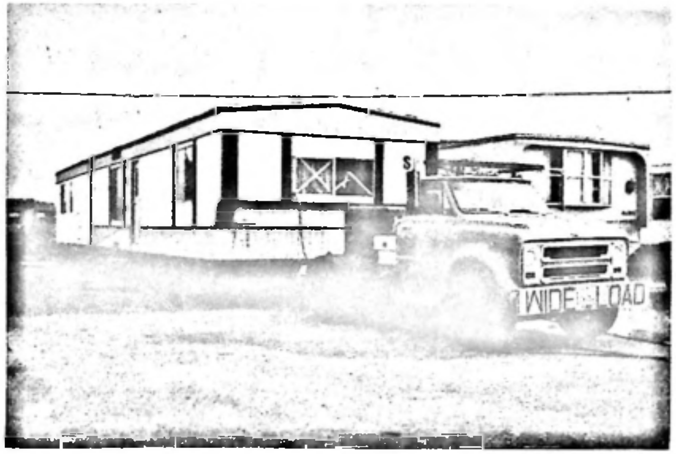


FIGURE C-1. TEST UNIT T-1 (NEW SINGLE-WIDE) AND TOW TRACTOR

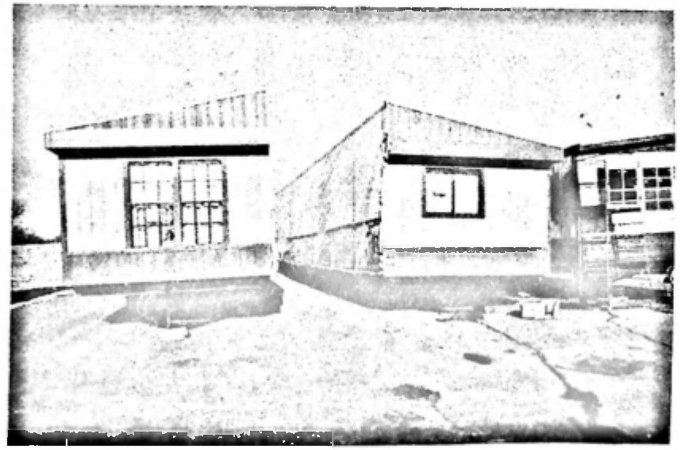


FIGURE C-2. TEST UNITS T-2B AND T-2A (NEW DRY AND WET DOUBLE-WIDE HALVES)

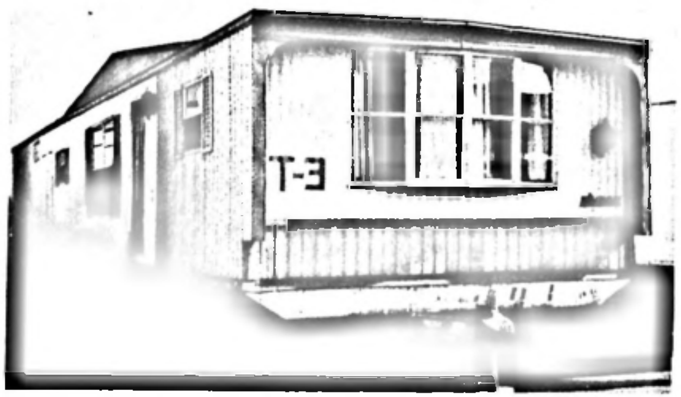


FIGURE C-3. TEST UNIT T-3 (USED SINGLE-WIDE)

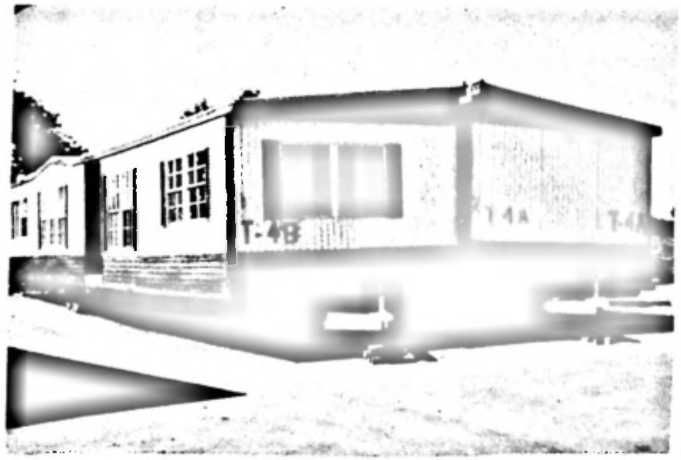


FIGURE C-4. TEST UNITS T-4B AND T-4A (USED DRY AND WET DOUBLE-WIDE HALVES)

FIGURE C-5. ELECTRONIC CONSOLE AND TAPE RECORDER

FIGURE C-6. UPPER LEFT REAR VERTICAL AND LATERAL ACCELEROMETERS

FIGURE C-7. UNCOATED I-BEAM STRAIN GAGE

FIGURE C-8. WALL/FLOOR JOINT DEFLECTION TRANSDUCER

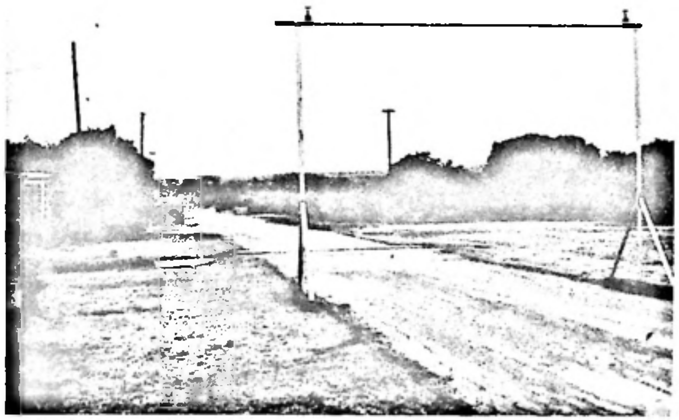


FIGURE C-9. EXTERNAL SPRAY BAR FIXTURE

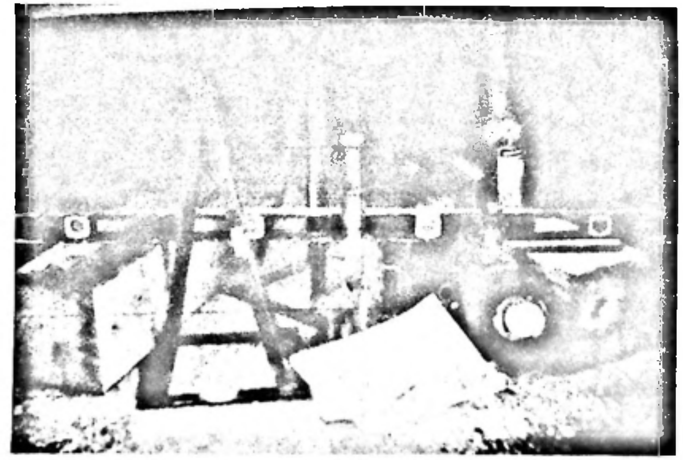


FIGURE C-10. TORSION TEST EQUIPMENT

FIGURE C-11. READING JACK FORCE IN TORSION TEST

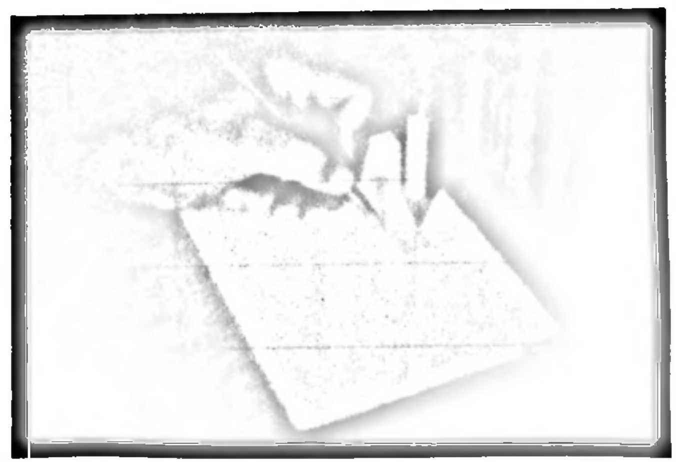


FIGURE C-12. RECORDING PENDULUM DISPLACEMENT IN TORSION TEST

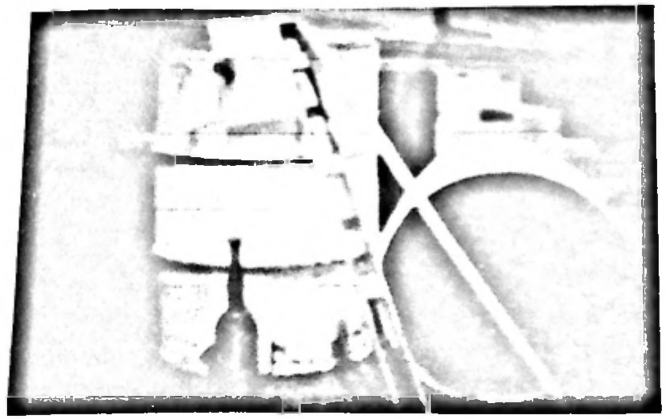


FIGURE C-13. VERTICAL FLEXURE TEST EQUIPMENT

FIGURE C-14. MEASURING WATER LEVEL (AND APPLIED WEIGHT) IN VERTICAL FLEXURE TEST

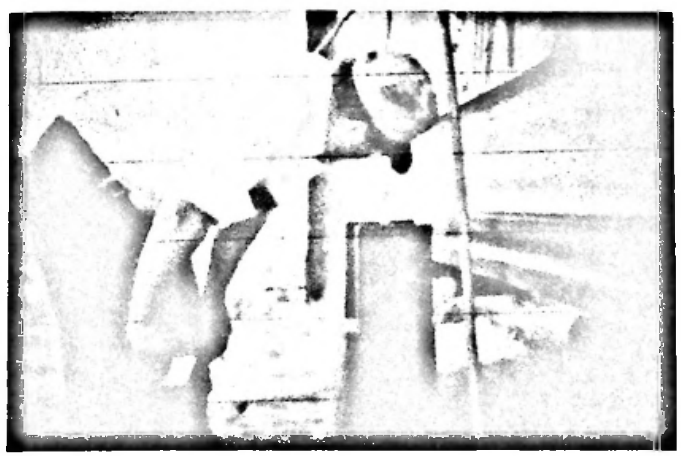
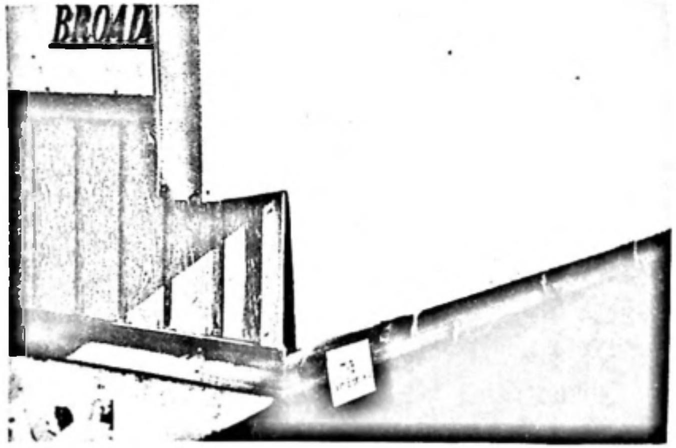


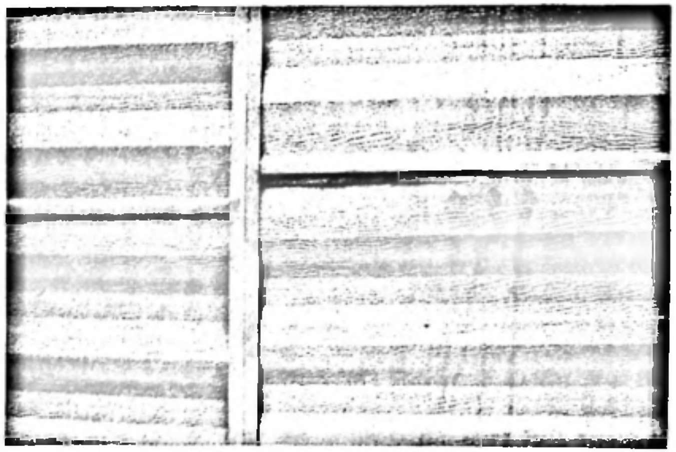
FIGURE C-15. READING VERTICAL DISPLACEMENT (FROM DIAL MICROMETER) IN VERTICAL FLEXURE TEST

FIGURE C-16. A-FRAME SIDE PULL TEST

A. POPPED-OUT WINDOW



B. SEPARATING SIDEWALL PANEL



C. BUCKLING SIDEWALL PANEL

D. SHIFTING SIDEWALL PANEL

FIGURE C-17. TRANSPORTATION DEGRADATION

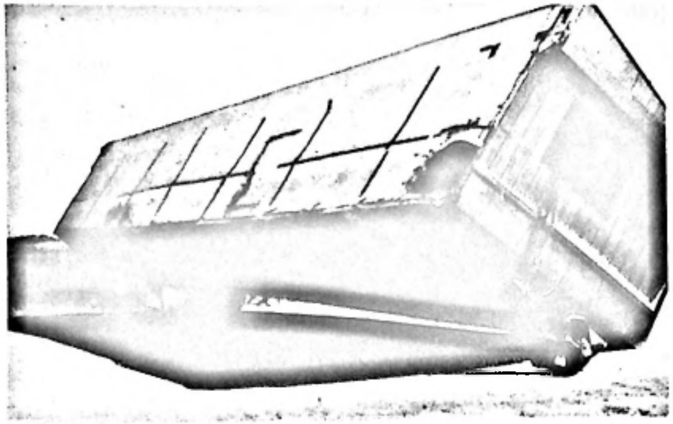


FIGURE C-18. ROLLOVER OF T-2A

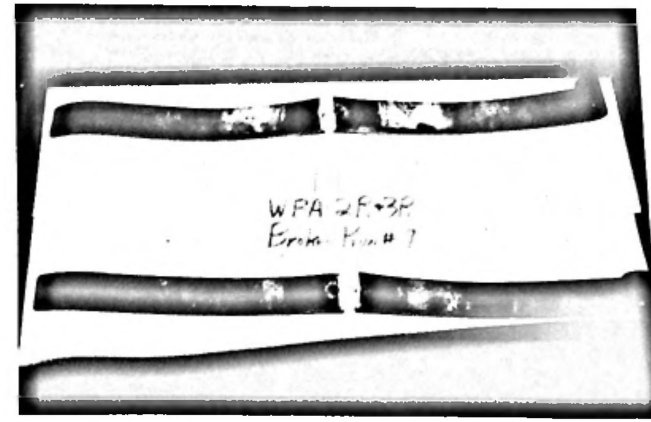


FIGURE C-19. BROKEN SINGLE-LEAF SPRINGS

FIGURE C-20. SPRING HANGER SEPARATED FROM I-BEAM

FIGURE C-21. ONE OF MANY TIRE BLOWOUTS

FIGURE C-22. T-1 RUNNING GEAR: SINGLE-LEAF SLIDING SPRINGS WITH EQUALIZERS

FIGURE C-23. RUNNING GEAR DISASSEMBLY AND INSPECTION

FIGURE C-24. RUNNING GEAR DISASSEMBLY AND INSPECTION

FIGURE C-25. RUNNING GEAR DISASSEMBLY AND INSPECTION

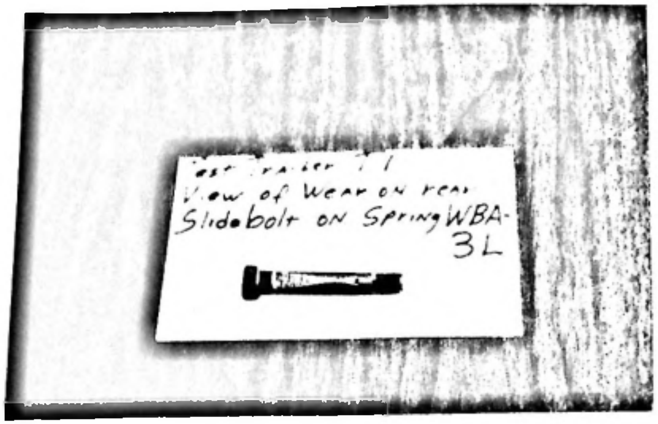


FIGURE C-26. WEAR ON SLIDE BOLT OF SPRING ASSEMBLY

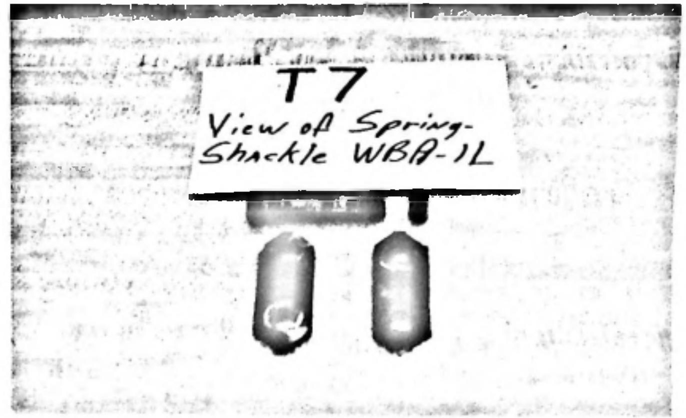


FIGURE C-27. SHACKLE WEAR

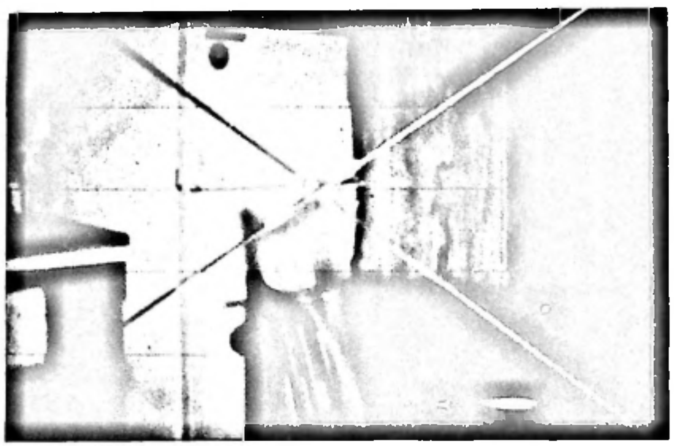


FIGURE C-28. TEMPORARY TORSIONAL STIFFENING INTERNAL, DIAGONAL CABLES

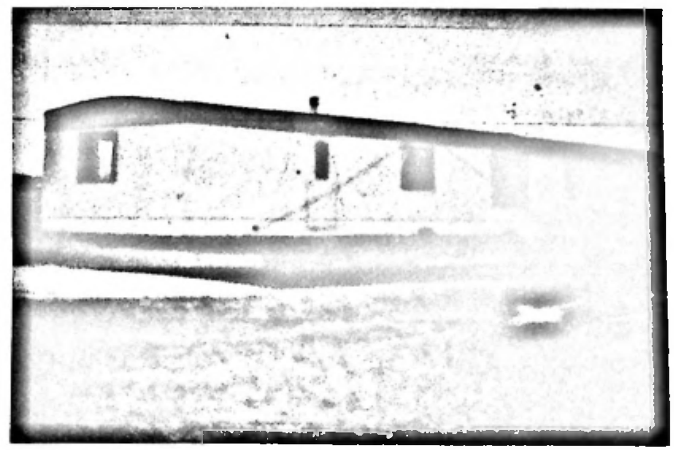


FIGURE C-29. TEMPORARY VERTICAL FLEXURE STIFFENING EXTERNAL LONGITUDINAL CABLES

EVALUATION OF TEST DATA

EVALUATION OF TEST DATA

Prepared By

C.R. Ursell, II

W.W. Raine

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

I. OBJECTIVE

The objective of this part of the project is to summarize the actual field data collected during the Task III program so that it can be correlated with the following major objectives of the total research effort.

(1) To validate mobile home degradation predictions.

(2) To develop proposed design criteria for incorporation in Subpart J "Transportation" of the Federal Mobile Home Construction Standard by analysis of experimental data.

II. INTRODUCTION

The testing and data retrieval efforts of the program were broken down into two phases:

(1) Validation of predicted degradation:

- Correlation of predicted accelerations based on torsion and flexural tests ($\overline{EI}$ and $\overline{J}$) to measured accelerations,
- Correlation of predicted degradation to observed degradation;

(2) Supportive data for recommended design criteria:

- Critical loading conditions due to setup and takedown,
- Critical load factors due to accelerations during transportation.

Torsion and flexural tests ($\overline{EI}$ and $\overline{J}$) used in calculations for percent structural degradation were considered equivalent to a setup and takedown. Critical loading conditions were determined from these tests. The two stiffness measurement tests were considered equivalent to a setup and takedown because the mobile home had to be jacked-up, set on six points, leveled and placed "out-of-level" for the torsion test, and concentrated weights had to be added for the vertical deflection test. Movement of any type within the mobile home structure adds to the total degradation to some degree. Therefore, there were no separate tests per se for setup and takedown. However, the doublewides were "pulled together" at the marriage walls to introduce the marriage line forces. A moderately severe condition during these operations was identified to provide the basis for recommended design criteria. This condition, defined as Load Case 4 in Task I, Volume III, entails applying an uplift load to the right rear corner of the home.

Acceleration data as required for validation of predictive methodology and design recommendations were obtained during in-transit testing. Several thousand feet of taped data were recorded--much of it repetitive. However, the data will be retained for a period of time to determine its usability for additional data analysis.

III. DISCUSSION

The data collected during this project and assembled in three forms--$\overline{EI}$ and $\overline{J}$, accelerations, and observations of degradation--are compiled in the following two sections of this volume and Volume 3 in total.

The data summaries of Section IV present the testing history and data of each unit. In each summary table, the activities or trips are listed in chronological order progressing through Conditions I and II. "Route numbers" refer to the routes described in Task III, Vol. I, Part I. Two mileages are entered: one for the trip, and one for the total accumulated during testing. Most of these miles were driven at a rate of about 45 mph, the speed limit, but, in order to reproduce representative situations of mobile home transport, other speeds were driven as the table shows. Under Condition I, the weights of the units were kept at the, as delivered, manufactured level. However, under Condition II (representing secondary moves), personal belongings were simulated by adding about 4,000 lb to the units. The weights during each run are listed in the tables. An important part of the test data recorded in the tables is the activity of the tires--whether or not blowouts occurred. Also summarized in the tables are the road conditions indicating the amount of roughness to which the test specimens were subjected. Natural frequency measurements taken after each trip are listed in the tables as well, revealing the progressive loosening of the structure by the reduction of their values. The tables also indicate when setups and takedowns were conducted and the results of several system integrity tests performed between trips. These tests included checking: leaks in the exterior walls, the plumbing, gas, and duct systems, and malfunctioning of the electrical wiring. Also, between trips, torsion and vertical flexure tests were conducted. The data of these tests are presented in separate tables from the summary but apparent bending stiffness $\overline{EI}$ and torsional stiffnesses $\overline{GJ}$ and $\bar{J}$ resulting from the two tests are compiled in the summaries by trip. (The quantities $\overline{GJ}$ and $\bar{J}$ are not proportional. $\overline{GJ}$ is used in initial stiffness criteria, $\bar{J}$ in RUL theory. See Volumes 4 and 6.)

General observations regarding degradation are noted in Section V. These observations in varying degrees apply to each of the units evaluated in this program.

In Section VI the predicted degradation is compared to the actual degradation as quantified by visual inspections, deflection and strain data, apparent torsional and bending stiffnesses, and accelerations.

Based upon the test results, supportive data for design recommendations are presented in Section VII. These include design recommendations for both static and dynamic critical loads.

The significant raw data traces (Volume 3) reproduced by a Honeywell Visicorder from the magnetic tape recordings of test runs for each mobile home include typical accelerations used to determine design criteria and typical strains and deflections obtained as a possible measure of degradation. Tabulated summaries of maximum and minimum magnitudes of the recorded quantities precede these traces.

IV. DATA SUMMARIES

OF

TEST MOBILE HOMES

T-1 NEW SINGLE WIDE

A new 1976 (14 x 65) single-wide mobile home (designed in compliance with 1976 HUD Specifications) was purchased from a dealer in Seguin, Texas and towed to San Antonio, Texas for instrumentation and further testing. The torsional and bending stiffnesses of the unit were determined at Seguin prior to the move to San Antonio. The unit was instrumented as described in Part I of this Task and tested in accordance with the approved test matrix. T-1 was also used in several other tests and subsequently acquired many more miles than other test units.

Throughout the test period of T-1, post-trip inspections found progressive degradation of the mobile home exterior and interior resulting from movement at the joints; however, the rate of degradation was not as rapid as the double-wide or used units based on visual observations. Leaks developed around the roof vent and exhaust fan outlet within the unit's first 600 miles. The attachments of the central heater, toilet, stove, and refrigerator gradually worked loose. Fasteners such as screws, nails, and staples began working loose from the beginning. This had a degrading effect on exterior panels which rubbed at the junctions and enlarged the screw holes. Improper gluing of an interior panel resulted in its buckling and increased working of adjacent exterior panels. The T-1 unit withstood the total mileage with less degradation and damage than any of the other mobile home test units.

Some loss in the precamber of the chassis frame was evidenced by the increasing dead load sag at the rear of the unit and between the hitch and axles. The rear dead load deflection increased from 2.741 in. after the first run to 4.455 in. after the eighth run, almost 2000 miles later. Torsional deflection to the left of the rear section increased from 0.447 in. after the first run to 1.020 in. after the eighth run. Once again, this is much better than deflections measured on the other test units.

TABLE 1

DATA SUMMARY AND DEGRADATION FACTORS FOR T-1 (14 x 65 NEW SINGLE-WIDE)

Date	Activity	Route No.	Trip Mileage (miles)	Total Mileage (Accum)	Vel. (mph)	Weight (lbs)	Tire Activity	$\overline{RC}$*	Nat. Freq. (Hz)	Setup/ Take-down	Spray Water Test	System Plumbing Test	System Electrical Test	System Gas Test	System Duct Test
		CONDITION I													
8-?-76	1	Del.	487	487	55 (est.)	16,000	Unknown	1.0,1.2	1.68	No	No Test	No Test	No Test	No Test	No Test
10-26-76	2	1	77	564	45/50	16,000	Blowout	1.0,1.2	1.56	Yes	Leaks(1)	No Leaks	No Failure	No Leaks	No Leaks
		CONDITION II Setup/Takedown													
3-4-77	3	3	107	671	45	20,300	Puncture	1.0,1.2, & 1.5	1.51	No	Leaks(1) Sealed	No Leaks	No Failure	No Leaks	No Leaks
3-8-77	4	5	316	987	45/50	20,300	No Failure	1.0,1.2, & 1.5	1.45	Yes	No Leaks	No Leaks	No Failure	No Leaks	No Leaks
		Setup/Takedown													
3-10-77	5	5	317	1304	45	20,300	No Failure	1.0,1.2, & 1.5	1.40	No	No Leaks	No Leaks	No Failure	No Leaks	No Leaks
3-11-77	6	2	256	1560	45/50	20,300	No Failure	1.0,1.2	1.40	Yes	No Leaks	No Leaks	No Failure	No Leaks	No Leaks
		Setup/Takedown - End of Condition II **													
3-17-77	7	5	308	1868	45	20,300	Blowout	1.0,1.2, & 1.5	1.38	No	No Leaks	No Leaks	No Failure	No Leaks	No Leaks
3-29-77	8	3	318	2186	40/45	20,300	No Failure	1.0,1.2, & 1.5	1.37	Yes	No Leaks	No Leaks	No Failure	No Leaks	No Leaks

*Road Condition as Defined in Task I, Volume I.
**End of required test program. However, T-1 was used in testing four modifications to the program.

DATE	$\overline{(EI)}_F$ (lb-in.^{2} x 10^8)	$\overline{(EI)}_R$ (lb-in.^{2} x 10^8)	$\overline{(GJ)}_F$ (lb-in.^{2} x 10^8)	$\overline{(GJ)}_R$ (lb-in.^{2} x 10^8)	$\overline{J}_F$ (lb-in.^{2} x 10^5)	$\overline{J}_R$ (lb-in.^{2} x 10^5)
8-?-76	—	—	—	—	—	—
10-26-76	209	1841	10.5	2.8	79.8	31.8
3-4-77	192	1691	7.9	1.8	76.3	30.8
3-8-77	170	1617	6.3	2.3	72.3	30.2
3-10-77	135	1337	4.9	2.1	70.0	28.5
3-11-77	111	1170	4.3	2.0	67.8	27.2

Note: $\overline{GJ}$ and $\overline{J}$ are not proportional.

T-2A NEW DOUBLE-WIDE (WET SIDE)

A new 1976, 24 X 60 double-wide mobile home (designed in compliance with 1976 HUD Specifications) was purchased from a dealer in Seguin, Texas. The new mobile home was picked up from a delivery lot in Grand Prairie, Texas by the SwRI crew. The performance of torsion and vertical deflection tests was not made when it arrived at Grand Prairie. The wet side of the mobile home was then transported to San Antonio, Texas, instrumented as described in Part I of this Task, and tested in accordance with the approved test matrix.

Throughout the testing of T-2A, several signs of degradation were noted in the post-trip inspections. The home, when new, listed to the heavy wall side approximately 5 to 7 degrees. Following the first trip, deep diagonal buckles were evident in the sheet metal roof. The majority of the precambering in the chassis was lost after 500 miles of towing. The box structure listing to the heavy wall side caused doors to bind, roof and panels to buckle, and windows to crack. During the third run, an emergency egress window fell out. Continuous loosening of the fasteners was noted which resulted in the working loose of exterior and interior panels. Other points of degradation which were common to all the mobile homes are listed in the General Observations.

T-2A experienced "wind blowover" 53 miles from the completion of Run No. 5. All of the instrumentation was operable at the time of the blowover which occurred at 27-mph vehicle velocity with cross-wind speeds of 28-35 knots and peak gusts to 44 knots. The wind direction was against the plastic covered side. The unit was righted, the hitch repaired, and the trip completed without instrumentation. Degradation was indicated by the increase in the torsional measurement to the left of the rear section from 0.66 in. after the first trip to 3.106 in. after the sixth trip, 1540 miles later.

TABLE 2

DATA SUMMARY AND DEGRADATION FACTORS FOR
T-2A (12 x 60) NEW WET HALF OF DOUBLE-WIDE

Date	Activity	Route No.	Trip Mileage (miles)	Total Mileage (Accum)	Vel. (mph)	Weight (lbs)	Tire Activity	$\overline{RC}$*	Nat. Freq. (Hz)	Setup/Takedown	Spray Water Test	System Plumbing Test	System Electrical Test	System Gas Test	System Duct Test
CONDITION I															
11-8-76	1	(a)	315	315	45	16,000	Blowout	1.0,1.2, & 1.5	1.42	Yes	Window Leak	Leak-Sink	No Failure	No Failure	No Leaks
2-17-77	2	5	272	587	45	16,000	No Failure	1.0,1.2, & 1.5	1.38	Yes	Door Leak	No Leaks	No Failure	No Failure	No Leaks
CONDITION II Setup/Takedown															
2-18-77	3	5	273	860	45	20,000	Blowout	1.0,1.2, & 1.5	1.32	Yes	No Leaks	No Leaks	No Failure	No Failure	Leak-HWH
2-22-77	4	4	259	1119	45	20,000	No Failure	1.2,1.5	1.29	Yes	No Leaks	No Leaks	No Failure	No Failure	Leak-HWH
Setup/Takedown - End of Condition II**															
2-23-77	5*	4	264	1383	45	20,000	No Failure	1.2,1.5	--	Yes	——	——	——	——	——

*Road Condition as Defined in Task I, Volume I.
**End of required test program.

DATE	$(\overline{EI})_F$ (lb-in.^{2} x 10^8)	$(\overline{EI})_R$ (lb-in.^{2} x 10^8)	$(\overline{GJ})_F$ (lb-in.^{2} x 10^8)	$(\overline{GJ})_R$ (lb-in.^{2} x 10^8)	$\overline{J}_F$ (lb-in.^{2} x 10^5)	$\overline{J}_R$ (lb-in.^{2} x 10^5)
11-8-76	155	1769	2.0	1.2	2.07	2.21
2-17-77	179	1827	1.8	0.61	1.63	1.06
2-18-77	150	656	1.5	0.50	1.16	0.86
2-22-77	125	389	1.2	0.41	1.01	0.65
2-23-77	108	324	1.2	0.36	0.92	0.55

Note: $\overline{GJ}$ and $\overline{J}$ are not proportional.

T-2B NEW DOUBLE-WIDE (DRY SIDE)

A new 1976, 24 X 60 double-wide mobile home (designed in compliance with 1976 HUD Specifications) was purchased from a dealer in Seguin, Texas. The new mobile home was picked up from a delivery lot in Grand Prairie, Texas, by the SwRI tow tractor and crew. The performance of torsion and vertical deflection tests was made when it arrived at Grand Prairie. The dry side of the mobile home was then transported to San Antonio, Texas, instrumented as described in Part I of this Task, and tested in accordance with the approved test matrix.

Throughout the testing of T-2B, evidence of physical degradation was compiled through post-trip inspections and tests. Like T-2A, T-2B (dry side) experienced listing of the box structure and subsequent roof buckling and door binding at factory delivery and during the first test run. This unit also suffered from loosening at the joints and fasteners which resulted in working loose of interior and exterior panels - an occurrence common to all the test units. T-2B is the lighter weight dry side of the new double-wide which listed to the heavy wall side because of asymmetrical loading.

This new mobile home also contained excessive precamber, evidenced by the fact that, after the sixth trip, the unsupported rear section was still up 2-5/16 in., and the unit could not be leveled for setup and measurements. Degradation was also indicated by the increase in deflections resulting from both the torsion and vertical flexure tests. Comparison of the $\overline{EI}$ and $\overline{J}$ factors revealed that the dry side of the double-wide unit did not degrade as rapidly as the wet side.

TABLE 3

DATA SUMMARY AND DEGRADATION FACTORS FOR
T-2B (12 x 60 NEW DRY HALF OF DOUBLE-WIDE)

Date	Activity	Route No.	Trip Mileage (miles)	Total Mileage (Accum)	Vel. (mph)	Weight (lbs)	Tire Activity	$\overline{RC}$*	Nat. Freq. (Hz)	Setup/Take-Down	Spray Water Test	System Plumbing Test	System Electrical Test	System Gas Test	System Duct Test
		CONDITION I													
11-10-76	1	*	315	315	45	12,000	Blowout	1.0,1.2	1.40	Yes	Leak-Window Sealed	N/A	No Failure	N/A	No Leaks
1-27-77	2	5	171	486	45	12,000	Blowout	1.0,1.2 & 1.5	1.37	Yes	Leak-Window Sealed	N/A	No Failure	N/A	No Leaks
		CONDITION II Setup/Takedown													
2-4-77	3	5	180	666	45	16,000	Blisters	1.0,1.2 & 1.5	1.32	Yes	No Leaks	N/A	No Failure	N/A	No Leaks
2-8-77	4	5	247	913	45	16,000	Blisters	1.0,1.2	1.27	Yes	No Leaks	N/A	No Failure	Leak at Heater	No Leaks
2-9-77	5	4	246	1159	45	16,000	Lost Tread	1.0,1.2 & 1.5	1.26	Yes	Window Leak	N/A	No Failure	Tested Heater	No Leaks
		Setup/Takedown - End of Condition II**													
2-11-77	6	6	254	1413	45	16,000	Blowout	1.0,1.2 & 1.5	1.26	Yes	Leak - Window	N/A	No Failure	Leak at Heater	No Leaks

*Road Condition as Defined in Task I, Volume I.
**End of required test program.

DATE	$(\overline{EI})_F$ (lb-in.^{2} x 10^8)	$(\overline{EI})_R$ (lb-in.^{2} x 10^8)	$(\overline{GJ})_F$ (lb-in.^{2} x 10^8)	$(\overline{GJ})_R$ (lb-in.^{2} x 10^8)	$\overline{J}_F$ (lb-in.^{2} x 10^5)	$\overline{J}_R$ (lb-in.^{2} x 10^5)
11-10-76	161	1820	3.9	1.1	7.42	6.75
1-27-77	132	1256	2.6	0.61	7.10	4.21
2-4-77	150	1212	1.6	0.30	6.84	3.79
2-8-77	149	1221	1.2	0.24	6.30	3.54
2-9-77	141	1122	1.0	0.18	6.00	3.10
2-11-77	95	—	0.91	0.18	5.41	2.78

Note: $\overline{GJ}$ and $\overline{J}$ are not proportional.

T-3 USED SINGLE-WIDE

A used 1971, 14 X 65 single-wide mobile home was purchased from a private owner who was currently occupying the home. The T-3 floor plan came as close as possible to matching that of the T-1. The used mobile home was purchased approximately 58 miles east of San Antonio on a ranch. The unit was properly set up and well maintained, and historical records were available on the home. The SwRI crew took it down and towed it to San Antonio. Torsion and deflection tests were conducted after the home was delivered to SwRI.

The unit was instrumented as described in Part I of this Task and tested in accordance with the approved test matrix. Upon receipt at SwRI, post-trip inspection, indicated that this mobile home showed some signs of degradation from prior occupancy and age. This included some rust on steel parts and buckling of the metal roof and some exterior side panels. None of these buckles increased significantly during the 1200 miles added to the unit during the program. After 500 miles, some binding was discovered in the exterior sliding glass door resulting in leaks around the frame. Also, at this time, an exterior aluminum siding panel blew off after substantial movement during the transportation mode.

The bending stiffness of the home after 5 years did not decrease at the same rate as T-1, implying that the structure may have already loosened up, and the degradation may have leveled off to some degree. Another indication of this factor pertains to the dead weight sag of the rear section. Over the period of testing, the rear dead load sag only increased from 2.34 to 2.79 in. Working of the exterior fasteners had already begun when the home was purchased on site. However, the data indicate that T-3 was probably more stiff than T-1 when it was new.

TABLE 4

DATA SUMMARY AND DEGRADATION FACTORS FOR
T-3 (1971 USED SINGLE-WIDE 14 x 65)

Date	Acti-vity	Route No.	Trip Mileage (miles)	Total Mileage (Accum)	Vel. (mph)	Weight (lbs)	Tire Activity	$\overline{RC}$*	Nat. Freq. (Hz)	Setup/ Take-down	Spray Water Test	System Plumbing Test	System Electrical Test	System Gas Test	System Duct Test
CONDITION I Setup/Takedown															
11-1-76	1	*	90	90	45	15,650	Blowout	1.0,1.2, & 1.5	1.59	Yes	Leak/ Window Sealed	No Leaks	No Failure	No Leaks	No Leaks
12-20-76	2	5	180	270	45	15,650	No Failure	1.0,1.2, & 1.5	1.51	Yes	Leak/ Vent Sealed	No Leaks	No Failure	No Leaks	Leak/ Heater
CONDITION II Setup/Takedown															
12-21-76	3	3	253	523	45	19,380	Blowout	1.0,1.2, & 1.5	1.47	Yes	Leak/ Roof Sealed	Leak/ Sink	No Failure	No Leaks	Leak/ Heater
12-28-76	4	4	269	1192	45	19,380	Blowout	1.0,1.2, & 1.5	1.45	Yes	No Leaks	Leak/ HWH	No Failure	Leak/ Heater	No Leaks

*Road Condition as Defined in Task I, Volume I

DATE	$(\overline{EI})_F$ (lb-in.^{2} x 10^8)	$(\overline{EI})_R$ (lb-in.^{2} x 10^8)	$(\overline{GJ})_F$ (lb-in.^{2} x 10^8)	$(\overline{GJ})_R$ (lb-in.^{2} x 10^8)	$\overline{J}_F$ (lb-in.^{2} x 10^5)	$\overline{J}_R$ (lb-in.^{2} x 10^5)
11-1-76	98	450	1.2	1.3	131	41.0
12-20-76	90	444	1.1	1.1	120	38.4
12-21-76	95	581	0.94	0.94	95	36.2
12-28-76	74	400	0.85	0.64	92	31.4

Note: $\overline{GJ}$ and $\overline{J}$ are not proportional.

T-4A USED DOUBLE-WIDE

A used 1974, 14 X 60 double-wide mobile home was purchased from a private owner who was currently occupying the home. The T-4 floor plan came as close as possible to matching that of the T-2 for test and correlation purposes. The used mobile home was purchased approximately 58 miles east of San Antonio in Sequin, Texas. The home was properly set up and well maintained, and historical records were available on the home. The SwRI crew took it down, separated the two halves, installed a plastic tarp, and transported each half to San Antonio for instrumentation and test. No deflection or torsion tests were conducted until after arriving at San Antonio.

The unit was instrumented as described in Part I of this Task and tested in accordance with the approved test matrix. Prior to the testing of this unit, binding of the sliding glass door, some buckling of the roof and side wall, and a list to the left, were recorded. Throughout the testing, these elements of degradation did not change significantly. However, after approximately 200 miles, daylight was visible over the top of the front wall revealing looseness of the front wall to roof joint.

The rear vertical bending stiffness only decreased about 10 percent compared to 30 percent for T-2A (the comparable new wet side of double-wide). This unit was only 2 years old when purchased; however, it was a "pre-HUD" home with minimum marriage walls and the large sliding glass door located in a critical area. Torsional stiffness decreased in the rear section comparable to T-2A, but the torsional stiffness of the front section decreased less rapidly. Degradation was significant as indicated by the buckling of exterior paneling, loosening of the minimum marriage walls, loosening of front end wall, settling of lower joints, ceiling panels coming loose at the joints, and structural deformation at corners of sliding glass door.

TABLE 5

DATA SUMMARY AND DEGRADATION FACTORS FOR
T-4A (WET HALF OF 24 x 60 USED DOUBLE-WIDE)

Date	Activity	Route No.	Trip Mileage (miles)	Total Mileage (Accum)	Vel. (mph)	Weight (lbs)	Tire Activity	$\overline{RC}$*	Nat. Freq. (Hz)	Setup/ Take-down	Spray Water Test	System Plumbing Test	System Electrical Test	System Gas Test	System Duct Test
CONDITION I Setup/Takedown															
10-11-76	1	*	78	78	45	14,170	Blowout	1.2,1.5	1.47	Yes	Leak/ Door	No Leaks	No Failure	No Leaks	No Leaks
11-5-76	2	2	100	178	45	14,170	Blowout	1.0,1.2 & 1.5	1.41	Yes	Leak/ Window	No Leaks	No Failure	No Leaks	No Leaks
CONDITION II Setup/Takedown															
11-15-76	3	2	156	334	45	18,200	---	1.0,1.2 & 1.5	1.36	Yes	No Leaks	Sink Leak	No Failure	No Leaks	No Leaks
12-1-76	4	4	287	621	45	18,200	Blowout	1.0,1.2	1.33	Yes	Vent Leak	No Leaks	Kitchen CB	No Leaks	Leak/ C.H.

*Road Condition as Defined in Task I, Volume I

DATE	$(\overline{EI})_F$ (lb-in.^{2} x 10^8)	$(\overline{EI})_R$ (lb-in.^{2} x 10^8)	$(\overline{GJ})_F$ (lb-in.^{2} x 10^8)	$(\overline{GJ})_R$ (lb-in.^{2} x 10^8)	$\overline{J}_P$ (lb-in.^{2} x 10^5)	$\overline{J}_R$ (lb-in.^{2} x 10^5)
10-11-76	150	1332	0.21	0.61	0.92	2.17
11-5-76	147	1274	0.20	0.49	0.89	1.94
11-15-76	135	1200	0.19	0.42	0.86	1.71
12-1-76	129	1190	0.18	0.34	0.83	1.47

Note: $\overline{GJ}$ and $\overline{J}$ are not proportional.

T-4B USED DOUBLE-WIDE

A used 1974 14 x 60 double-wide mobile home was purchased from a private owner who was currently occupying the home. The T-4 floor plan came as close as possible to matching that of the T-2 for test and correlation purposes. The used mobile home was purchased approximately 58 miles east of San Antonio in Seguin, Texas. The home was properly setup and well maintained, and historical records were available on the home. The SwRI crew took it down, separated the two halves, installed a plastic tarp and transported each half to San Antonio for instrumentation and test. No deflection or torsion tests were conducted until after arriving at San Antonio.

The unit was instrumented as described in Part I of this Task and tested in accordance with the approved test matrix. The receiving inspection of this home recorded several significant signs of degradation. Among them were deep wrinkles in the metal roof, some buckling in the aluminum side wall panels and a significant list toward the heavy wall side.

The degradation in this unit was more pronounced by the actual loosening of interior walls at the attachment to the floor and exterior wall. Buckling along the exterior aluminum siding around windows and doors was critical in this unit. The floor in the entrance porch area degraded very rapidly due to the combined transportation loads and moisture.

During test runs, loosening of fasteners and joints contributed to approximately a 15-percent reduction in the rear bending stiffness of T-4B compared to almost 50 percent for its new counterpart, T-2B; however, the bending stiffnesses of the two units were not far apart after 700 test miles. Torsional stiffness of the two decreased at similar rates.

TABLE 6

DATA SUMMARY AND DEGRADATION FACTORS FOR
T-4B (DRY HALF OF 24 x 60 USED DOUBLE-WIDE)

Date	Activity	Route No.	Trip Mileage (miles)	Total Mileage (Accum)	Vel. (mph)	Weight (lbs)	Tire Activity	$\overline{RC}$*	Nat. Freq. (Hz)	Setup/ Take-down	Spray Water Test	System Plumbing Test	System Electrical Test	System Gas Test	System Duct Test
CONDITION I Setup/Takedown															
10-12-76	1	[illegible]	77	77	45	15,770	Blowout	1.2,1.5	1.43	Yes	Leak/ Window Sealed	No Failure	N/A	N/A	No Failure
12-10-76	2	2	100	177	45	15,770	No Failure	1.0,1.2	1.39	Yes	Leak/ Vent Sealed	No Failure	N/A	N/A	No Failure
CONDITION II Setup/Takedown															
12-13-76	3	5	162	339	45	19,800	No Failure	1.0,1.2, & 1.5	1.30	Yes	Leak/ Window Sealed	No Failure	N/A	N/A	No Failure
12-14-76	4	4	256	595	45	19,800	Blowout	1.0,1.2, & 1.5	1.26	Yes	No Leaks	No Failure	N/A	N/A	No Failure

*Road Condition as Defined in Task I, Volume I

DATE	$(\overline{EI})_F$ (lb-in.^{2} x 10^8)	$(\overline{EI})_R$ (lb-in.^{2} x 10^8)	$(\overline{GJ})_F$ (lb-in.^{2} x 10^8)	$(\overline{GJ})_R$ (lb-in.^{2} x 10^8)	$\overline{J}_F$ (lb-in.^{2} x 10^5)	$\overline{J}_R$ (lb-in.^{2} x 10^5)
10-12-76	161	1146	0.24	0.59	11.0	7.58
12-10-76	155	1070	0.22	0.51	10.7	7.13
12-13-76	95	1169	0.17	0.44	9.97	6.63
12-15-76	96	920	0.16	0.39	9.45	5.88

Note: $\overline{GJ}$ and $\overline{J}$ are not proportional.

T-5 USED PALO PINTO SINGLE-WIDE

A used 1972 12 x 65 single-wide mobile home was borrowed from the HUD Strategic Storage Center at Palo Pinto, Texas for use in developing the instrumentation, routes, testing methodology and fixtures for the proposed test fleet of mobile homes being purchased. The tabulated data contained in Table 7 were generated during the developmental phases of the program.

TABLE 7

DATA SUMMARY AND DEGRADATION FACTORS FOR
T-5 (USED 12 x 65 SINGLE-WIDE)

Date	Activity	Route No.	Trip Mileage (miles)	Total Mileage (Accum)	Vel. (mph)	Weight (lbs)	Tire Activity	$\overline{RC}$*	Nat. Freq. (Hz)	Setup/Takedown	Spray Water Test	System Plumbing Test	System Electrical Test	System Gas Test	System Duct Test
CONDITION I Setup/Takedown															
8-19-77	1	*	318	318	45	13,940	Blowout	1.0,1.2 &1.5	1.60	No	--	Leak Sink	No Failure	No Leaks	Leaks
9-8-76	2	1	65	383	45	13,940	--	1.0,1.2	1.56	Yes	--	No Leaks	No Failure	No Leaks	Leaks
CONDITION II Setup/Takedown															
9-17-76	3	2	100	483	45	18,000	Blowout	1.0,1.2 &1.5	1.50	No	--	No Leaks	No Failure	No Leaks	Leaks
9-21-76	4	2	100	583	45	18,000	--	1.0,1.2 &1.5	1.49	Yes	--	Leak Toilet	No Failure	No Leaks	Leaks
Setup/Takedown															
9-28-76	5	2	100	683	45	18,000	Blowout	1.0,1.2 &1.5	1.45	No	Leak/Window	Leak Toilet	No Failure	No Leaks	Leaks
10-6-76	6	2	156	839	45	18,000	--	1.0,1.2 &1.5	1.41	Yes	Leak/Vent	Leak Toilet	No Failure	No Leaks	Leaks

*Road Condition as Defined in Task I, Volume I

V. GENERAL OBSERVATIONS

From the data presented in this volume and the appendix, supplemented by the observations made during the test program, the following generalizations were made:

(1) Any movement, no matter how small, within the structure of a mobile home causes some degree of structural degradation. This includes setups, takedowns, transportation, looseness in the foundation and vibrations caused by occupancy, improper setup and maintenance.

(2) Indications of structural degradation are torsional and bending stiffnesses and natural frequency of the structure. These quantities decrease with increased degradation of the unit.

(3) As the torsional and bending stiffnesses of the box structure decrease due to loosening of the joints, resulting in larger deflections, a greater proportion of the overall stiffness of the structure must be assumed by the longitudinal I-beams. In addition to increased loading of the I-beams and increased deflections are increased stresses, both in the box structure and the I-beams.

(4) There were no catastrophic failures of the mobile home structural box; but a steady and continual degradation of the joint structure with each mile of transportation and each test/setup-takedown.

(5) An important element contributing to the constant joint degradation is: a vibration frequency in the mobile home ranging from 5 to 10 Hz introduced during transportation.

(6) Usually, the pre-camber in the steel chassis is gone by the time the unit has traveled approximately 500 miles. From this point on, the unit sags both between the hitch and axles and aft of the axles. These static and dynamic deflections continue to increase with additional mileage. Sidewalls being pulled down to the pre-cambered contour during assembly, thereby, preloading the walls in an upward direction, and then the pre-camber being lost permitting the pre-load in the wall to reverse, can contribute significantly to the loosening of the joints.

(7) Transportation effects and degradation indicators are visible on the exterior structure (e.g., loosening of exterior paneling and attachments, breaking of seals on roof attachments, and leaking around vents, windows, and doors).

(8) Interior evidence of transportation effects and degradation indicators are increased air infiltration, loosening of appliance fasteners, loosening of panels, binding of doors and movement at the interfaces of roof, wall, and ceiling.

(9) The long sidewalls are designed as beams, but they lack a beam's structural integrity. The flexural rigidity of the sidewalls could be significantly increased if the exterior paneling could be made to carry a proportionate amount of the beam load. Also, the upper tension cap (plate) and metal roof experience a significant degree of elongation, especially during dynamic loading.

(10) The adhesives used in attaching the interior plywood paneling to the shear walls and exterior walls significantly increase the longevity of the structural components.

(11) The degradation factors observed during the transportation mode are affected by the velocity of the mobile home and the type of road over which the unit is transported.

(12) The asymmetrical loading on each half of the double-wide units introduces significant torsional deflections during the static and transportation mode. When T-2A rolled over during high winds (35 to 45 mph) on Highway 281, it rolled in the direction of the "heavy side" at 28 mph forward speed; the high side and the plastic sheet were against the wind.

One of the most significant results of the testing is that the amount of structural degradation of a mobile home is contained within the sum of the incremental movements within all individual joints having less than 100-percent integrity. Examples of the joints in question are:

- Floor to wall - exterior (including lower plate),
- Roof to wall - exterior (including upper plate),
- Chassis to floor (including end to end joints of the 2 x 6's)
- Sidewall to endwall,
- Interior walls to ceiling,
- Exterior siding to wall,
- Components to floor and/or wall,
- Doors and windows to exterior walls.

The overall structure of a mobile home is suspended over the running gear and must have a certain degree of flexibility to withstand the loads (bending, torsion, shock and vibration) imposed by the transportation mode. If the unit is not flexible to some degree, it will receive higher accelerations, but it will not necessarily degrade more rapidly. However, flexibility must be minimized; that is, there must be flexibility within the basic materials but not within the joints. For example, the number of stud/plate joints from front to back on both side walls of a 65-ft mobile home need only experience a small change in each horizontal joint along the top plate to permit sufficient vertical movement in the total side wall system and enable the rear wall of the mobile home to sag in excess of 2 inches at the rear wall, as measured from the level position, because of its own static weight. A small amount of movement in the joint is difficult to measure or even see under direct visual inspection, especially when the coefficient of expansion of wood is about the same amount from a dry day to a wet or humid day.

The above-noted items are the kind of factors that contributed to the degradation of the mobile homes in this program. Individual joint degradation is difficult to measure because:

- There is an estimated 50-percent variation in the integrity/rigidity of joints during initial assembly because of the materials, designs, methods and human factors involved.
- Individual joint integrity varies significantly throughout the mobile home.
- Pre-cambered steel frames lose the pre-camber because of the vertical dynamic and static loadings resulting from repeated load cycles during the transportation mode.
- The side walls are fabricated as straight assemblies and set on pre-cambered chassis. If the total wall/roof system is not set upon the chassis at one time, the chassis cannot become level

and the walls are preloaded when pulled down to the chassis camber contour or the walls are preloaded by straightening out the chassis camber. Either way, significant loads/stresses are introduced through the wall by assembly of the wall to the floor/chassis or vice versa. One mobile home (T-2B) was found to contain 2-5/8-in. "up-camber" on the rear end which prevented leveling. A check of the upper side wall plate or roof line revealed the same camber. Therefore, in this case, the steel chassis pre-camber was stronger than the one wall (dry half of a double-wide) resulting in the side wall being contoured to the pre-camber, and thereby, preloading the glued-on interior paneling, studs plate, and all other joints.

Degradation of individual joints has been thwarted somewhat through the glued joint design which has significantly improved the structural integrity of the exterior side wall beams of the mobile home when applying interior glued paneling that can carry a significant percentage of the load. The glued joint design, however, is not applied to the numerous wall stud butt joints because it would have minimal effect.

VI. VALIDATION OF PREDICTED DEGRADATION

The predicted remaining useful life (RUL) of each test mobile home unit, after each test activity, is tabulated in Section VIII of Task III, Volume II. These predictions were compared to degradation, as measured in Task III, in terms of visual inspections, deflection and strain data, apparent torsional and bending stiffnesses ($\overline{EI}$ and $\overline{J}$), and accelerations.

A. Inspections

Visual inspections, system functional tests, and dynamic response characteristics (natural frequency tests) were conducted after each test activity. The results of these tests are included in Section IV of this document. These results were used as a basis for evaluating predicted degradation as tabulated in Task III, Volume II. Analysis of these data shows reasonable agreement between predicted degradation and experimental data.

B. Deflection and Strain Data

As described in Task III, Volume I, Part I, instrumentation was included in test units to measure deflections at critical joints, and strains of high stress areas of the steel longitudinal I beams. The intent was to determine if changes in these values, as affected by use, could be related to degradation. The tabulated values of Appendix A show a slight correlation between mileage of test units and increase in joint deflections. The table on the following page summarizes some of the joint deflection data from three mobile homes, T-1, T-2A, and T-3, at early and late mileages. The maximum peak average of the T-2A left wall at the floor deflector increased from 0.05 to 0.075 inches. The average of the maximum peaks of the T-3 deflector increased from 0.11 to 0.20

inches over 200 miles. Although these changes were slight, they did indicate that loosening of the sidewall/floor joints occurred with additional mileage and were indications of transportation-induced degradation.

DEFLECTION DATA INDICATING A RELATIONSHIP BETWEEN MILEAGE OF TEST UNITS AND INCREASE IN JOINT DEFLECTIONS

Test Unit	Run	Approximate Mileage	Location of Wall Deflector*	Max (in.) +	Max (in.) −	Min (in.) +	Min (in.) −
T-1	1	500	Left Wall Center at Floor	0.021 0.013	0.088 0.088	0 0	0 0
	6	1560	Left Wall Center at Floor	0.057 0 0.025 0.028	0.035 0.020 0 0.008	0 0 0 0	0 0 0 0
T-2A	1	400-500	Left Wall at Floor	0.069 0.156	0 0	0 0	0 0
	4	1200-1300	Left Wall at Floor	0.163 0.110 0.023	0.103 0.016 0.036	0 0 0	0 0 0
T-3	1	300-400	Right Wall Above Window to Floor Center	0.04 0.19 0.03 0.03 0.21 0.09 0.12	0.07 0.02 0 0.07 0.68+ 0 0.05	0 0 0.01 0 0.08 0.05 0.03	0 0 0 0 0.12 0 0.02
	3	500-600	Right Wall Above Window to Floor Center	0.08 0.04 0.24 0.28	0 0.60 0.26 0.12	0 0 0.1 0.09	0 0 0.1 0.02

* Specific locations in Volume 3.

Correlation between mileage and increasing longitudinal I-beam strain could not be adequately ascertained because certain critical strain gages failed during the course of the test program. However, the Torsion and Vertical Deflection test data do indicate that increased mileage resulted in greater bending and twisting at specific load levels.

C. Apparent Stiffness ($\overline{EI}$, $\overline{GJ}$, and $\overline{J}$)

The Task I dynamic analysis (Volumes I and II), which includes predictive degradation, is based, in part, on the apparent stiffnesses of the mobile home units. Stiffness values measured from the test units were analyzed to determine correlation with predicted and observed degradation.

Figures 1a, 1b, 2a, and 2b present the progressive reduction of structural stiffnesses versus miles of testing. Solid black symbols denote rear stiffness values; open symbols denote front values. In Figure 2b, the values for units tested new are connected with solid lines; dashed lines for values of used units.

During the course of testing, an important modification was made in the methodology for evaluating mobile home apparent bending stiffness, $\overline{EI}$. The development of $\overline{EI}$ by Battelle Memorial Institute* does not consider dead load sag--the inherent vertical deflection of a unit due to its own weight. Further, the simplistic Euler beam theory upon which the Battelle work is based assumes an a priori undeformed initial position. Thus, the reference point from which vertical deflections, including dead load sag, are measured should correspond to a leveled home.

Ignorant of this subtle detail, SwRI conducted several early tests measuring deflection from a unit's initially deflected position rather than from level. Such methodology derived inaccurate apparent bending stiffnesses and did not include recording of all data required

---

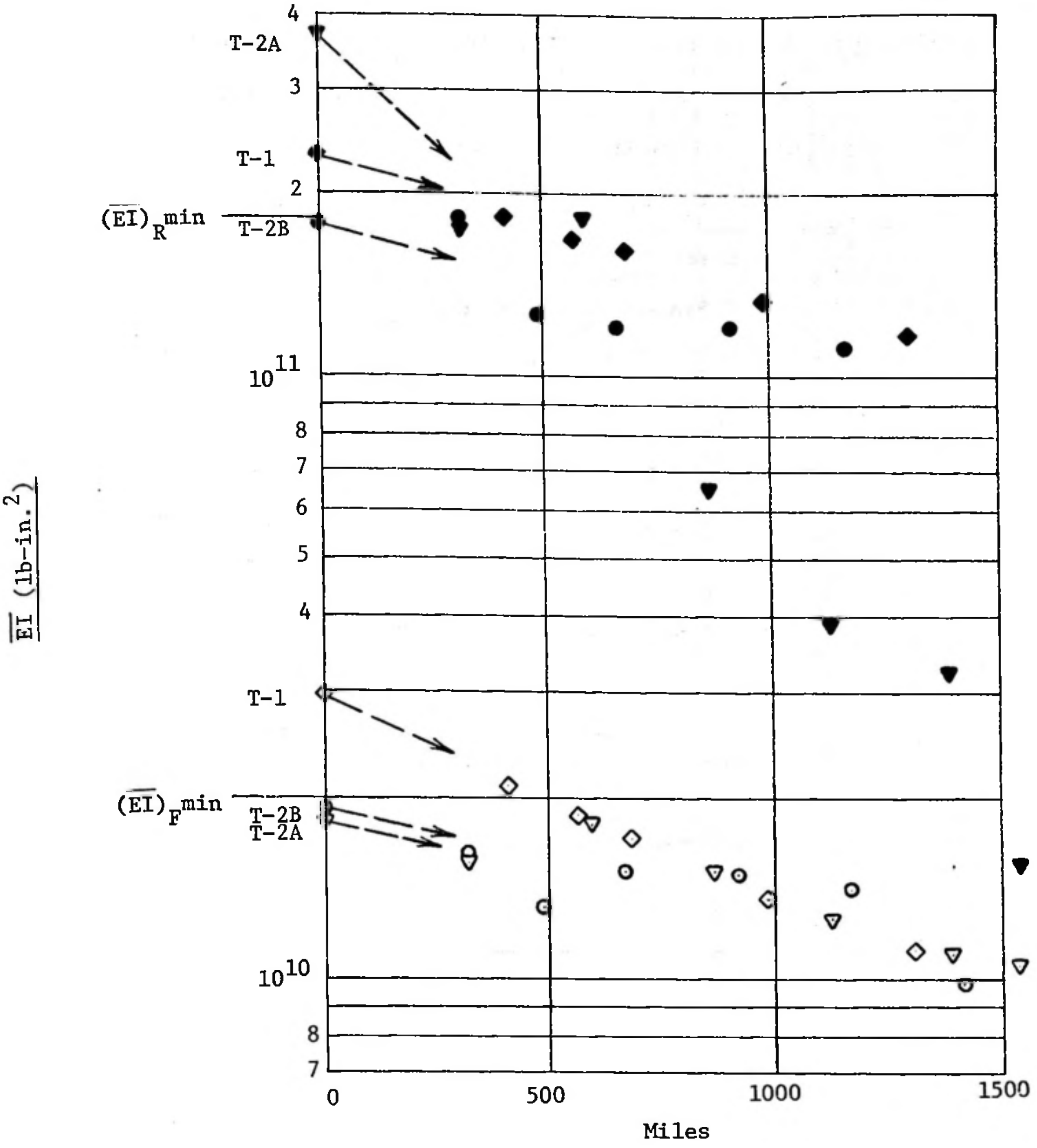
* Battelle Memorial Institute, "The Development of Performance-Based Tests to Determine the Minimum Structural Integrity of Mobile Homes." Research Report, July, 1966.

for correct calculations. However, actual $\overline{EI}$ values which do consider dead load sag can be approximated and are indicated in Figures 1a and 1b.

Figures 2a and 2b plot the torsional stiffness values of all test units versus test mileages. Figure 2a values are $\overline{GJ}$ stiffnesses (see Volume 6) and Figure 2b are $\overline{J}$ values based upon the 6 torsional stiffness formulas - front and rear formulas for each of the three mobile home types (single-wide, wet double-wide half, and dry double-wide half). Table 8 summarizes the flexural and torsional stiffness values, $\overline{EI}$, $\overline{GJ}$, and $\overline{J}$, for the front and rear of both new and used mobile homes. The values were calculated from data taken early and late in each test history.

Based upon the stiffness plots and Table 8, the following observations are noted:

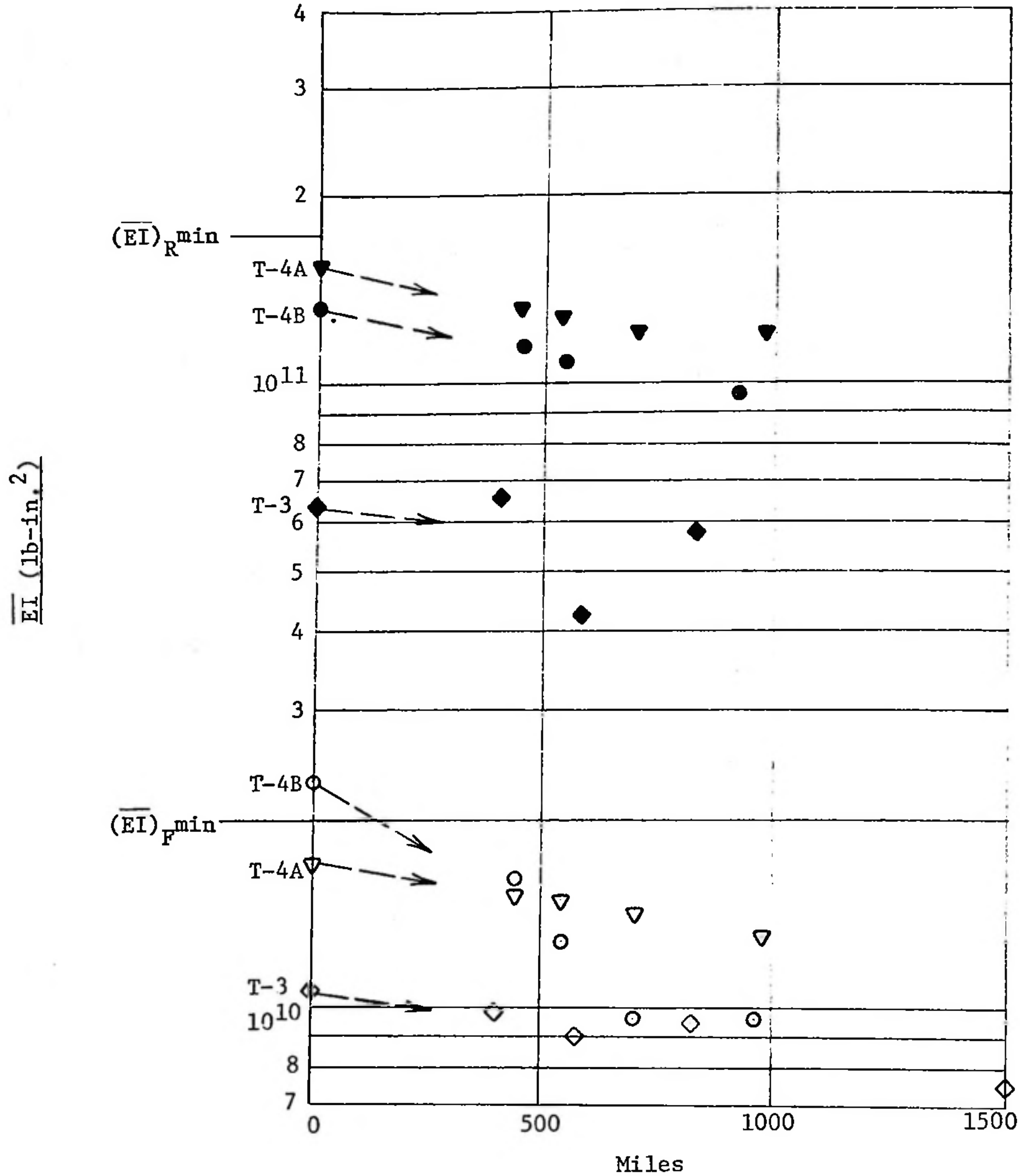
- Front and rear $\overline{GJ}$ torsional stiffnesses of single-wide units greatly exceed those of double-wide units.
- The degradation rate of $\overline{GJ}$ torsional stiffness is not as great for single-wides as double-wides.



Notes:

- Zero mileage values are linear extrapolations of a first order least squares fit to log values of the empirical data.
- Dashed lines are the first order best fit curves.
- Open symbols indicate front values; closed indicate rear.
- Front and rear recommended minimum new $\overline{EI}$ values are indicated as $(\overline{EI})_F$ min and $(\overline{EI})_R$ min, respectively.

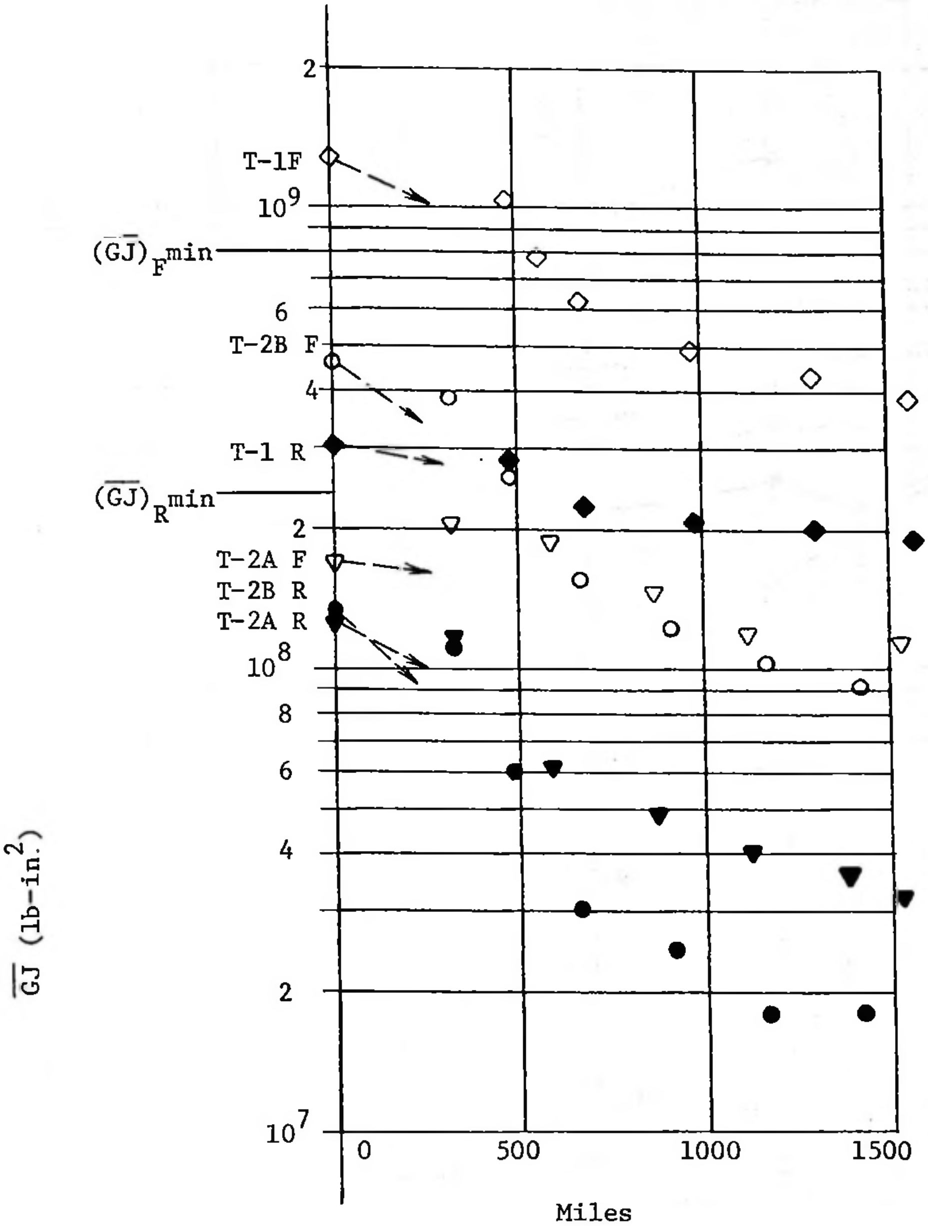
FIGURE 1a. SEMI-LOG PLOT OF $\overline{EI}$ APPARENT BENDING STIFFNESSES OF TEST UNITS T-1, T-2A, AND T-2B



Notes:

- Zero mileage values are linear extrapolations of a first order least squares to fit to log values of the empirical data.
- Dashed lines are the first order vest fit curves.
- Open symbols indicate front values; closed indicate rear.
- Front and rear recommended minimum new $\overline{EI}$ values are indicated as $(\overline{EI})_F$ min and $(\overline{EI})_R$ min, respectively.

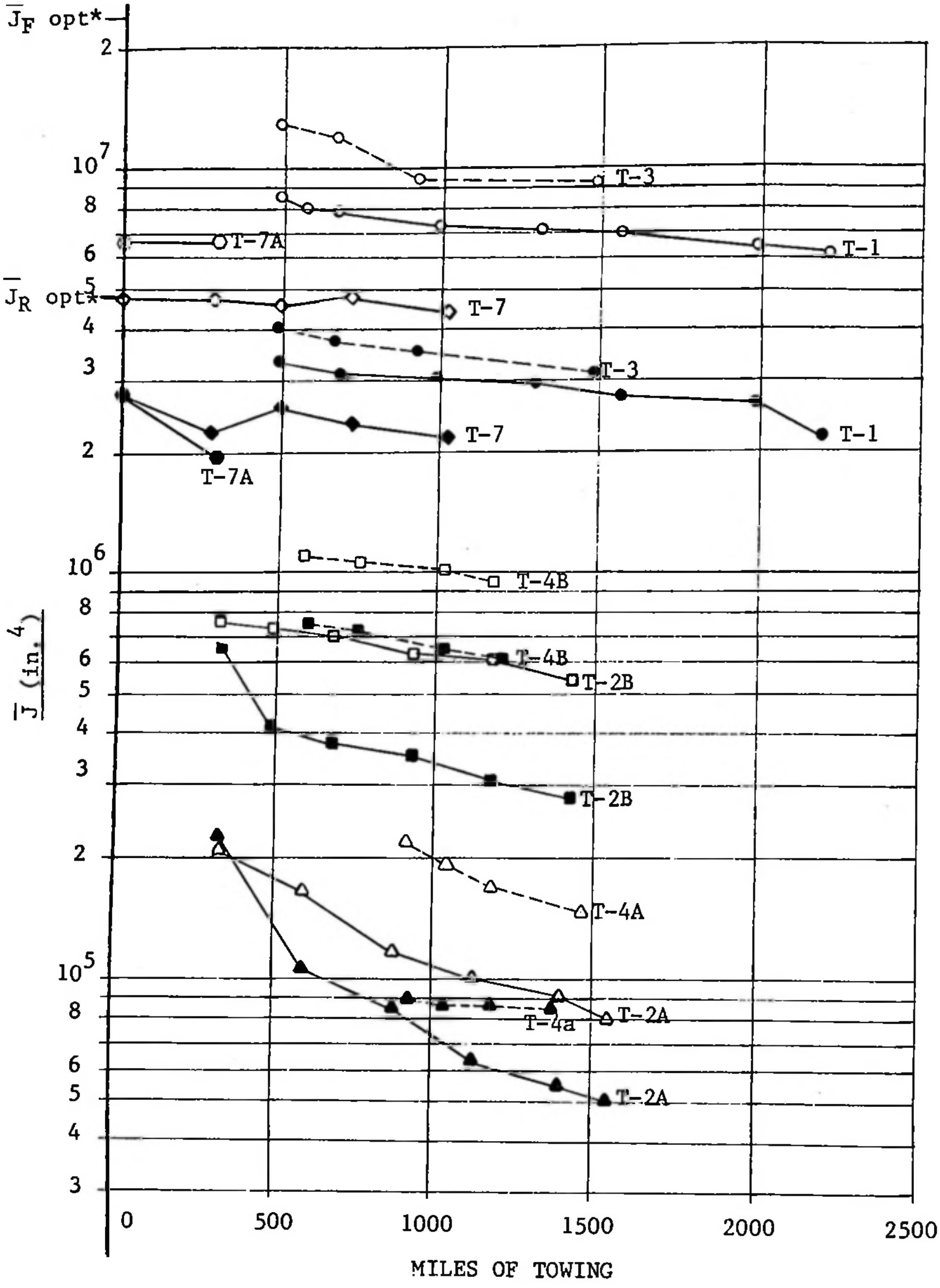
FIGURE 1b. SEMI-LOG PLOT OF $\overline{EI}$ APPARENT BENDING STIFFNESSES OF TEST UNITS T-3, T-4A, AND T-4B



Notes:

- Zero mileage values are linear extrapolations of a first order least squares fit to log values of the empirical data.
- Dashed lines are the first order best fit curves.
- Open symbols indicate front values; closed indicate rear.
- Front and rear recommended minimum new $\overline{GJ}$ values are indicated as $(\overline{GJ})_F$ min and $(\overline{GJ})_R$ min, respectively. See Volume 6.

FIGURE 2a. SEMI-LOG PLOT OF $\overline{GJ}$ APPARENT TORSIONAL STIFFNESSES OF TEST UNITS T-1, T-2A, AND T-2B



NOTE:
Solid symbols denote rear stiffnesses; open, front stiffnesses.
Solid lines denote new units; dashed lines denote used units.
*Recommended torsional stiffness values. See Task IV, Volume I.

FIGURE 2b. SEMI-LOG PLOT OF APPARENT $\overline{J}$ TORSIONAL STIFFNESSES

TABLE 8. SUMMARY OF $\overline{EI}$, $\overline{GJ}$, AND $\overline{J}$ STIFFNESS VALUES FOR ALL SIX MOBILE HOMES

Test Unit	Mileage	$\overline{EI}_F$ (lb-in.^{2} x 10^8)	$\overline{EI}_R$ (lb-in.^{2} x 10^8)	$\overline{GJ}_F$ (lb-in.^{2} x 10^8)	$\overline{GJ}_R$ (lb-in.^{2} x 10^8)	$\overline{J}_F$ (in.^{4} x 10^5)	$\overline{J}_R$ (in.^{4} x 10^5)
T-1	487	209	1840	10.5	2.8	83.8	32.7
	1304	111	1170	4.3	2.0	67.8	27.2
T-3*	394	98	650	1.2	1.3	131	41.0
	1496	74	400	0.85	0.64	92	31.4
T-2A	315	155	1770	2.0	1.2	2.07	2.21
	1119	141	1122	1.0	0.18	1.01	0.65
T-4A*	436	150	1332	0.21	0.61	0.92	2.17
	979	129	1190	0.18	0.34	0.83	1.47
T-2B	315	161	1820	3.9	1.1	7.42	6.75
	1159	141	1122	1.0	0.18	6.00	3.10
T-4B*	436	161	1146	0.24	0.59	11.0	7.58
	954	96	920	0.16	0.39	9.45	5.88

* Actual mileages are presented for Test Units T-3, T-4A, and T-4B, not just test mileages.

Note: $\overline{GJ}$ and $\overline{J}$ are not proportional.

D. Acceleration Data

Task I, Volumes I and II, the dynamic analysis, developed methodology to estimate accelerations based on apparent stiffnesses for purposes of predicting degradation and determining remaining useful life. The Task I predictions were based on theoretical idealized test conditions, e.g., towing a unit at 45 mph over a smooth, paved road as opposed to the actual data collected over a road surface that was not completely smooth in order to be more representative of actual transportation conditions.

The formulae developed under Task I to predict front and rear in-transit accelerations are used in Task III, Volume II for correlation of the predictive methodology to the actual test data. The predicted accelerations are computed using measured values for $\overline{EI}$, $\overline{J}$, a road condition factor, and transit velocity. A comparison of predicted versus experimental acceleration data is shown in Section VII of Task III, Volume II. Examination of tabulated data indicates that predicted accelerations compare favorably with actual in-field data collected.

The predicted accelerations contained in documentation describing the finite element model should not be compared to experimental data. Task I, Volume III, the finite element model, identified areas of stress concentrations as points of expected degradation. Also, from the finite element modeling, Task I, Volume IV presented predicted stresses in components resulting from various dynamic and static conditions. The stiffness values used in the dynamic analysis were only estimates used to test the acceleration and RUL predictive methodology under parametric analysis. Since no values had been measured for $\overline{EI}$ and $\overline{J}$ at the time of the writing of Task I, Volumes I and II, values used were based on best available data* as well as anticipated structural properties. (The assumed torsional stiffness values were extremely small in contrast to actual values measured in Task III.) Therefore, accelerations calculated from the Task I $\overline{EI}$ and $\overline{J}$ values should not be compared to those measured and tabulated under Task III.

---

* Battelle Memorial Institute, "The Development of Performance-Based Tests to Determine the Minimum Structural Integrity of Mobile Homes." Research report, July, 1966.

VII. SUPPORTIVE DATA FOR DESIGN RECOMMENDATIONS

A. Design for Setup and Takedown Loads

Setup and takedown are critical static conditions to which a mobile home unit may be subjected. Manufacturers provide procedures for each of these maneuvers for the purpose of minimizing induced loads. However, it cannot be assumed that these procedures will be followed exactly. Hence, designers must allow for asymmetrical loading conditions, for instance, supporting with minimum jack assistance. The loads are determined by knowing the mobile home weight distribution. It is believed that the Torsion Test described in Task III, Volume I, Part I results in typical forces and deflections for this condition. In order to examine the effect of this possible load condition on localized structure, the finite element model was analyzed for one typical asymmetrical loading condition. This condition assumes that the mobile home is partially lifted from a level position by applying a vertical up-load at a point near the rear end of the right longitudinal I beam. The adjacent structure effected by this loading condition is shown by the stress distribution figures for Load Case 4 in Task I, Volume III. The same structure is effected by removing support from under the same point on the longitudinal I beam; tension members are then loaded in compression and vice versa.

The test data presented in Tables 9 through 14 are typical forces and deflections for these conditions. The forces tabulated are those in excess of the forces required to support that corner of the mobile home under level conditions. The first and last tests are presented indicating the increase in deflections. See Volume 3 for total data collected from inspection.

TABLE 9 . TYPICAL DATA TABULATIONS FOR T-1 IN THE TORSION AND VERTICAL DEFLECTION MODE

Front Torsion (Load in lbs; Deflection in in.)

487 Mi. 16,300 lbs			318/2186 Mi* 20,300 lbs		
#1 Load	L.H. Deflec.	R.H. Deflec.	#8 Load	L.H. Deflec.	R.H. Deflec.
0	0	0	0	0	0
500	0	0	500	.020	.030
1000	.022	.015	1000	.040	.050
1500	.040	.123	1500	.270	.390
2000	.145	.435	2000	.700	.820
2200	-	-	2200	-	-
2500	.275	.661	2500	1.020	1.180

Rear Torsion (Load in lbs; Deflection in in.)

487 Mi. 16,300 lbs			318/2186 Mi. 20,300 lbs		
#1 Load	L.H. Deflec.	R.H. Deflec.	#8 Load	L.H. Deflec.	R.H. Deflec.
0	0.00	0.00	0	0.00	0.00
500	0.00	0.00	500	0.060	0.050
1000	0.00	0.105	1000	0.250	0.090
1500	0.058	0.280	1500	0.550	0.380
2000	0.247	0.470	2000	0.770	0.630
2200	-	0.542	2200	-	-
2500	0.447	-	2500	1.020	0.880

Vertical Deflection (Front and Rear)

487 Mi. 16,300 lbs			318/2186 Mi. 20,300 lbs		
#1 Load	Fwd Deflec.	Aft Deflec.	#8 Load	Fwd Deflec.	Aft Deflec.
0	0	0	level	0	0
sag	0.057	2.741	sag-jacks removed	0.115	4.455
180	0.073	2.767	150	0.145	4.599
255	0.080	2.779	228	0.163	4.735
330	0.088	2.790	478	0.195	5.005
405	0.095	2.801	728	0.230	5.309
505	0.106	2.817	978	0.256	5.568
728	0.126	2.851	1228	0.287	5.890
978	0.149	2.892	set-remove load	0.185	5.405
1228	1.172	2.961			
0	0.085	2.811			

* Trip miles/Total miles.

TABLE 10. TYPICAL DATA TABULATIONS FOR T-2A IN THE TORSION AND VERTICAL DEFLECTION MODE

Front Torsion
(Load in lbs; Deflection in in.)

315 mi - 16,000 lbs			0/1540 mi* - 20.370 lbs		
#1 Load	L.H. Deflec.	R.H. Deflec.	#7 Load	L.H. Deflec.	R.H. Deflec.
0	0	0	0	0	0
500	0.020	0	500	0.080	0.060
1000	0.29	0.05	1000	960/3.320**	0.180
1500	0.48	0.15	1000	4.150	-
2000	0.76	0.22	1000	5.830	-
0	0	0	1500	-	2.88
			1500	-	3.22

Rear Torsion
(Load in lbs; Deflection in in.)

315 mi - 16,000 lbs			0/1540 mi - 20.370 lbs†		
#1 Load	L.H. Deflec.	R.H. Deflec.	#7 Load	L.H. Deflec.	R.H. Deflec.
0	0	0	0	0	0
500	0.11	0.06	500	0.360	0.380
1000	0.32	0.19	1000	1.350	0.840
1500	0.55	0.24	1500	2.460	1.800
2000	0.66	0.30	2000	1700/3.41**	2.700
2500	0.74	0.38	0	0.220	0.110
0	0	0			

Wet Side Vertical Deflection
(Load in lbs; Deflection in in.)

315 mi - 16,000 lbs			0/1540 mi - 20,370 lbs†		
#1 Load	Fwd Deflec.	Aft Deflec.	#7 Load	Fwd Deflec.	Aft Deflec.
0	0	0	0	0	0
180	.021	.027	0	.600	2.690 sag
255	.034	.038	150	.638	2.800
330	.038	.053	228	.668	2.924
405	.043	.062	478	.728	3.210
505	.054	.085	728	.780	3.515
			778	.826	3.885
			1228	.885	4.085
			0 ret.	.707	3.680

* Trip miles/Total miles.
† Torsion and Deflection test after setup/takedown and repairs.
** Deflections achieved at the load indicated.

TABLE 11. TYPICAL DATA TABULATIONS FOR T-2B IN THE TORSION AND VERTICAL DEFLECTION MODE

Front Torsion
(Load in lbs; Deflection in in.)

315 mi - 12,200 lbs			16,200 lbs		
#1 Load	L.H. Deflec.	R.H. Deflec.	#7 Load	L.H. Deflec.	R.H. Deflec.
0	0	0	0	0	0
500	0.00	0.010	500	0.080	0.060
1000	0.23	0.021	1000	960/3.320 *	0.180
1500	2.10	0.081	1500	1000/4.150 *	2.88
2000	2.85	0.83	2000	1000/5.830 *	1500/3.22 *
2500			0	0	0

Rear Torsion
(Load in lbs; Deflection in in.)

315 mi - 12,200 lbs			16,200 lbs		
#1 Load	L.H. Deflec.	R.H. Deflec.	#7 Load	L.H. Deflec.	R.H. Deflec.
0	0	0	0	0	0
500	0.0	0.0	500	0.080	0.060
1000	0.030	0.020	1000	960/3.320*	0.180
1500	0.29	0.25	1500	1000/4.150*	2.88
2000	0.470	0.31	2000	1000/5.830*	1500/3.22*
2500	0.96	0.84	2500	-	-

Dry Side Vertical Deflection
(Load in lbs; Deflection in in.)

315 mi - 12,200 lbs			16,200 lbs		
#1 Load	Fwd Deflec.	Aft Deflec.	#7 Load	Fwd Deflec.	Aft Deflec.
0	0	0	0	0	0
227	.023	.030	150	.060 .087 } sag	5.20 5.299 } sag
302	.034	.044	228	.105	5.425
377	.043	.058	478	.155	5.910
452	.051	.073	728	.198	6.245
552	.062	.094	778	.230	7.575
			1228	.270	7.965
			0 ret.	.120	6.965

* Deflections achieved at the load indicated.

TABLE 12. TYPICAL DATA TABULATIONS FOR T-3 IN THE TORSION AND VERTICAL DEFLECTION MODES

Front Torsion

Miles: 90/90*-15,650 lbs			Miles: 269/1192-19,380 lbs		
Load (lbs)	L.H. Deflec. (in.)	R.H. Deflec. (in.)	Load (lbs)	L.H. Deflec. (in.)	R.H. Deflec. (in.)
0	0	0	0	0	0
1050	+0.18	-0.17	1050	+0.34	-0.25
2330	+0.39	-0.40	2330	+0.57	-0.53
3630	+0.50	-0.49	3630	+0.69	-0.67
4980	+0.60	-0.59	4980	+0.81	-0.76
0	-0.37	0	0	-0.26	+0.29

Rear Torsion

Miles: 90/90-15,650 lbs			Miles: 269/1192-19,380 lbs		
Load (lbs)	L.H. Deflec. (in.)	R.H. Deflec. (in.)	Load (lbs)	L.H. Deflec. (in.)	R.H. Deflec. (in.)
0	0	0	0	0	0
1050	+0.10	-0.12	1050	+0.20	-0.28
2330	+0.18	-0.20	2330	+0.38	-0.49
3630	+0.35	-0.46	3630	+0.69	-0.67
4980	-	-	4980	-	-
0	-0.20	+0.27	0	-0.25	+0.32

Front Vertical Deflection

Miles: 90/90-15,650 lbs		Miles: 269/1192-19,380 lbs	
Added Load (lbs)	Deflec. (in.)	Added Load (lbs)	Deflec. (in.)
0	level on jacks	0	level on jacks
0(sag)	0.111	0(sag)	0.134
185	0.149	185	0.179
260	0.162	260	0.197
335	0.174	335	0.226
435	0.200	435	0.271
0	0.128	0	0.158

Rear Vertical Deflection

Miles: 90/90-15,650 lbs		Miles: 269/1192-19,380 lbs	
Added Load (lbs)	Deflec. (in.)	Added Load (lbs)	Deflec. (in.)
0	level on jacks	0	level on jacks
0(sag)	2.34	0(sag)	2.79
185	2.412	185	2.890
260	2.455	260	2.825
335	2.487	335	2.866
435	2.543	435	3.055
0	2.400	0	2.940

* Trip miles/Total miles.

TABLE 13. TYPICAL DATA TABULATIONS FOR T-4A IN THE TORSION AND VERTICAL DEFLECTION MODES
(Wet half of Used Double-wide)

Front Torsion						Rear Torsion					
Miles: 436/436*- 14,170 lbs.			Miles: 287/979 - 18,200 lbs			Miles: 436/436 - 14,170 lbs			Miles: 287/979 - 18,200 lbs		
Load (lbs)	L.H. Deflec. (in.)	R.H. Deflec. (in.)	Load (lbs)	L.H. Deflec. (in.)	R.H. Deflec. (in.)	Load (lbs)	L.H. Deflec. (in.)	R.H. Deflec. (in.)	Load (lbs)	L.H. Deflec. (in.)	R.H. Deflec. (in.)
0	0	0	0	0	0	0	0	0	0	0	0
500	0.50	0.42	500	0.67	0.59	500	+0.050	-0.061	500	+0.11	-0.18
1050	1.18	1.09	1050	1.37	1.28	1050	+0.13	-0.22	1050	+0.26	-0.39
2330	1.62	1.45	2330	1.82	1.71	2330	+0.40	-0.61	2330	+0.65	-0.81
3630	1.92	1.77	3630	2.15	2.03	3630	+0.75	-1.02	3630	+0.98	-1.33
4980	2.10	1.95	4980	2.47	2.27	4980	-	-	4980	-	-
0	0.70	0.65	0	0.99	0.92	0	+0.10	0.16	0	+0.20	0.32

Front Vertical Deflection				Rear Vertical Deflection			
Miles: 436/436 - 14,170 lbs		Miles: 287/979 - 18,200 lbs		Miles: 436/436 - 14,170 lbs		Miles: 287/979 - 18,200 lbs	
Added Load (lbs)	Deflec. (in.)	Added Load (lbs)	Deflec. (in.)	Added Load (lbs)	Deflec. (in.)	Added Load (lbs)	Deflec. (in.)
0	level on jacks	0	level on jacks	0	level on jacks	0	level on jacks
0	(sag)0.009	0	(sag)0.020	0	(sag)0.047	0	(sag)0.069
222	0.028	222	0.045	222	0.074	222	0.098
297	0.047	297	0.061	297	0.114	297	0.152
372	0.060	372	0.078	372	0.152	372	0.187
472	0.076	472	0.093	472	0.198	472	0.234
0	(set)0.017	0	(set)0.028	0	0.060	0	0.081

* Trip miles/Total miles.

TABLE 14. TYPICAL DATA TABULATIONS FOR T-4B IN THE TORSION AND VERTICAL DEFLECTION MODES
(Dry half of Used Double-wide)

Front Torsion

Miles: 436/436* - 15,770 lbs			Miles: 256/954 - 19,800 lbs		
Load (lbs)	L.H. Deflec. (in.)	R.H. Deflec. (in.)	Load (lbs)	L.H. Deflec. (in.)	R.H. Deflec. (in.)
0	0	0	0	0	0
500	+0.029	-0.041	500	0.056	0.074
1050	+0.060	-0.097	1050	1.19	0.153
2330	+1.17	-1.39	2330	1.89	1.92
3630	+1.53	-1.86	3630	2.30	2.57
4980	+2.05	-2.63	4980	2.92	3.55
0	+0.025	-0.037	0	0.061	0.059

Rear Torsion

Miles: 436/436 - 15,770 lbs			Miles: 256/954 - 19,800 lbs		
Load (lbs)	L.H. Deflec. (in.)	R.H. Deflec. (in.)	Load (lbs)	L.H. Deflec. (in.)	R.H. Deflec. (in.)
0	0	0	0	0	0
500	0.08	0.09	500	0.15	0.19
1050	0.17	0.22	1050	0.25	0.32
2330	0.30	0.40	2330	0.45	0.56
3630	0.61	0.73	3630	0.78	0.89
4980	-	-	4980	-	-
0	0.07	0.08	0	0.11	0.13

Front Vertical Deflection

Miles: 436/436 - 15,770 lbs		Miles: 256/954 - 19,800 lbs	
Added Load (lbs)	Deflec. (in.)	Added Load (lbs)	Deflec. (in.)
0	level on jacks	0	level on jacks
0	(sag)0.020	0	(sag)0.049
222	0.035	222	0.071
297	0.056	297	0.125
372	0.074	372	0.142
472	0.095	472	0.173
0	0.028	0	0.053

Rear Vertical Deflection

Miles: 436/436 - 15,770 lbs		Miles: 256/954 - 19,800 lbs	
Added Load (lbs)	Deflec. (in.)	Added Load (lbs)	Deflec. (in.)
0	level on jacks	0	level on jacks
0	(sag)0.059	0	(sag)0.083
222	0.094	222	0.123
297	0.129	297	0.168
372	0.176	372	0.219
472	0.192	472	0.269
587	0.229	587	0.333
0	0.062	0	0.093

* Trip miles/Total miles.

B. Design for Transportation Loads

1. Acceleratlons

In this study, design recommendations for transportation loads are based on measured accelerations incurred vertically, longitudinally, and laterally during transport of both single- and double-wide mobile homes. The variations in accelerations from front to rear during transportation do not remain constant. The variation depends, in part, on the road surface condition generating the vertical displacement in response to the weight and velocity of the test unit. Small surface waves on the road produce higher accelerations over the axle. Large distortions generate higher accelerations in the rear. Undulations can produce the higher acceleration at any one of the three locations depending on the wave shape, velocity, and number and period of oscillations. A sharp hole in the road will produce the higher acceleration over the axle. Road roughness also varies from run to run because the same track in each road cannot be duplicated each trip; the route is the same, the weight and velocity are the same, but the exact bump or hole that was hit the first trip may not have been hit the second. Varying accelerations also occur with respect to the location of walls, windows, doors, etc.

Since the accelerations vary at each of the three locations, in the vertical, lateral, and longitudinal directions, the differential between these accelerations is a key factor. For example, if the rear wall bends downward and generates a high acceleration because of its cantilever design, the critical stresses caused by the rear wall acceleration will not occur at the rear wall, but over the axle at the point of maximum bending where a lower acceleration may have been recorded. Similarly, the lateral acceleration, during the majority of test conditions, will be higher at the rear wall than over the axle or at the front wall due to the "overhang" behind the running gear. This is indicated by the recorded data. Since the tow tractor stabilizes the front end, the predominant lateral motion at the axles is "side-sway" and roll due to the action of the springs/shackles/tires; this is amplified by the rear overhang.

Briefly then, accelerations are affected by several items including:

- Road conditions,
- Velocity of tractor/mobile home combination,
- Weights, including furnishings and fixed equipment,
- Weight distribution,
- Joints and fabrication tolerances or variations,
- Variations in towing vehicles.

In order to derive realistic design acceleration factors from the test data, the "average peak occurrence" data reduction technique was used, and then these average accelerations were modified to allow for inherent variables. The measured accelerations and modification of these accelerations are described later in this section.

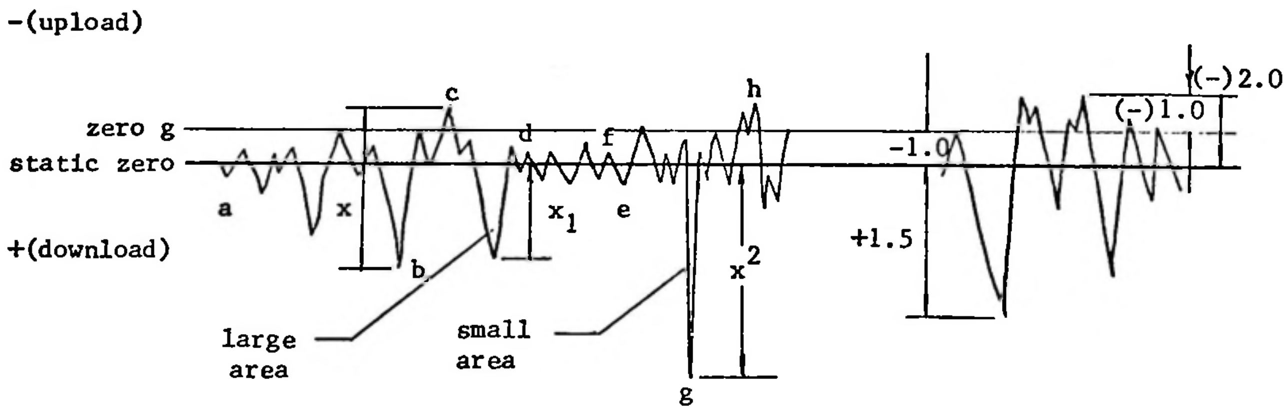
2. Test Data

The test data included in this report cover the spectrum of tests from the "new" Condition I, to the "used" (secondary move) Condition II. These data reflect the maximum stiffness factor for each unit when new, resulting in higher vertical and lower lateral accelerations. The dynamic response phenomenon occurs, in part, because the joints in the mobile home structure have not yet begun significant loosening from initial transportation. Based on data from tests on new and used test units, the greater the unit stiffness, the higher the acceleration peaks; and conversely, the "softer" and more flexible the unit becomes, the lower the acceleration peaks.

Volume 3 consists of significant raw data traces reproduced during the test program by the playback method from magnetic tape to the Visicorder. Peak accelerations were measured from these traces. Tabulated summaries of maximum and minimum peak accelerations derived from the traces precede each set of traces. The data presented are particularly significant for use in the formulation of the recommended acceleration factors (AF) for inclusion in the revision to Subpart J "Transportation" of the Federal Mobile Home Construction and Safety Standards. These recommendations are to be based, in part, on average acceleration occurrences per mile that are considered related to the damage and degradation of the mobile home structure during transportation. In addition, design factors for mobile homes must include adequate allowances for minimum production quality, excessive transportation loads and on-site loads and vibrations as well as inconsistencies in production, transportation, predicted loads, etc.

3. Data Reduction Technique

In order to determine the occurrences per mile of the various levels of accelerations (peaks) generated by the varying road conditions, a "g" level intercept count for every 1/2 g of magnitude was made using the computer and the tape recorder with accelerometer data channels. The range of accelerations checked during the intercept analysis were from 6.0 g down to 0.5 g. This data reduction technique was applied to several recorded accelerometer signals in each direction that were generated over a 3.75 mile section of typical mobile home transport road. Tables 15, 16, and 17 present the results of the peak count measurements for the vertical accelerometer located on the floor over the axles of Test Units T-1, T-2A, and T-2B, one of each mobile home type. The three traces, Figures 3, 4, and 5, illustrate the typical signal patterns measured by these three transducers. A sketch follows to elucidate the method used in measuring and interpreting the acceleration traces generated by the mobile home road tests:



where

x = peak to peak measurement;

x_1 = peak measurement (from static zero);

x_2 = high "g" factor with minimum area (or energy);

a,e are minimum download positive peaks;
b,g are maximum download positive peaks;
c,h are maximum upload negative peaks;
d,f are minimum upload negative peaks;
Area under the curve relates to energy contained in the acceleration.

Note Example: ±1.5 g measured plus 1.0 g static = 2.5 g's total positive (downward);
-1.5 g measured plus 1.0 g static = -.5 g total negative (upward)

The interpretation of "significant" peak traces is related to the degree of "damage-energy" each acceleration peak contains. Rather than the amplitude of an acceleration, the dwell time or duration of the acceleration seems to be the more significant cause of degradation in a mobile home. For example, 6-g peak acceleration that occurs in 2 msec contains practically no energy or dwell time (area under curve). However, a 3-g peak acceleration that occurs over a period of 85 msec contains significant energy, more energy than the 6-g peak. The range of 2 to 3 g's shown in Table 15, contains acceleration levels with significant area (duration of occurrence) under the curve, creating the damaging fatigue-like effect. Hence, a review of the tables containing acceleration occurrences per mile and a study of the degree of energy contained in various types of acceleration curves indicate that the higher "g" levels of 4, 5, and 6 would probably do less damage than those in the 1.5, 2.0, 2.5, and 3.0 g levels occurring per mile of travel. (See Tables 15, 16, and 17.) The 1.5 to 3-g levels occur 20 to 20,000 times as frequent as the high g's. This theory was one of the prime considerations in selecting the damaging g levels* for each axis for input into the design recommendations.

---

* Data available from SwRI.

TABLE 15. T-1 FLOOR OVER AXLE VERTICAL ACCELEROMETER PEAK COUNTS ($\overline{RC}$=1.2)

"G"s*	RUN #3		RUN #6	
	(+) ct	(-) ct	(+) ct	(-) ct
6.0 - 5.5	1		1	1
5.5 - 5.0	1		1	1
5.0 - 4.5	2		1	4
4.5 - 4.0	1		1	5
4.0 - 3.5	1	1	4	5
3.5 - 3.0	8	2	6	10
3.0 - 2.5	18	6	3	10
2.5 - 2.0	31	3	13	18
2.0 - 1.5	** 103	8	27	81
1.5 - 1.0	** 2683	43	116	295
1.0 - 0.5	33,188	120	953	6095
0.5 - 0.1	2096	1012	20,775	33,538

* Measured 0 to peak from zero static reference line which is 1-g above static.
** Maximum damage area.

NOTE: (1) These peak occurrences were measured over a 3.75 mile section of typical mobile home transport road.
(2) The raw data traces indicated the comparative energy via the area under the acceleration curve.

TABLE 16. FLOOR OVER AXLE VERTICAL ACCELEROMETER PEAK COUNTS FOR T-2A AND T-2B ($\overline{RC}$=@1.0)

"G"s*	T-2A Run #1 $\overline{RC}$=1.1 to 1.0		T-2B Run #2 $\overline{RC}$=1.0	
	(+) count	(-) count	(+) count	(-) count
6.0 - 5.5				
5.5 - 5.0				
5.0 - 4.5				
4.5 - 4.0				
4.0 - 3.5	1	1		
3.5 - 3.0	1	1		
3.0 - 2.5	5			
2.5 - 2.0	11	3		
2.0 - 1.5	** { 30	10		1
1.5 - 1.0	347	27	8	23
1.0 - 0.5	40,873	49	1156	2021
0.5 - 0.1	3797	534	29,235	28,029

* Measured 0 to peak from zero static reference line which is 1-g above static.

** Maximum damage area.

NOTE: (1) These peak occurrences were measured over a 3.75 mile section of typical mobile home transport road.

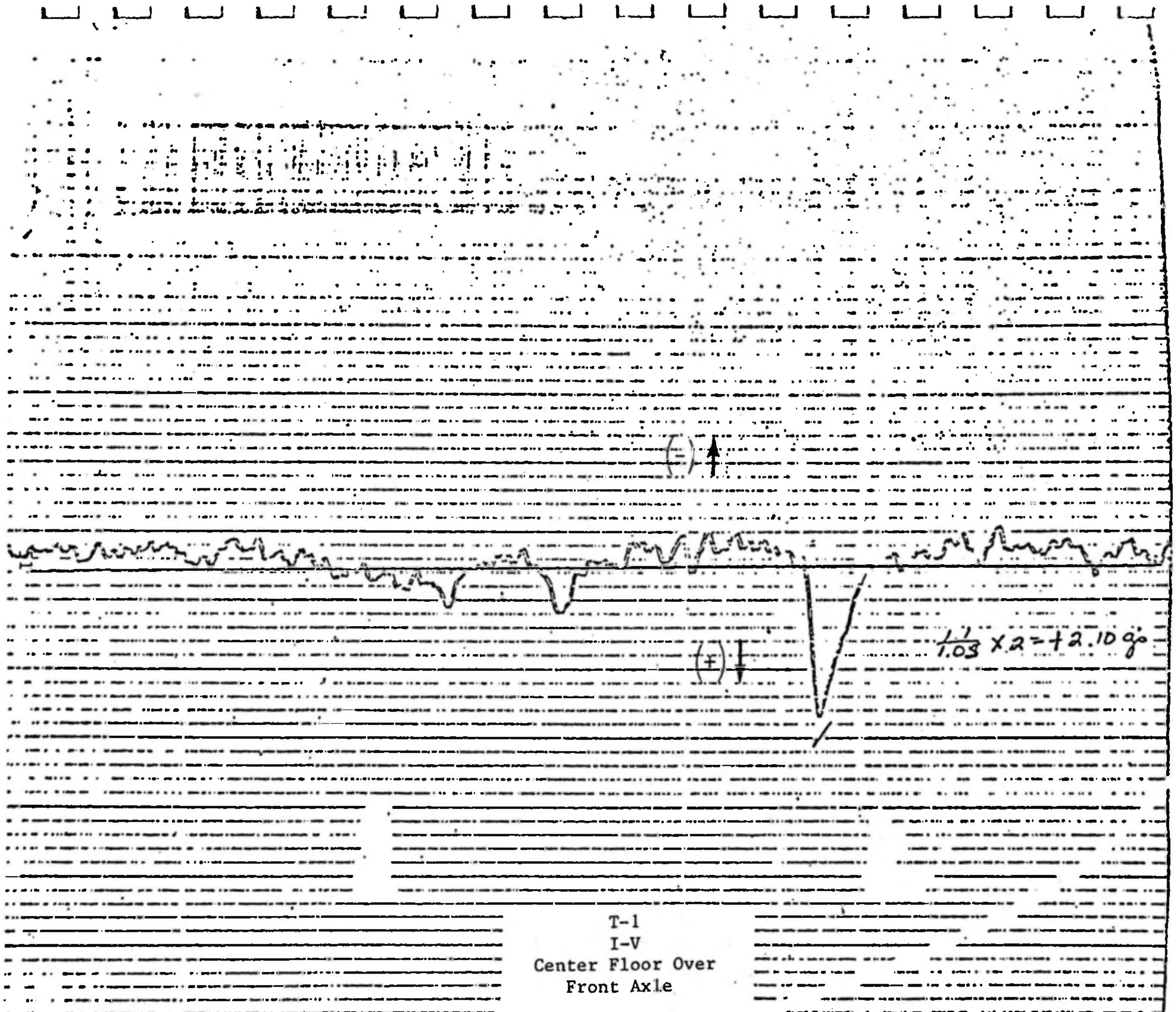
(2) The raw data traces indicate the comparative energy via the area under the acceleration curve.

TABLE 17. FLOOR OVER AXLE VERTICAL ACCELEROMETER
PEAK COUNTS FOR T-2A AND T-2B (RC=1.2)

"G"s*	T-2A Run #1		T-2B Run #2	
	(+) count	(-) count	(+) count	(-) count
6.0 - 5.5				
5.5 - 5.0				
5.0 - 4.5			1	
4.5 - 4.0	2	1	1	
4.0 - 3.5	4	3	3	1
3.5 - 3.0	7	1	3	2
3.0 - 2.5	15	5	13	3
2.5 - 2.0	47	9	42	7
2.0 - 1.5	** 131	9	101	11
1.5 - 1.0	** 3941	88	2957	109
1.0 - 0.5	49,333	341	38,416	777
0.5 - 0.1	5796	3729	21,339	28,123

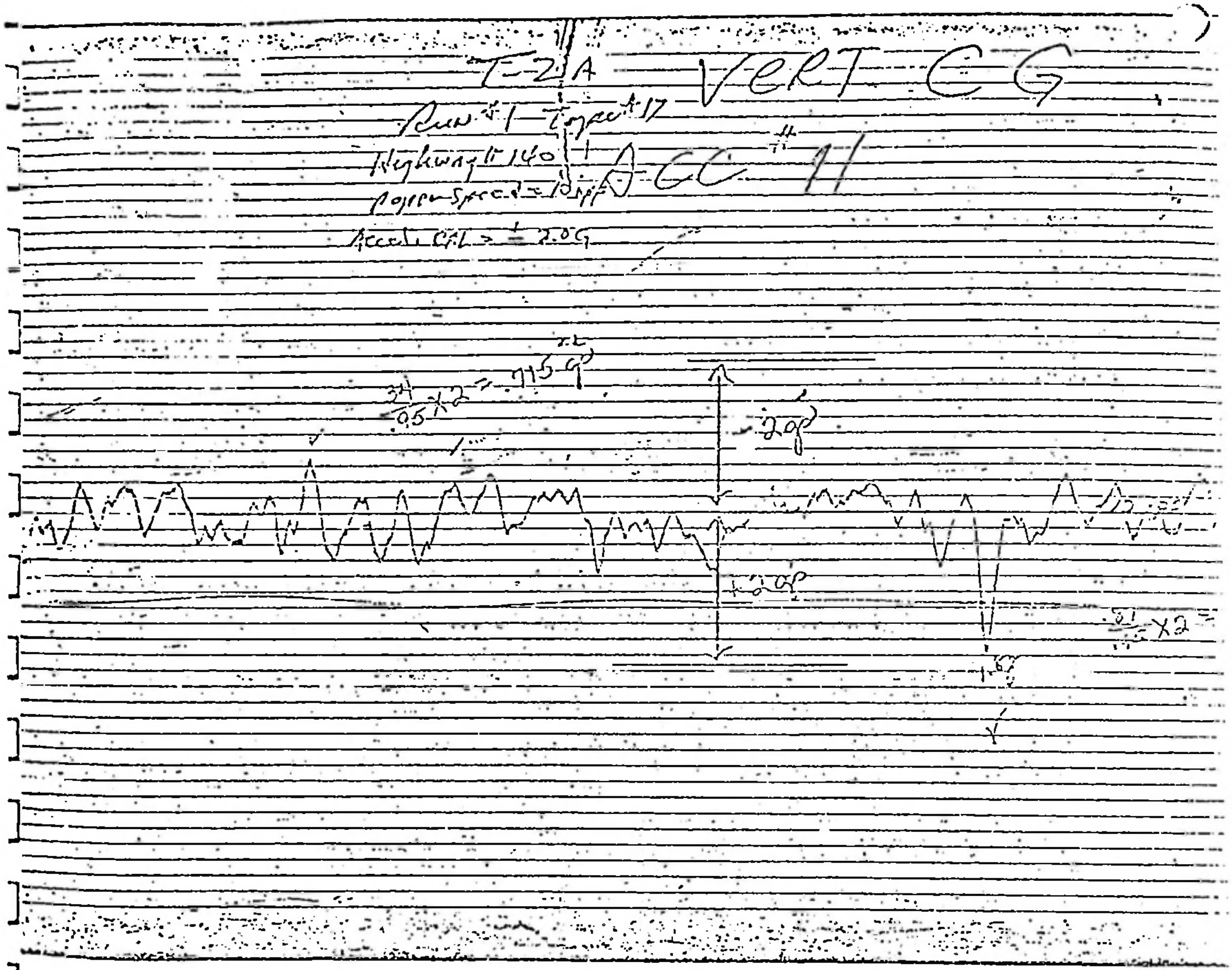
* Measured 0 to peak from zero static reference line which is 1-g above static.
** Maximum damage area.

NOTE: (1) These peak occurrences were measured over a 3.75 mile section of typical mobile home transport road.
(2) The raw data traces indicate the comparative energy via the area under the acceleration curve.



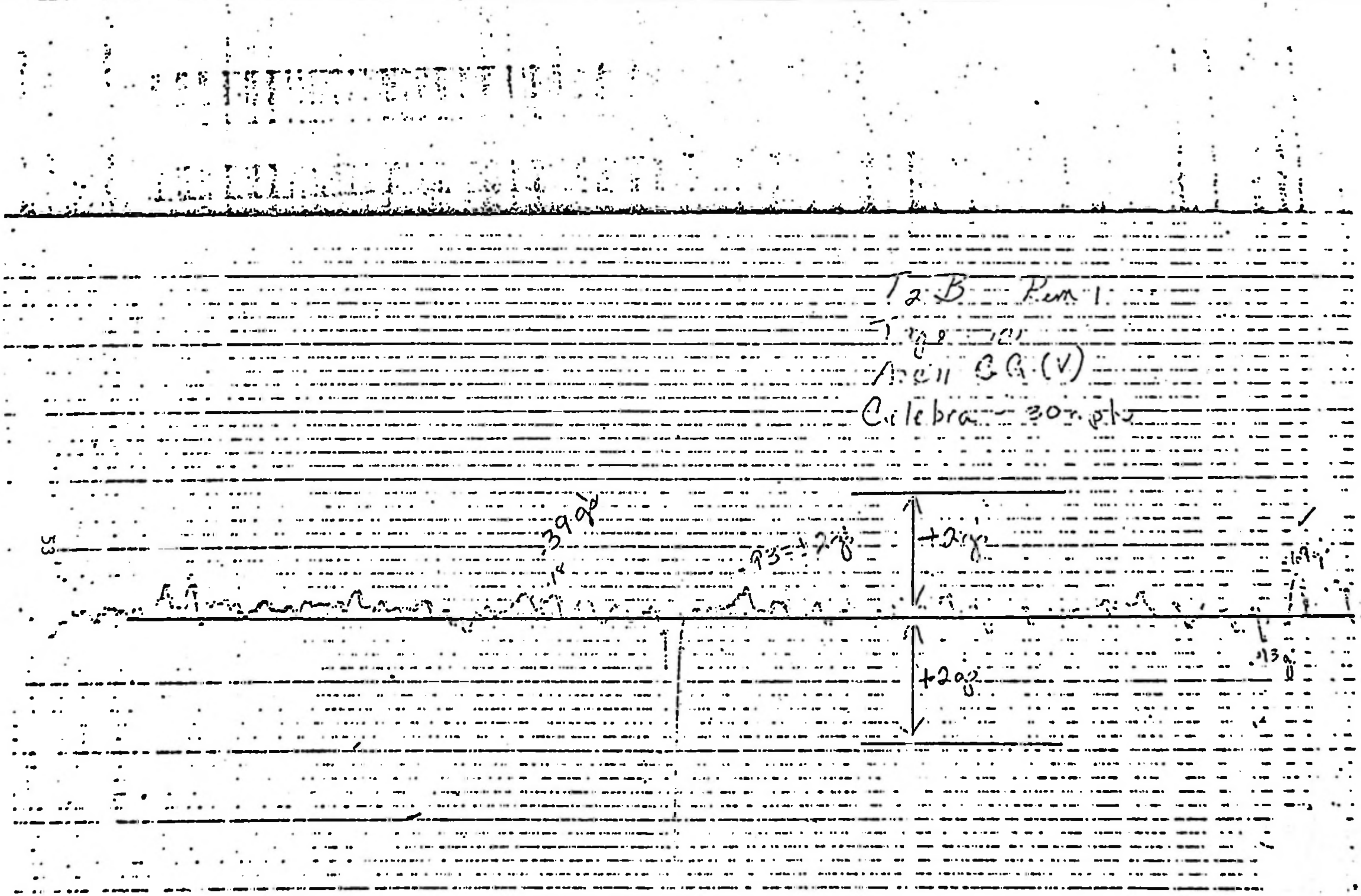
T-1
I-V
Center Floor Over
Front Axle

Figure 3.



T-2A
4-V
CG (V)

Figure 4.



T-2B
6V
CG (V)

Figure 5.

4. Measured Accelerations for Structural Box

The following are the average accelerations selected that relate to the structural box assembly.

Vertical Acceleration, g's = 2.50*

Longitudinal Acceleration, g's = 1.25

Lateral Acceleration, g's = 1.80 (at ceiling)

The selection of a single acceleration for each axis was based on a review of the accelerations generated along each of three axes in the front, over the axle, and in the rear section of the mobile home test units. Accelerations among the units, single-wides, and each half of the double-wides were then compared to determine the relationship to model variations.

(a) Rationale for Selection of Single Acceleration for Each Axis Along the Length of the Mobile Home

- Vertical--Comparison of vertical accelerations for the three mobile home configurations appears in Table 18, which presents data from a selected section of road (Culebra Road) with an $\overline{RC}$ of 1.0 to 1.1, over which each mobile home test unit was towed. These are not maximum accelerations.

The data in Table 18 indicate that the acceleration peaks generated by this stretch of road have a degree of commonality. The accelerations in general varied depending on the type of road condition causing the movement (accelerations over the axle were usually the highest); however, because of the minimal variation evidenced between the front, middle, and rear sections of the mobile home, one vertical acceleration was chosen for the entire structural box.

- Longitudinal--The following longitudinal accelerometer values were generated during sudden stops and starts of the tow tractor and

* Includes 1-g static (dead weight) load; negative (upward) loading equals 0.5 g's, usually not critical.

TABLE 18. VERTICAL ACCELERATIONS
(Acceleration Peaks)*
Difference Between Double-Wide and Single-Wide and Variations Along Length

LOCATION	Single-Wides				Wet Half--Double-Wides				Dry Half--Double-Wides			
	T-1		T-3		T-2A		T-4A		T-2B		T-4B	
	-	+	-	+	-	+	-	+	-	+	-	+
Rear	0.77	2.05	0.95	2.27	0.60	1.71	0.56	1.65	0.74	1.50	0.41	1.66
Middle	0.89	1.92	1.10	2.33	0.52	1.87	0.86	1.72	0.58	1.63	0.96	1.87
Front	0.96	1.67	0.86	1.95	0.83	1.52	0.86	1.59	0.90	1.50	0.70	1.77

* Refer to Appendix A for tabulated data and traces.

mobile home Test Unit T-1. Two accelerometers in the longitudinal direction were mounted along the centerline of the unit on the floor at the front wall. Stops and starts were made in both the forward and rearward directions denoted by F and R, respectively. Also, stops from speeds of 5 and 20 mph were recorded as indicated on the traces (See Volume 3). Table 19 summarizes the longitudinal accelerations experienced under each of these conditions

TABLE 19. LONGITUDINAL ACCELERATION PEAKS FOR TEST UNIT T-1

Direction	Velocity (mph)	Acceleration (g's)*	
		−	+
Forward	start/stop	0.4	0.4
		0.4	0.36
		0.46	0.4
Rearward	start/stop	0.3	0.4
		0.28	0.4
Forward	5	0.48	-
		0.56	-
Rearward	5	-	0.4
		-	0.3
Forward	20	0.54	-
		0.54	-

* Positive longitudinal acceleration is toward the rear of the mobile home.

These longitudinal accelerations are consistent along the length of the mobile home because of the inherent stiffness of a unit in this direction. Therefore, a single longitudinal acceleration factor is applicable throughout the length of the unit.

Note that the acceleration values of Table 19 are low compared to what would be expected under normal transport conditions. These values are low because Test Unit T-1 was heavy and the SwRI tow tractor was considered light. Greater accelerations are generated by combinations of lighter mobile homes and heavier tractors. Hence, the magnitude of accelerations is dependent upon the relative weights of the mobile home and tractor; however, since the particular tractor/mobile home combination to be used during transport is not known or controlled, a single longitudinal acceleration factor was considered for all units. The final design acceleration factor (discussed later in this section) reflects a conservative situation of a heavy tractor unit towing a light mobile home.

Also note that forward deceleration values from 5 and 20 mph differ little. This indicates that even at velocities as low as 5 mph, maximum decelerations occur.

- Lateral--The measured lateral accelerations were generally greater at the ceiling than the floor because of the greater radius of rotation at higher points. The values were assumed to vary linearly between the two vertical extremes of the structural box. This is a reasonable assumption since (1) the angular acceleration should be fairly constant along a vertical line at a point in time and (2) the tangential (or lateral) acceleration is the rate of change of the tangential velocity which varies linearly with the radius of rotation. Because of this vertical variation of the lateral accelerations, the recommended lateral acceleration factor of the structural box is actually a linear function which increases with height.

Although the lateral accelerations at the ceiling do vary somewhat from front to rear, a definite trend does seem to exist, as noted in Table 20 which summarizes the accelerations generated by the same section of road from which the vertical accelerations were selected. The trend indicates that the middle or over-the-axle lateral ceiling accelerometer readings are within the same general magnitude as the front and rear. As a result of a review covering several sections of road from $\overline{RC}$ = 1.0 to $\overline{RC}$ = 1.5, similar

TABLE 20. LATERAL ACCELERATIONS (at ceiling)
(Acceleration Peaks)*
Difference Between Double-Wide and Single-Wide and Variations Along Length

LOCATION	Single-Wides				Wet Half--Double-Wides				Dry Half--Double-Wides			
	T-1		T-3		T-2A		T-4A		T-2B		T-4B	
	-	+	-	+	-	+	-	+	-	+	-	+
Rear	0.95	0.47	0.82	0.35	1.35	0.67	0.82	0.49	1.22	0.51	1.07	0.41
Middle	0.62	0.53	0.56	0.42	0.87	0.55	0.37	0.45	0.33	0.49	0.89	0.47
Front	0.89	0.31	0.70	0.52	0.69	0.72	0.66	0.32	0.87	0.61	0.94	0.66

* Refer to Appendix A for tabulated data and traces.

results were indicated that would justify the use of a single lateral acceleration factor function for the entire length of the mobile home.

(b) <u>Rationale for Selection of Same Accelerations or Acceleration Function for Both Single- and Double-Wide Units</u>

A prime consideration in the selection of "g's" was the condition of the test mobile home following the road test program. As indicated by the data, T-1 performed adequately as did T-3 (although degradation did occur), while T-2A and T-4A and B did not withstand the test series within acceptable margins. The difference in degradation is not because input accelerations differed substantially among the units, but, rather, because the response to the accelerations differed, particularly in the lateral direction. The double-wides logically offer less resistance to vertical, lateral, and longitudinal acceleration than single-wides, which are inherently more stiff. If both single- and double-wides are designed to the same stiffness requirements (vertically, longitudinally, and <u>laterally</u>) and they both achieve the minimum required $\overline{EI}$ and $\overline{J}$ recommended in Subpart J, then they both should perform the same with respect to degradation. Since acceleration factor design requirements are related to stiffness, the same accelerations for single- and double-wide units were selected for design purposes. (Presently, only the vertical acceleration performance criteria are required by the Federal Standard.) Since the double-wides degraded at a rapid rate, then they should be assembled to generate a higher $\overline{EI}$ and $\overline{J}$, and if necessary, use temporary stiffeners to supplement stiffness during transportation.

5. <u>Design for Joints and Attachments</u>

Loosening of joints used in assembling the structure of the mobile home is the largest contributor to the degradation of mobile homes. The structural components of the unit do not fail; rather, the joints and fasteners simply loosen to the point that the structural box then loses a large percentage of its original stiffness and integrity. The stud, header or plate do not fail, but the attachment of these items to other items works loose and permits large deflections resulting in high stresses and opening up of seams/joints.

In order to design for increased stiffness and margins of safety in the joints and attachments, a "joint design factor" of 1.5 times the loads and moments in the joint under consideration are recommended. The application of this factor is made by first determining the loads in the joint, multiplying these loads by the 1.5 factor, and then applying these loads to the detailed analysis for the joint stresses and fasteners. The 1.5 factor is introduced to increase the stiffness or integrity of the joints, which in turn, will increase the integrity of the mobile home. The 1.5 factor is also used to offset any inconsistencies in the joints during fabrication and assembly. This joint design factor is based upon road test measurements indicating a significant looseness of the joints, thereby requiring added integrity in the form of the 1.5 factor. Tests on the mobile home units also revealed a 5- to 10-Hz frequency throughout the mobile home structure causing the joints to degrade. The designer should also consider the structure, chassis, hitch/coupler, components, and appliances as subject to a vibration of: 0.3-g amplitude, 8-Hz frequency, and 540,000 cycles (total application equivalent to 825 miles).

6. Measured Accelerations for Hitch Coupler and A-frame

In addition to the accelerations for the structural box assembly, the following accelerations were selected from data applying to the hitch coupler and A-frame:

Vertical Acceleration, g's = 2.50*

Longitudinal Acceleration, g's = 1.80

Lateral Acceleration, g's = 1.10

These accelerations represent the combined inputs from the mobile home running gear and the tow tractor.† Table 21 presents data used to support the selection of the aforementioned accelerations. The tabulated values are average peak accelerations in the vertical, lateral, and longitudinal directions experienced at the front wall of a mobile home which represent accelerations virtually identical to those at the A-frame and hitch coupler. These acceleration values are typical for both single- and double-wide units.

TABLE 21. AVERAGES OF T-1's FRONT ACCELEROMETER SIGNAL PEAKS (g's)*

	VERTICAL	LATERAL	LONGITUDINAL
POSITIVE	2.40	1.10	2.1 (0.5)†
NEGATIVE	1.73	1.03	1.4 (0.5)†

* Refer to Volume 3 for tabulated data and traces.
† Minimum g's with lightweight tow tractor.

The longitudinal minimum acceleration values in the parentheses were produced during normal test runs with the SwRI light tractor (about 8950 lb) compared to heavy diesel equipment weighing as much as 18,000 lb for use as a tow unit generating the higher g's. The acceleration peaks in the longitudinal direction reflect sudden starts,

---

* Includes 1-g static load (dead weight); negative (upward) loading not critical.
† See Modification 2, Task IV.

and stops, the severity of which depend greatly upon the size, weight, and power of the tow tractor and the effectiveness of the brake system. Thus, in determining the longitudinal acceleration factor, the effect of heavy tractors was given more consideration since the majority of mobile homes are towed by these heavy rigs.

7. Measured Accelerations for Running Gear

The following are the accelerations selected from data applying to the running gear and its points of attachment to the mobile home chassis:

Vertical Acceleration, g's = 2.80*

Longitudinal Acceleration, g's = 1.25

Lateral Acceleration, g's = 1.80

As far as the mobile home manufacturer is concerned, these acceleration factors apply only to the attachment of the spring hangers and other connection points between frame and running gear, such as equalizer brackets and shackle brackets.

The recommended lateral and longitudinal acceleration factors for the running gear assembly are equal to those of the frame and structure of the mobile home. The lateral accelerations are the same because there is minimal damping in the lateral direction; the longitudinal accelerations because of the rigid attachment between the running gear, chassis, floor, and box structure. However, the determination of the vertical acceleration was based on the axle accelerometer that measured vertical accelerations with peaks averaging those presented in Table 22.

---

* Includes 1-g static load (dead weight); negative (upward) loading not critical.

TABLE 22. AXLE VERTICAL ACCELERATION PEAK AVERAGES (g's)*

MOBILE HOME	POSITIVE	NEGATIVE
T-1	4.22	4.76
T-2B	2.3	1.9

* Refer to Volume 3 for tabulated data and traces.

Higher g's peak were measured on the axle along with the frequency of accelerations, but these higher g values cannot be considered because of the action of the spring system; therefore, only frequency measurements were taken from these traces of vertical accelerations.

The axle (running gear) design is factored by the axle manufacturer for normal road dynamics using the spring as the absorbing media as well as acting as the damper between the road and box structure. The axle manufacturer will certify his axle, spring, wheel, shackle, and hanger assembly to the designated static weight rating without any reference to the dynamic capabilities. The running gear will experience higher vertical accelerations than the box structure, and the interface spring will damp the inputs into the box structure resulting in lower inputs for the structure. The running gear on most mobile homes is classed as "limited life" which interprets to mean up to 2000 miles. However, concern is expressed for a set of limited life running gear that is delivered 800 miles to the first setup site where it is static for 2 or 3 years and then put back on the road in this condition for another 700 miles with rusty/sticking components.

8. <u>Acceleration Factors: Modification of Accelerations for Structural Box, Hitch Coupler and A-frame and the Running Gear</u>

The next analysis involved the modification of the aforementioned measured accelerations to reflect the nominal conditions applicable to the <u>average</u> transporting of a mobile home. SwRI believes the actual velocity generated by most transporters, the handling of the mobile homes, the road conditions, and the usual setup and takedown procedures vary significantly, and, frequently, may be much more severe than the conditions of the SwRI testing. The selection of the accelerations from the predictive analysis and tow test data covered controlled conditions at 45 mph and nominal weight. Therefore, in order to compensate for the potential difference between the controlled test conditions and those of actual operating modes, the test accelerations were increased by a factor of 1.45. The 1.45 factor was developed by application of the following ratio formulas to the critical rear section of the test units:

$$\frac{G_{\overline{RC}}\ (\text{norm})}{G_{\overline{RC}}\ (\text{test})} = \left(\frac{\left(V_{\text{norm}}\right)^{x}}{\left(V_{\text{test}}\right)^{x}}\right)\left(\frac{\overline{RC}\ (\text{norm})}{\overline{RC}\ (\text{test})}\right)$$

where,

V = velocity (45 mph for test and 55 mph for normal highway speeds);

x = 0.734 (Task III, Volume II);

$\overline{RC}$ (test) = 1.2. This is the RC factor of most SwRI test roads;

$\overline{RC}$ (norm) = 1.5. This is the RC factor to apply to many "back roads" over which mobile homes are being transported.

Therefore,

$$\frac{G_{1.5}}{G_{1.2}} = \left(\frac{(55)^{0.734}}{(45)^{0.734}}\right)\left(\frac{1.5}{1.2}\right) = 1.45$$

(Refer to Task III, Volume II.)

This ratio factor is considered realistic since correlation was established in this area between the predictive analysis and the test program. Moreover, it is a significant indicator of the contribution of speed and road conditions in the degradation cycle of mobile homes during the transportation mode.

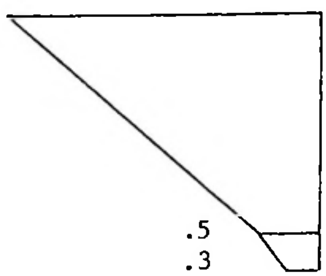
Using this modification factor of 1.45 produces the acceleration factors (AF) listed on the following page. Theses AF's are recommended to be incorporated in Subpart J "Transportation" of the Federal Mobile Home Construction and Safety Standards. See Task IV for recommended revisions to the existing standard. Considerable work has been accomplished on the correlation of data supporting these recommendations. Refer to the predictive analysis, test data, and correlative analysis. (Volumes 1 through 4.)

STRUCTURAL BOX

Axis	Measured Accelerations	Factor	Recommended AF
Vertical	2.50	1.45	3.6*
Longitudinal	1.25	1.45	1.8
Lateral	1.80	1.45	2.6 (roof) .5 (floor/frame interface) .3 (frame/running gear interface)

* Includes 1-g static load (dead weight).

During the application of the AF's, it must be kept in mind that because of impact loads, the NFPA material design allowables can be increased by a factor of 2.0. Also, the lateral load is to be applied as uniformly distributed along the side of the mobile home. However, because of the vertically increasing acceleration, the lateral acceleration factor shall be as diagrammed on the following page.



The designer is to consider the AF's noted above as acting independently in order to simplify the analysis and eliminate the use of combined loading requirements.

HITCH COUPLER AND A-FRAME

Axis	Measured Accelerations	Factor	Recommended AF
Vertical	2.50	1.45	3.6*
Longitudinal	1.80	1.45	2.6
Lateral	1.10	1.45	1.6

The hitch coupler and A-frame AF's differ slightly than those of the structural box, especially in the longitudinal axis, because of the concentrated input point as well as the panic stops and sudden starts. These concentrated inputs are damped as they progress aft along the chassis and structural box.

* Includes 1-g static load (dead weight).

RUNNING GEAR

Axis	Measured Accelerations	Factor	Recommended AF
Vertical	2.80	1.45	4.0*
Longitudinal	1.25	1.45	1.8
Lateral	1.80	1.45	2.6

The above acceleration factors were developed for the running gear because of the detailed test data that was assembled. However, the designer normally would not use these data for purposes other than the attachment of the running gear to the chassis of I-beams. The manufacturer of the running gear has his own design criteria for certification of the axle assemblies. The designer of the mobile home simply uses the maximum weight of the mobile home and subtracts the 12 percent applicable to the tongue and divides the results by the axle rating to determine the number of certified axles required. Therefore, these AF's have minimum applicability for the mobile home designer.

Because the loads induced by these acceleration factors at the running gear are transmitted to the mobile home frame through the spring hangers and other attachment hardware, it is recommended that special attention be given this area by the designer. In particular he should ensure that the weldment of the hangers is capable of withstanding these forces. Therefore the recommended revisions of Subpart J include the requirement of 100% weld between hanger and frame.

---

*Includes 1-g static load (dead weight).

GYPSUM BOARD INTERIOR
MOBILE HOME

TRANSPORTATION TESTING OF A GYPSUM BOARD

INTERIOR MOBILE HOME

Prepared By

C.R. Ursell, II

W.W. Raine

ABSTRACT

The research contained herein was conducted for HUD, Office of Policy Development and Research, to compare the effects of transportation on gypsum board interior mobile homes to plywood interior units with regard to structural durability performance. This study is patterned after previous research with plywood interior mobile homes, and involves dynamic and stationary testing of a gypsum board interior unit as well as finite element modeling and dynamic analysis.

Dynamic evaluation included collecting data from several instruments about the mobile home while it was under tow and later analyzing the data. Stationary tests were the measurements of the apparent torsional and bending stiffnesses. Finite element modeling simulated severe static and dynamic conditions for examination of the stresses in elements and displacements of points. Dynamic analysis included estimation of the remaining useful life of the unit at various stages in the testing.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

I. OBJECTIVES AND INTRODUCTION

Southwest Research Institute (SwRI) conducted an investigation of transportation effects on a mobile home containing interior gypsum board paneling in comparison to the units with interior plywood paneling from a previous study. Gypboard is an attractive alternative to plywood. It provides a degree of sound and thermal insulation not available in other construction materials, and more importantly, gypboard is more fire resistant than plywood. On the other hand, gypsum board is relatively heavy, inflexible, brittle, moisture absorbing, and less able to carry concentrated point loading as well as other wall and ceiling materials.

From previous testing and analysis of mobile homes in transit, SwRI determined that twisting about the longitudinal axis of the box structure was the major contributor to the deterioration of a unit's integrity. Torsion and vertical bending of units produced severe membrane stresses in floor, ceiling, and wall components. The methods of fastening or attaching components were found to be critical and determined the overall performance of a material.

The objective of this study, as stated by HUD, was:

> "...to evaluate whether a mobile home, constructed of gypsum walls and ceiling, is capable of resisting shock and vibration forces caused by highway transportation and on-site installation during a minimum of fifteen years planned useful life; and to provide construction and safety standards."

To accomplish this task, SwRI acquired a single-wide unit for in-transit and stationary testing. The unit was instrumented to measure and record dynamic responses throughout 1500 miles of towing. Stiffness measurements and system performance tests were also conducted periodically during the towing program. Both the dynamic and stiffness data as well as periodic visual inspections were used to determine the progressive effects of transportation degradation.

Finally, an analytical evaluation was performed on the test unit for comparison with a previous evaluation of plywood interior units. This included dynamic analysis, remaining useful life predictions, and computer simulation of dynamic and stationary load conditions (finite element analysis). These analyses were correlated with actual measurements and observations.

II. TEST PROGRAM

A. Scope

The field test program consisted of in-transit and stationary testing. The two are described further as follows*:

(1) In-Transit Testing -- data retrieval and recording of transportation-induced vibrations, forces, stresses, and deflections during 1500 miles of towing;

(2) Stationary Testing -- measurement of apparent torsional and vertical bending stiffnesses of the unit, visual inspections and system integrity checks periodically during the 1500-mile test span, and measurement of natural frequency.

The test unit was given preliminary testing at the factory and towed to San Antonio by SwRI personnel. After arrival, further stationary tests were performed, and the unit was instrumented to retrieve and record the dynamic data. Dynamic and stationary testing continued throughout the test period.

B. Test Specimen

The test unit designated T-7A, is a single-wide, 14 x 66-ft box with 3 bedrooms, 1-1/2 bathrooms, a kitchen over the axles, and 12-in. I-beams. It weighed about 18,800 lb at the factory. Wall interiors are gypsum boards glued and stapled to 2 x 4 exterior studs on 16-in. centers and 1 x 4 top and bottom plates. (See Figure 1.) The ceiling, also gypsum, is stapled to the roof siderails and adhesively foamed to the roof rafters. A typical cross-section of the mobile home is presented in Figure 1.

C. Dynamic Testing

In order to determine the actual stresses, deflections, accelerations, and forces imposed on the unit during transport, SwRI equipped T-7A with measurement and recording devices. Figure 2 indicates the locations of

---

*The scope of this work is essentially the same as that of previous work with plywood interior units.

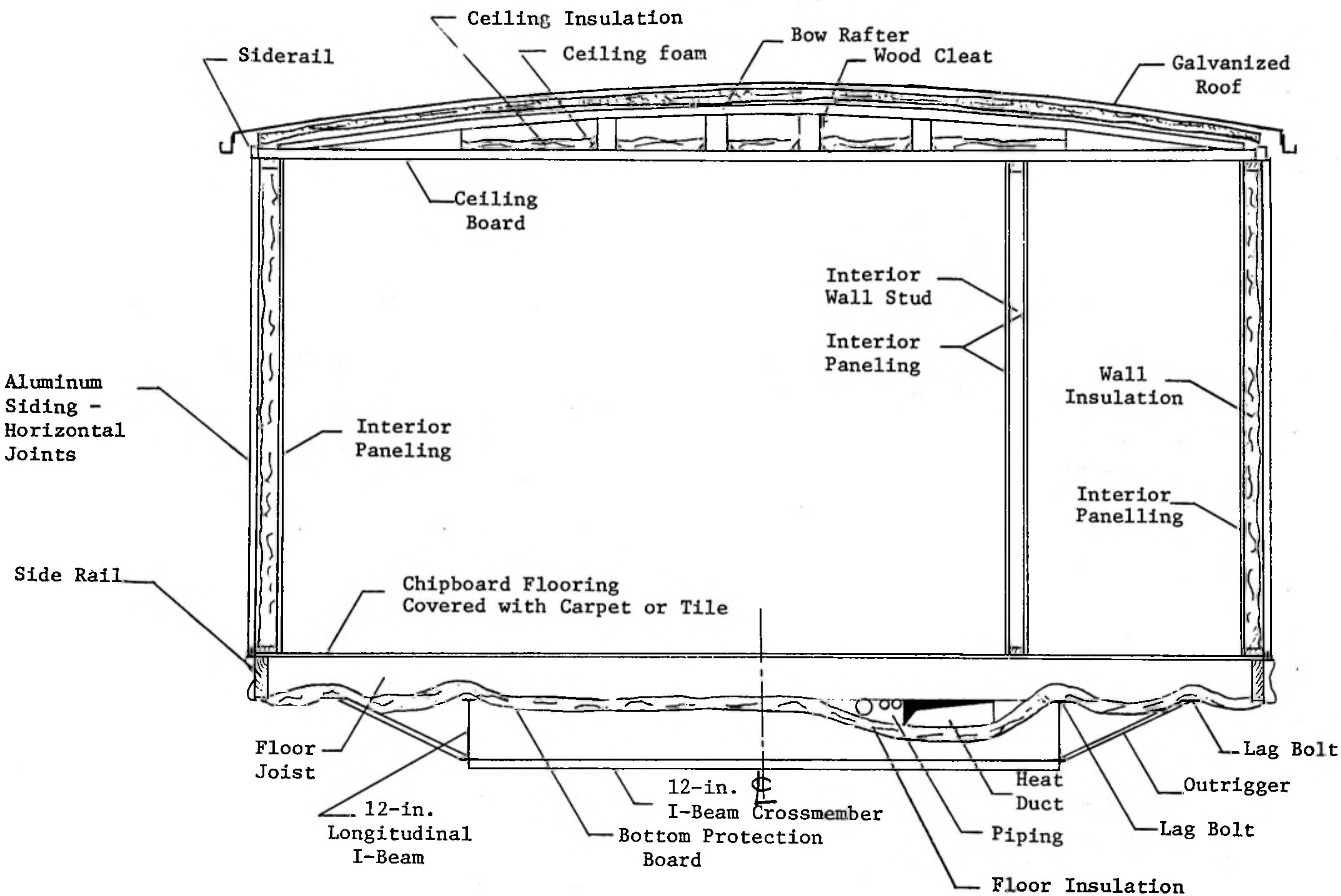


FIGURE 1. TYPICAL T-7A CROSS SECTION

Accelerometer Code

1st Letter	2nd Letter	3rd Letter
U-Upper L-Lower	R-Right L-Left	R-Rear F-Front

V-Vertical
La-Lateral
Lo-Longitudinal

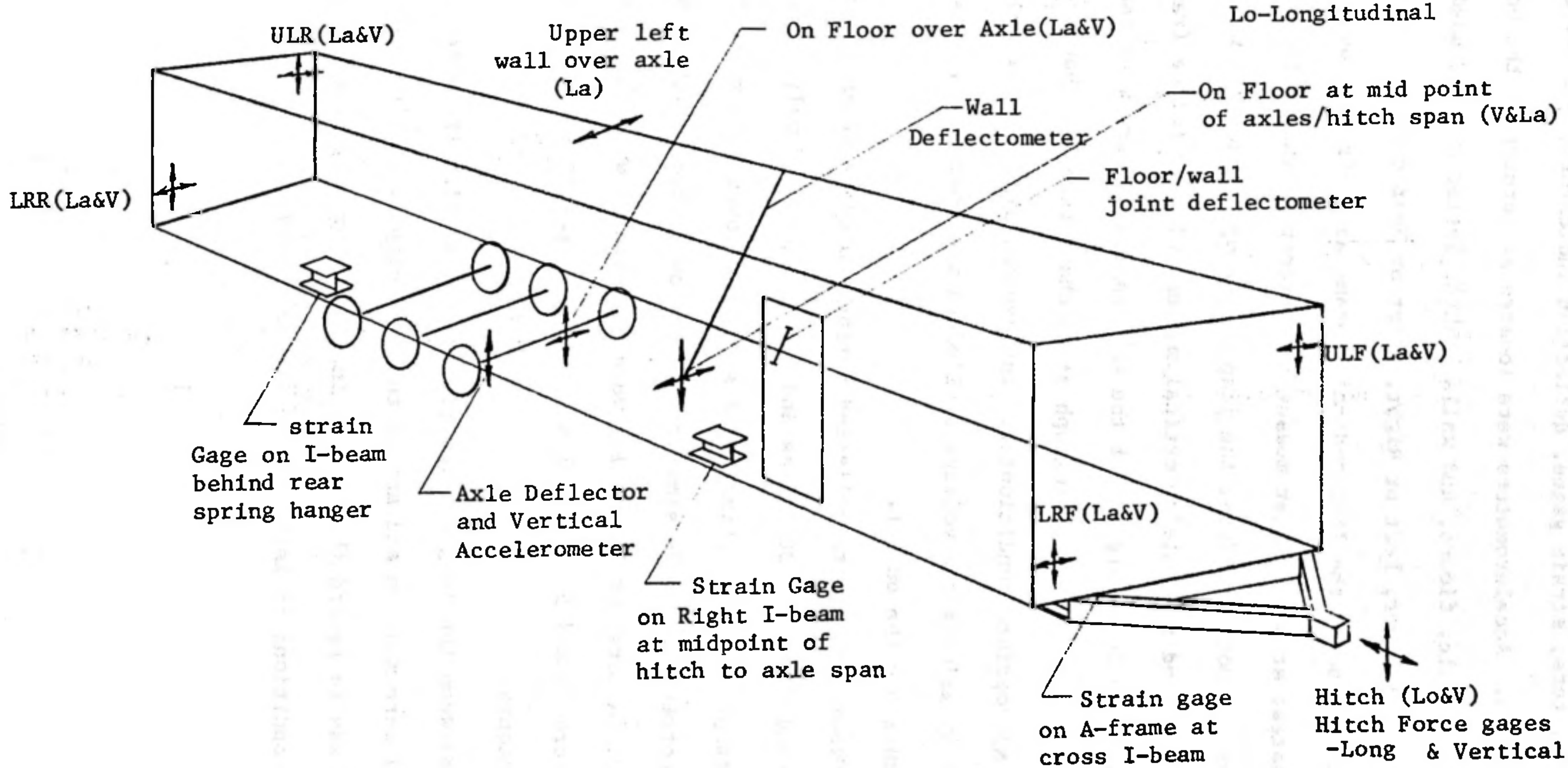


FIGURE 2 ACCELEROMETER, STRAIN GAGE, AND DEFLECTOR LOCATIONS

accelerometers, strain gages, deflection indicators, and force transducers. Accelerometers were located at corners of the box structure and on the axle, floors, and walls. Three letter code is used to specify the Upper or Lower, Left or Right, Front or Rear corners. Strain gages were installed on the longitudinal I-beams and A-frame drawbar at points of greatest strain. Other measurements recorded the deflections at the side wall/floor interface, the lean of the upper sidewall with respect to the floor, and the axle's vertical motion relative to the frame.

The low level signals of the various transducers were recorded on tape and on a light beam oscillograph strip chart recorder (Honeywell Visicorder) after appropriate conditioning. The typical signal conditioner, shown in Figure 3, adjusts the voltage applied to the transducer, balances the bridge, and amplifies the output.

Dynamic data were collected during two types of excursions - (1) daylong test runs of 200 to 300 miles and (2) along short, well defined routes. The long trips simulated primary and secondary moves by a typical owner or transporter over roads similar to those over which a mobile home is normally routed. A total of 1538 miles were accumulated over the routes shown in Figures 4 and 5 in addition to the delivery trip from manufacturer to San Antonio.

Between the long transports, the short trips (referred to as "Institute runs") were made on and around the SwRI campus. The purpose of the "Institute runs" was to record the changes in transducer outputs occurring over repeatable road conditions at intervals in the test program.

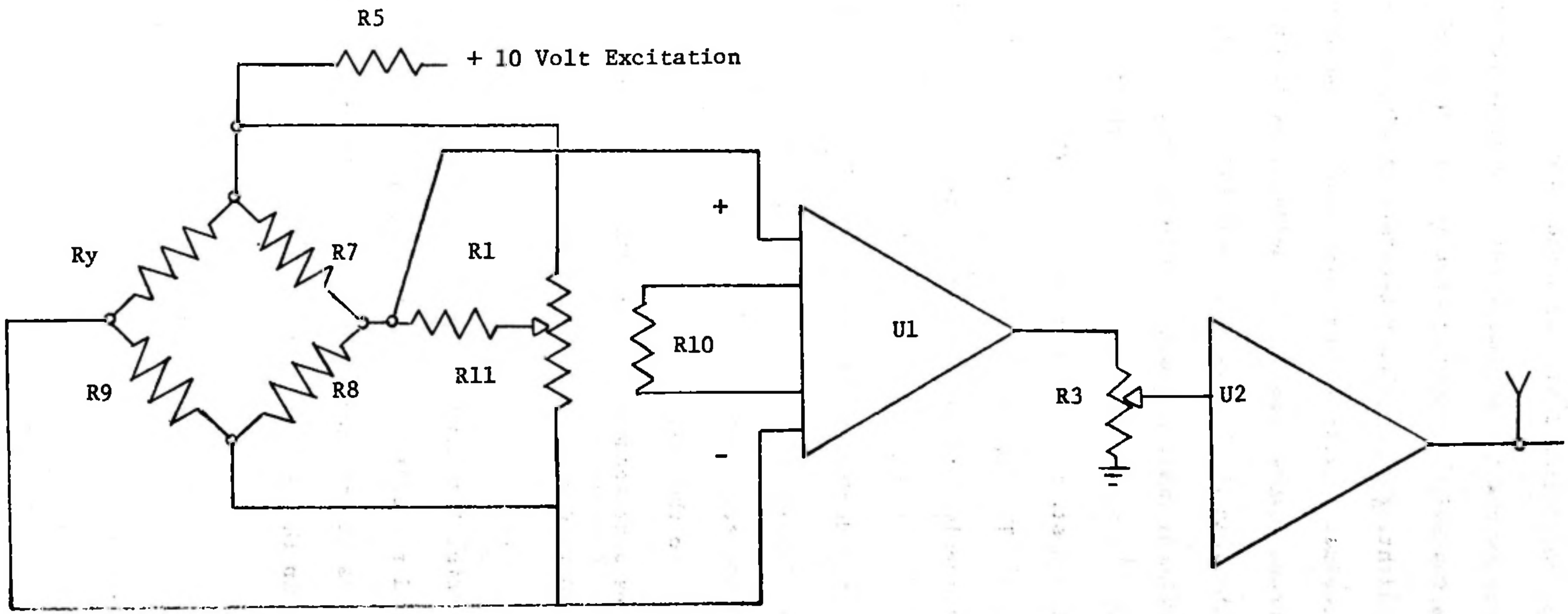


FIGURE 3. SIGNAL CONDITIONER

ROUTE NO. 4

This route is referred to as the "Hill Country Run." The sections from Bandera to Kerrville, Fredericksburg and Marble Falls are in the rough hill country with inclines and downgrades up to 8 percent. All of the roads are in the hills and are two-lane rough roads with minimum shoulders. SH16 from IH410 to Bandera is a four-lane expressway. The SH281 from Marble Falls to FM 1604 is a two-lane smooth road with grades up to 4 percent. Highway 281 is heavily travelled by mobile homes, travel and tractor trailers, trucks, and passenger vehicles.

SH16 & SH71:

Rough, two lane with min. shoulders, narrow, undulations, sharp turns, high crown road.
Grades: 0 - 8% ±

SH281:

Medium rough two & four lane with shoulders.
Grades: 0 - 4% ±

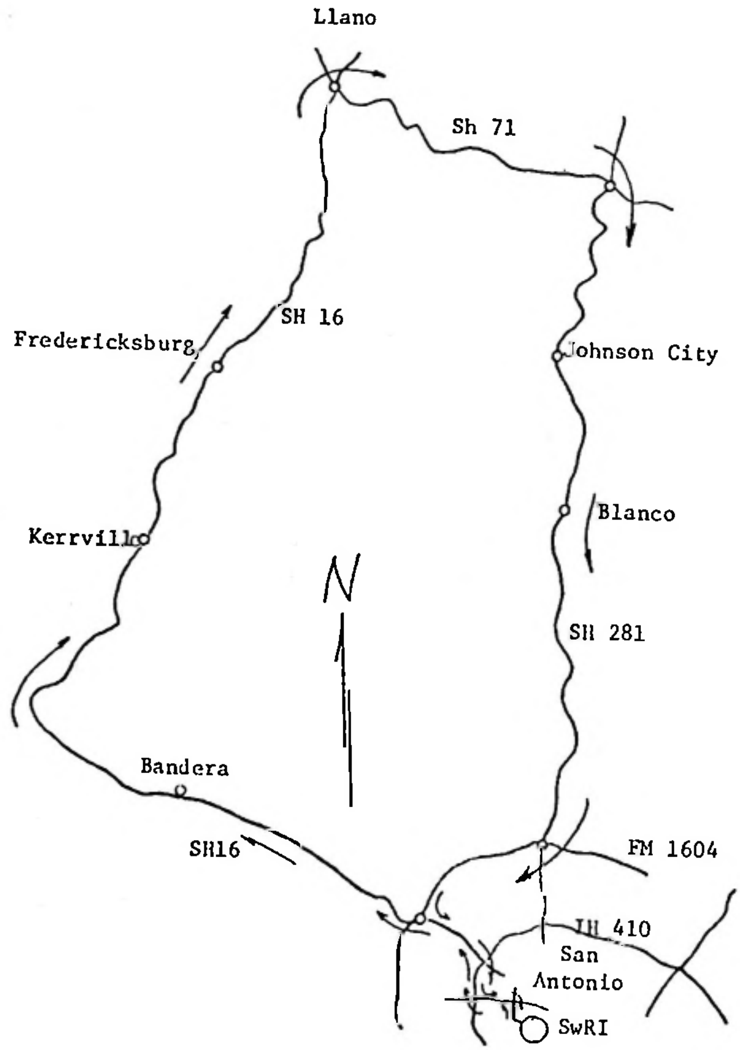


FIGURE 4. ROUTE NO. 4

ROUTE NO. 5

This route provided a mixture of road surface conditions. Roads FM 1604 and SH16 were relatively smooth compared to the rough FM 97 and FM 140. With other mobile homes, tire blowouts and spring and hanger failures occurred in the rough sections of this route. Truck and tractor trailer are heavy, forcing use of the shoulder occasionally.

FM 140: Extremely rough, two lane, undulations, mini shoulders
SH16: Smooth
FM 97: Very rough, narrow two lane, high crown, mini shoulders
SH57: Rough two lane with undulations and mini shoulders
FM 1604: Two lane with shoulders, some undulations and min. grades
Grades: 0 - 4% ±

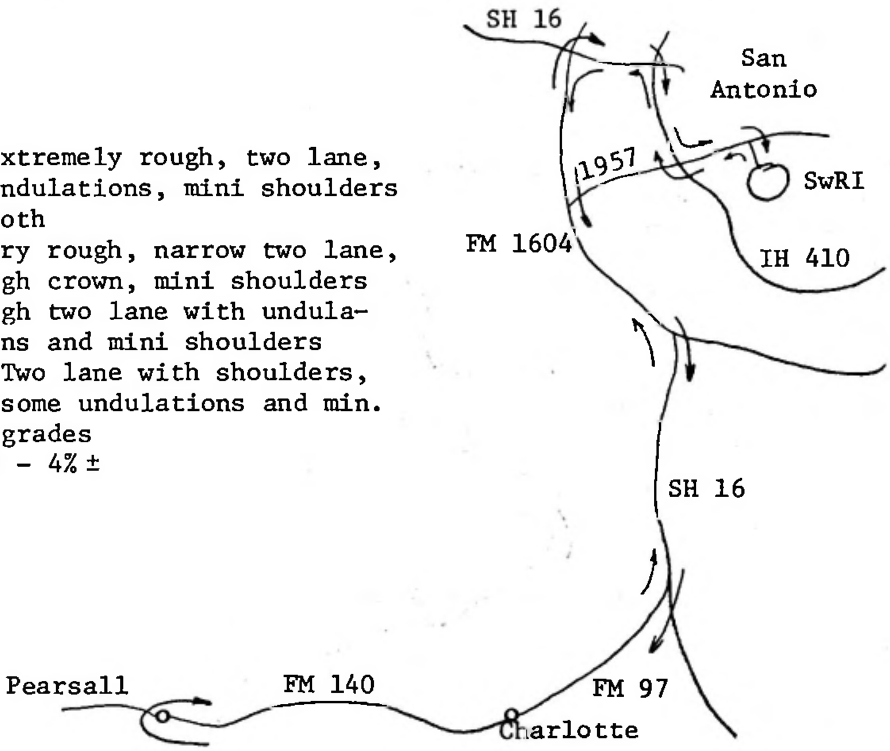


FIGURE 5. ROUTE NO. 5

Four particular road events were recorded, each with a slightly different road condition factor, $(\overline{RC})$*, or average roughness.

- Institute dips - a set of undulating bumps along the entranceway of SwRI ($\overline{RC}$ = 1.3);
- Callaghan "S" curve - a double reversing curve on Callaghan Road, a road bordering SwRI ($\overline{RC}$ = 1.4);
- 90-deg corner - a 15-mph right turn from Callaghan onto W. Commerce, another bordering road ($\overline{RC}$ = 1.2);
- Library road - a fairly smooth stretch of pavement in front of the SwRI Library ($\overline{RC}$ = 1.1).

The data collected over these roads were analyzed to show the effects of increased mileage on the dynamic response of the test unit.

D. Stationary Testing

In addition to measuring the natural frequency, SwRI measured the stiffness of the test unit and the integrity of the on-board utility systems at regular intervals. Two stiffness tests were performed, the Vertical Bending and Torsional Stiffness Tests. (Their procedures are outlined in Vol 5.) These tests were performed at the factory preceding the unit's first mile and following every long transport run. From these tests, apparent, or effective, bending and torsional stiffnesses were determined for each end of the mobile home. The effect of transportation on these quantities was later evident by plotting their values versus miles of travel.

1. Torsion Test - The Torsion Test determines the relationship between a torsional moment applied about the longitudinal axis of a mobile home and the resulting angular deflection. That relationship is expressed as $\overline{GJ}$, the effective torsional stiffness. This value is derived from applying the general torsional stiffness formula to the data generated by the Torsion Test.

---

*RC is a factor that describes the average roughness of a road relative to a well-paved, smooth road. See Volume 1 of SwRI Mobile Home Research final report to HUD, "Analytical Evaluation of Transportation Effects on Mobile Homes."

Applied to mobile home testing the formula for front or rear sections is:

$$\overline{GJ} = Phy/\tan^{-1}(W/\ell) \tag{1}$$

where,

P is the applied load at the lower corner of the mobile home (lb);

h is the distance from the center of rotation to the point of loading (in);

W is the measured lateral displacement of a pendulum attached to mobile home (in);

ℓ is the pendulum length (in).

The applied moment is the product of the load P at a corner and the distance h from the center of the mobile home to the point of application. Rather than angular deflection, the formulas use the displacement of a pendulum with respect to the twisted mobile home and wall.

2. Vertical Bending Test - The vertical bending test was performed to relate vertical deflection of the box structure to the applied load. At each of two points, one midway between axle and hitch and the other at the rear of the mobile home, vertical down loads were applied and deflections were measured. The collected data were put into formulas for front and rear effective $(\overline{EI})$'s, Equations 3 and 4.

$$(\overline{EI})_F = 36_F^3(P/y)_F \tag{2}$$

$$(EI)_R = 570_R^3(P/y)_R(1 + \ell_R/\ell_R) \tag{3}$$

where,

ℓ_F = length from front to middle supports (ft);

ℓ_R = length from middle to rear supports (ft);

P = loads (lb);

y = deflection of mobile home (in.).

Initial load and deflection were defined as the unsupported weight of the mobile home and the sag from level due to this dead weight.

3. Natural Frequency Test - The natural frequency of the test unit was determined by examination of the signals generated by vertical accelerometers when the unit was subjected to a significant shock. The accelerometers were located along the centerline of the unit on the floor at two points, the rear wall and the midpoint of the hitch to A-frame span. With the unit sitting on its running gear, the A-frame drawbar was dropped 3 in. to obtain the shock. Front and rear natural frequencies and damping coefficients were determined from the signals of each accelerometer.

III. TEST RESULTS

A. Dynamic Testing

The results of this phase of the project are presented in two forms: (1) plots of rms values from several transducers versus miles; and (2) tabulated peak counts of the various transducer signals.

Figures 6 through 11 present rms (root mean square) values of six transducer signals for the road events of five Institute runs. The transducers from which the data were collected include two vertical and two lateral accelerometers, a strain gage on the longitudinal I-beam behind the rear axle, and a deflectometer at the floor/side wall interface. These data, and the peak counts which follow, begin at 500 miles because of the impracticality of installing electronic data measuring equipment at the factory. However, stationary testing was performed on the unit new.

Tables 1 through 4 present peak counts for the S-curve signals of four of the above transducers--2 vertical accelerometers, strain gage, and wall deflectometer. Peak counts are the summation of a signal's positive and negative peaks that occur within an absolute interval (positive and negative) during a time period of dynamic data collection. The S-curve was chosen for this comparison because it is a severe road condition of relatively long duration. The tabulated values represent the number of occurrences of vibration peaks in an interval for 29 s travel on the S-curve.

B. Stationary Testing

This phase of testing consisted of the determination of the natural frequency of the test unit and the periodic measurement of its apparent torsional and bending stiffnesses. Apparent stiffnesses are presented in Table 5 along with other relevant test data including trip routes, mileage, tire activity, and road conditions. Figures 12 and 13 plot the stiffness versus mileage. Stiffness test data are tabulated in Appendix A.

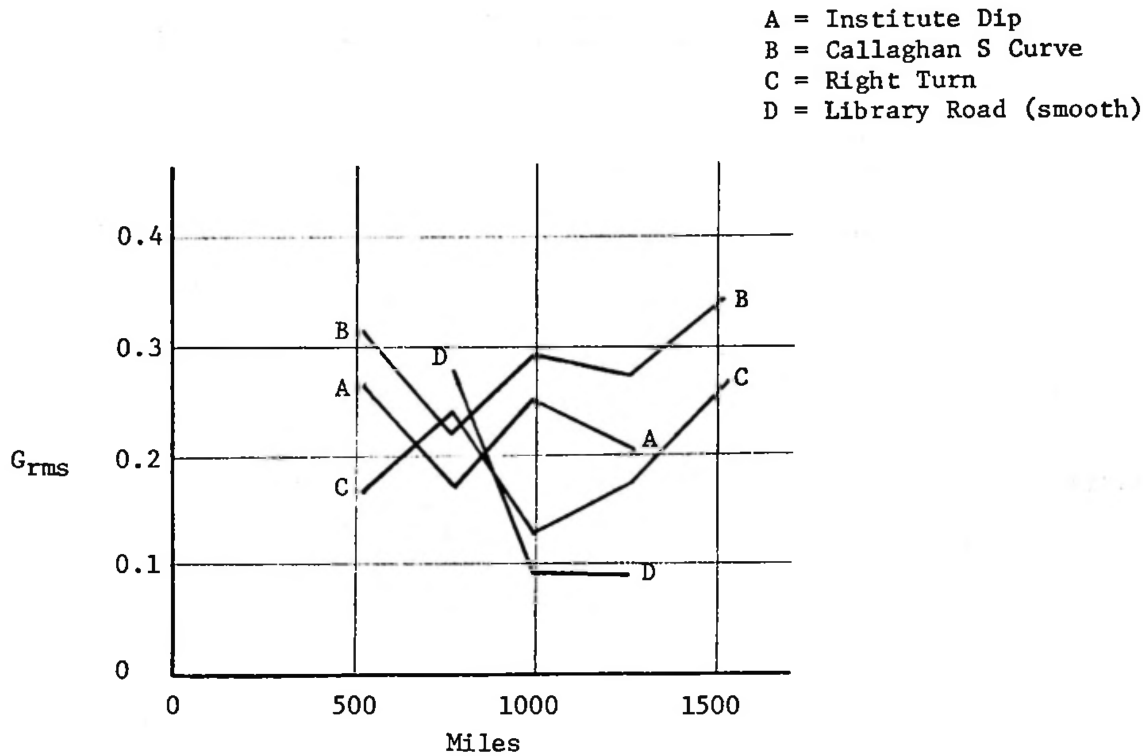


FIGURE 6. LRR(V) G_{rms} VERSUS MILES

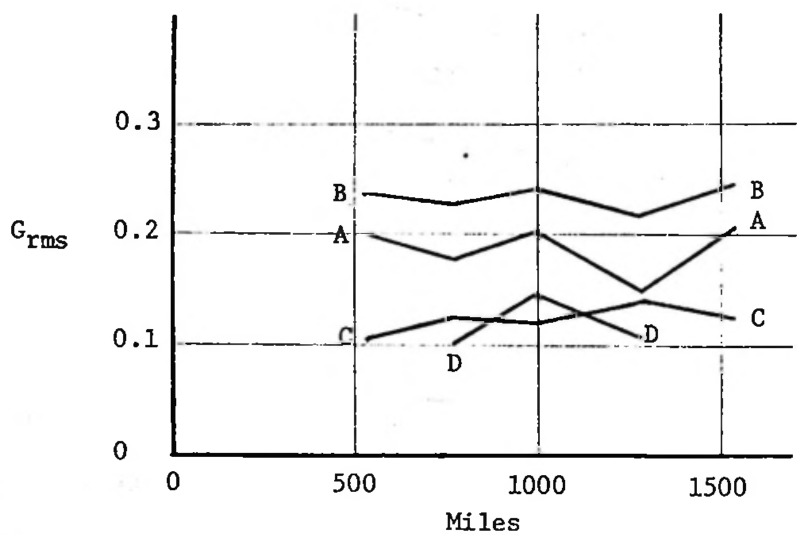


FIGURE 7. LRF(V) G_{rms} VERSUS MILES

A = Institute Dip
B = Callaghan S Curve
C = Right Turn
D = Library Road (smooth)

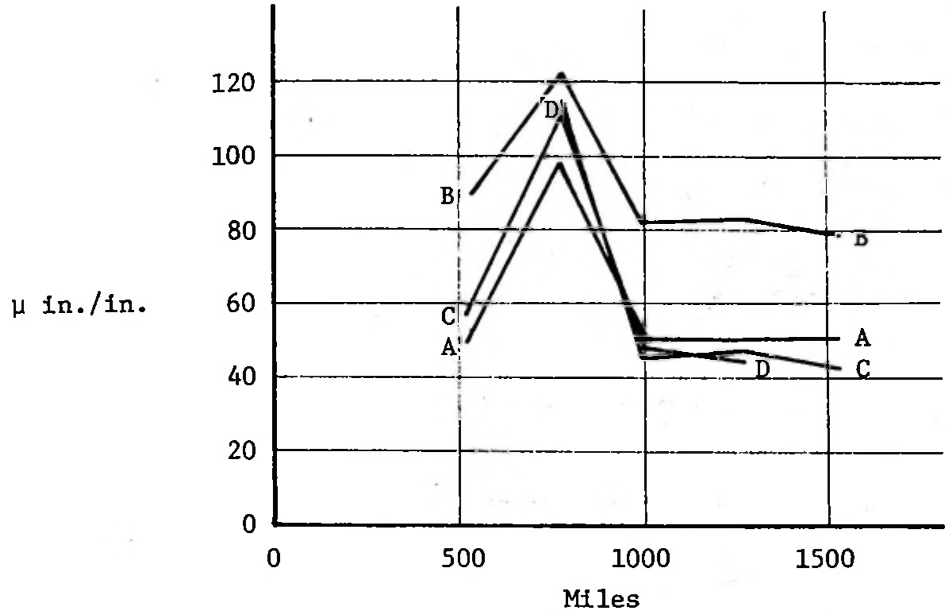


FIGURE 8. I-BEAM STRAIN VERSUS MILES

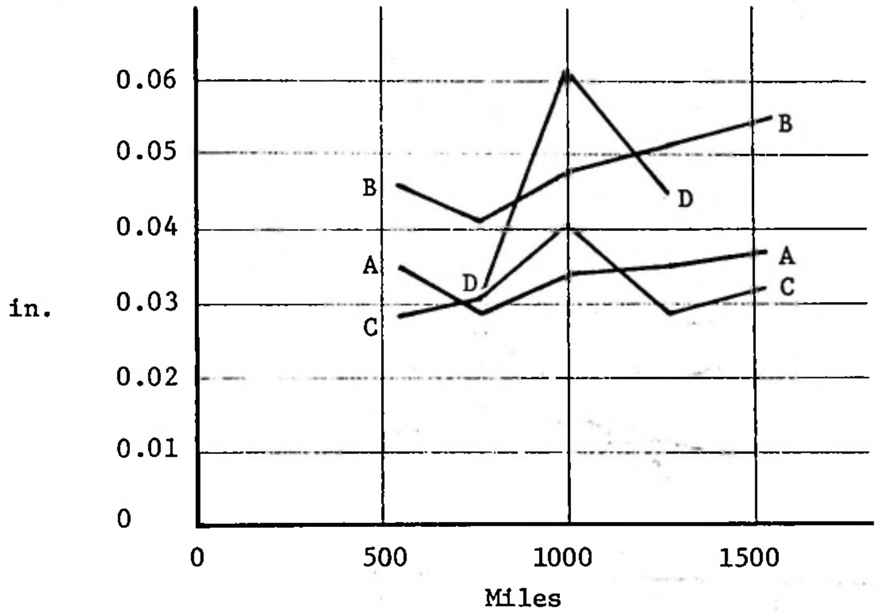


FIGURE 9. SMALL WALL DEFLECTOR MOVEMENT VERSUS MILES

A = Institute Dip
B = Callaghan S Curve
C = Right Turn
D = Library Road (smooth)

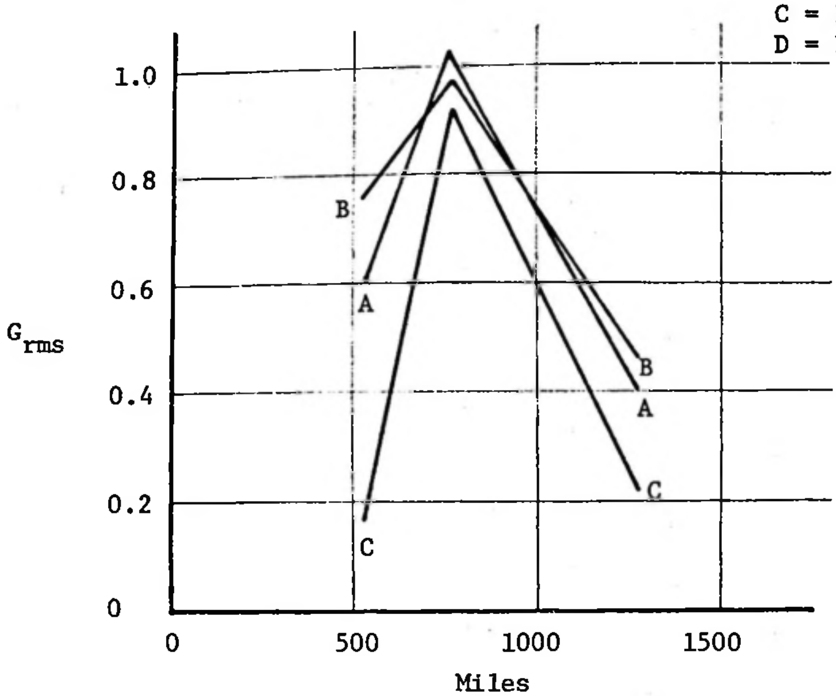


FIGURE 10. ULF(La) G_{rms} VERSUS MILES

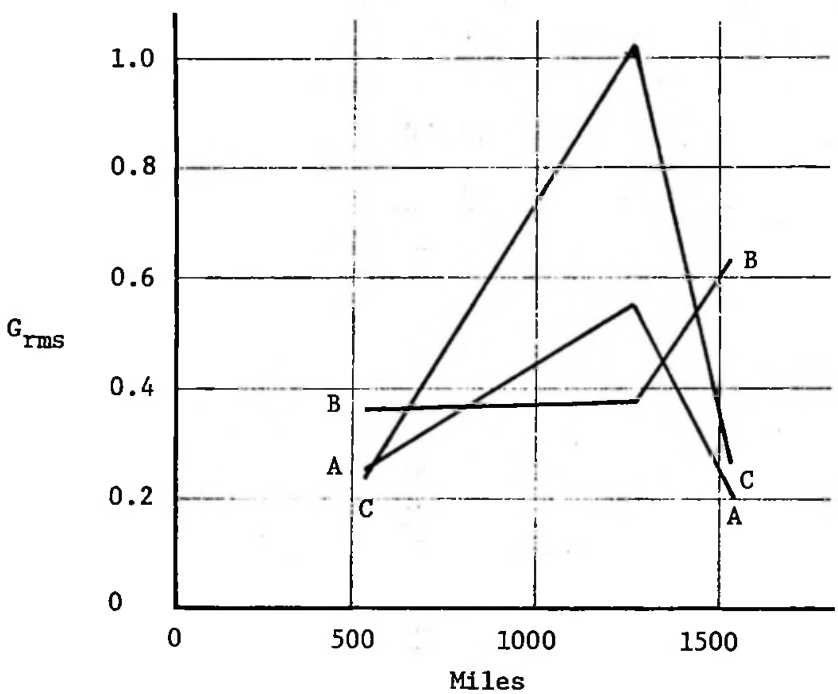


FIGURE 11. HITCH (La) G_{rms} VERSUS MILES

TABLE 1. LRR(V) PEAK ACCELERATION OCCURRENCES

ABSOLUTE INTERVAL* (g's)	INSTITUTE RUN NO.									
	3		4		5		6		7	
	+	-	+	-	+	-	+	-	+	-
4+										
4 - 3.5										
3.5 - 3				1						
3 - 2.5										
2.5 - 2										
2 - 1.5	2	2		2						
1.5 - 1	5	12	2	2	4	7	2	7	1	9
1 - 0.5	80	75	1	2	89	63	38	103	62	134
0.5 - 0.1	221	217		346	200	188	224	240	270	277
Subtotals	308	306	3	353	293	258	264	350	333	410
Totals	614		356		551		614		743	

* Measured from 0 to positive or negative peak.

TABLE 2. LRF(V) PEAK ACCELERATION OCCURRENCES

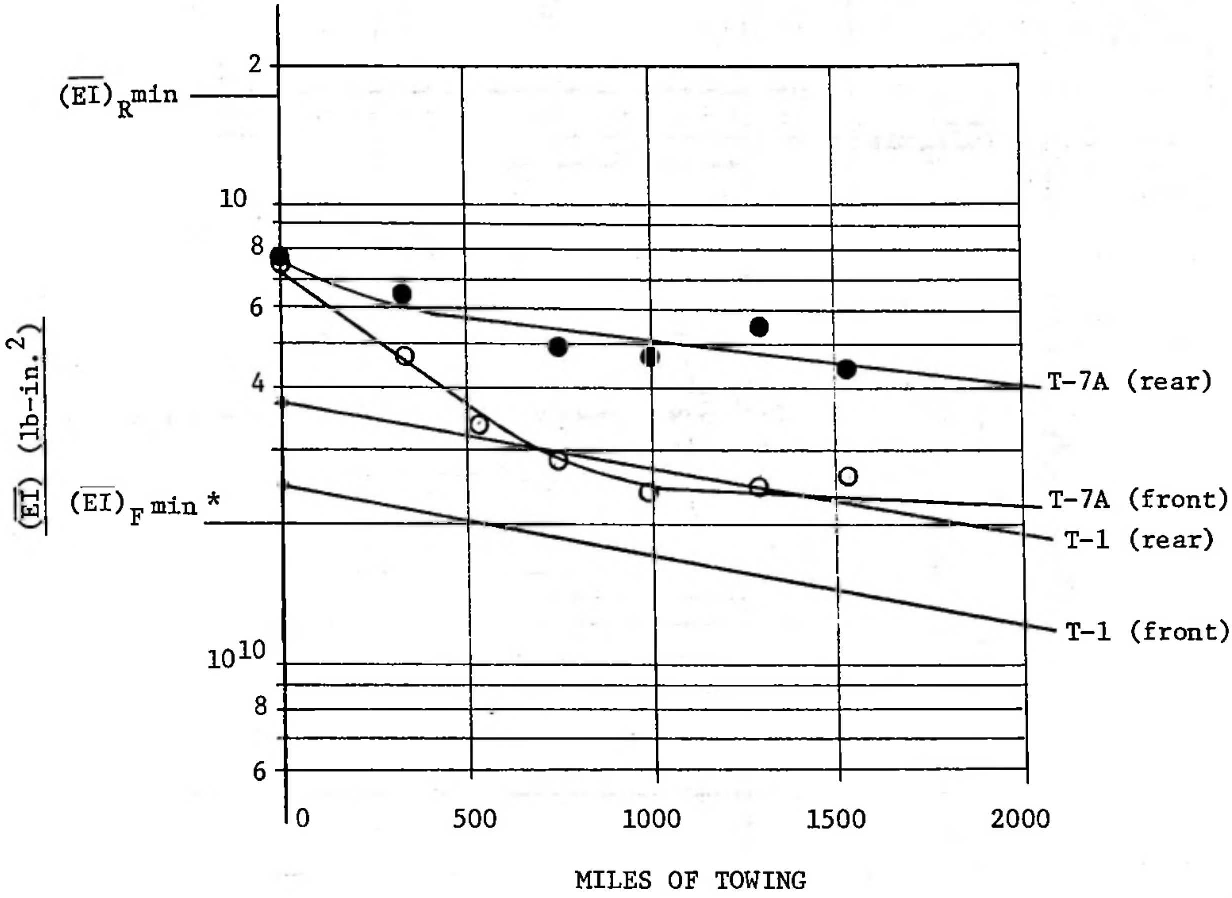
ABSOLUTE INTERVAL (g's)	INSTITUTE RUN NO.									
	3		4		5		6		7	
	+	-	+	-	+	-	+	-	+	-
4+										
4 - 3.5										
3.5 - 3										
3 - 2.5										
2.5 - 2		2		4				1		
2 - 1.5		99		41		88		67		83
1.5 - 1		455		501		447		473		443
1 - 0.5		21		25		10		13		28
0.5 - 0.1	1	1	3	1	2		2		1	1
Subtotals	1	578	3	573	2	645	2	554	1	555
Totals	579		576		647		556		556	

TABLE 3. I-BEAM STRAIN GAGE PEAK STRAIN OCCURRENCES

ABSOLUTE INTERVAL (μ in./in.)	INSTITUTE RUN NO.									
	3		4		5		6		7	
	+	−	+	−	+	−	+	−	+	−
900+				2						
800 - 700						1				
700 - 600		1								
600 - 500		1		2		5		1		3
500 - 400		14		6		5		23		21
400 - 300		89	4	38	3	85	1	131	1	202
300 - 200	4	417	17	186	5	397	5	531	3	980
200 - 100	44	443	77	569	32	455	24	535	22	603
100 - 0.1	146	44	275	116	136	37	97	15	72	45
Subtotals	192	609	373	919	176	1285	127	1036	98	1854
Totals	801		1292		1261		1163		1952	

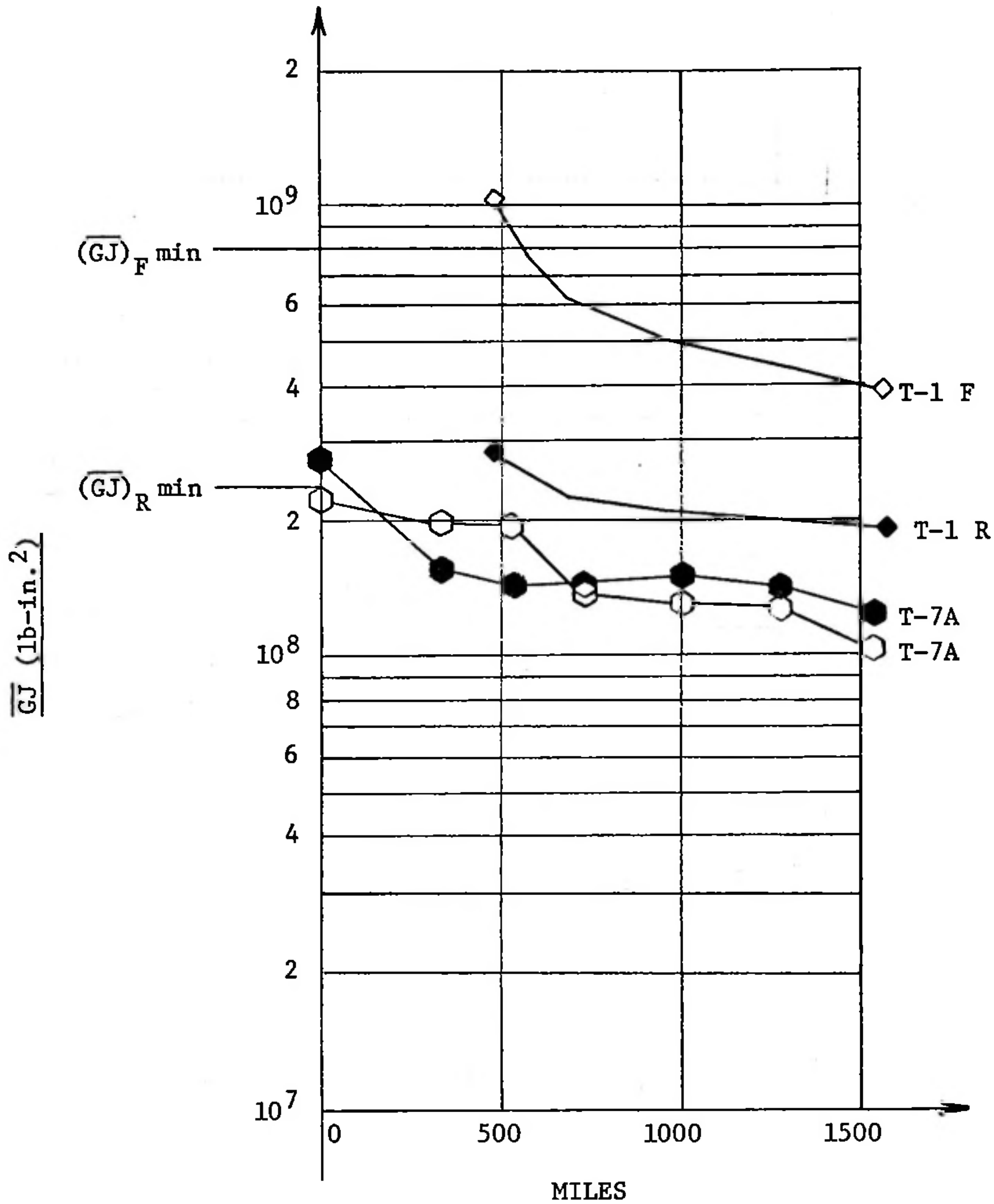
TABLE 4. WALL DEFLECTOR PEAK DEFLECTION OCCURRENCES

ABSOLUTE INTERVAL (in.)	INSTITUTE RUN NO.									
	3		4		5		6		7	
	+	−	+	−	+	−	+	−	+	−
0.9+										
0.8 - 0.7										
0.7 - 0.6										
0.6 - 0.5										
0.5 - 0.4		2		2						
0.4 - 0.3		3	2	11						
0.3 - 0.2	39	2	7		11	2	3		5	1
0.2 - 0.1	1670	41	138	90	498	46	229	113	347	164
0.1 - 0.01	729	778	2065	2060	1643	1429	2021	1924	3316	3263
Subtotals	2738	826	2212	2164	2152	1477	2253	2037	3608	3428
Totals	3564		4376		3629		4290		7096	



* Recommended minimum (min) front (F) or rear (R) apparent bending stiffness value. Refer to Volume 5.

FIGURE 12. T-7A & T-1 APPARENT BENDING STIFFNESS $(\overline{EI})$ VERSUS MILES OF TOWING--SEMI-LOG PLOT



Notes:

- Open symbols indicate front values; closed indicate rear.
- Front and rear recommended minimum new $\overline{GJ}$ values are indicated as $(\overline{GJ})_F$min and $(\overline{GJ})_R$min, respectively. See Volume 6.

FIGURE 13. SEMI-LOG PLOT OF $\overline{GJ}$ APPARENT TORSIONAL STIFFNESSES OF T-7A AND T-1

TABLE 5. T-7A DATA SUMMARY

Trip Date / Test Date	Activity	Route No.	Mileage		Tire Activity	$\overline{RC}$ *	Torsional Stiffness		Bending Stiffness	
			Trip	Total			$\bar{J}_F$ (in.^{4})	$\bar{J}_R$ (in.^{4})	$(\overline{EI})_F$ (lb-in.^{2})	$(\overline{EI})_R$ (lb-in.^{2})
- / 6/29	0	-	0	0	no failure		6.38×10^6	2.80×10^6	7.23×10^{10}	7.71×10^{10}
6/30 / 7/12	1	del'y	325	325	no failure	1.0,1.2 1.5	6.55	1.95	4.65	6.30
9/28 / 9/29	2	5	200	525	no failure	1.0,1.2 1.5	5.92	2.21	3.25	8.85
10/3 / 10/5	3	5	200	725	no failure	1.0,1.2 1.5	5.74	1.81	2.78	4.92
10/6 / 10/9	4	4	274	999	slow leak	1.0,1.2	5.48	2.07	2.25	4.75
10/10 / 10/11	5	4	271	1270	no failure	1.0,1.2	5.21	2.06	2.35	5.40
10/16 / 10/17, 11/14	6	4	268	1538	no failure	1.0,1.2	4.95	1.88	2.56	4.41

Electrical, plumbing, and heating systems were still operational at the conclusion of the testing.

*$\overline{RC}$ is a road condition factor (defined in the analysis section) which increases with road roughness. A value for $\overline{RC}$ of 1.0 indicates smooth, well-paved.

The signal obtained from performing the natural frequency test according to SwRI's recommended revisons to the HUD Mobile Home Standard is presented in Figure 14. This trace, taken at the conclusion of all testing, shows the natural frequency to be about 2.50 Hz for the section forward of the axles and 2.56 Hz for the rear section. Damping coefficients, C_D, can be computed from measurements of the trace using the formula:

$$C_D = \ln (x_1/x_2)/2\pi,$$

where x_1 and x_2 are successive peaks. The trace of Figure 14 illustrates damping coefficients of 0.14 for the front and 0.05 for the rear.

C. Visual Inspections

In addition to the quantitative measurements, qualitative evidence of the progressive state of the mobile home was recorded after each trip. The major exterior signs of degradation were the working of sheet metal siding and attachment screws, buckling of some panels, loss of sheet metal trim, wavy roof panels, difficulty in closing exterior doors without the unit leveled, and working and loss of outrigger lag bolts. The results of stresses were particularly evident at the midpoint of the span between hitch and axles; panel buckling in this area showed the effects of vibration at the longitudinal I-beam and the resultant load transference to the sidewalls. Similar bending, though not as drastic, occurred just rear of the axles.

The interior of the unit indicated the same areas of concentrated stresses, the forward section being the most degraded, although some working of interior panels and components occurred throughout the mobile home. Staples pulled through gypsum wall boards, molding vibrated loose, doors sagged, wall board shifted (evidenced by chalk leaking from behind at the floor line and gaps occurring between adjacent panels).

In contrast, the ceiling panels showed no sign of increased mileage due to their own working or experiencing of undue stresses. The only ceiling

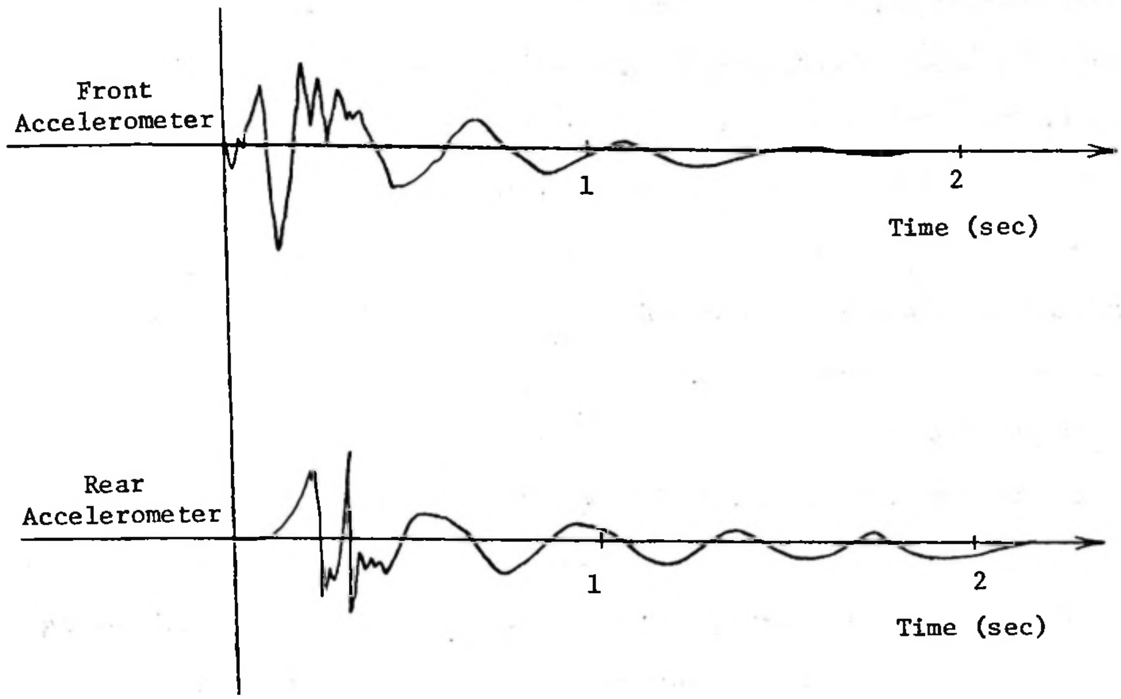


FIGURE 14. FRONT AND REAR VERTICAL ACCELEROMETER TRACES FOR T-7A NATURAL FREQUENCY TEST

damage occurred at the intersection of two front bedroom interior walls which punctured the ceiling. The fact that ceiling panels are adhesively foamed to rafter headers rather than merely glued and stapled (as are the wall panels to their studs) explains, in part, the lack of ceiling degradation. In addition, they do not suffer the degree of vibratory racking experienced by the wall.

IV. DYNAMIC PREDICTIVE ANALYSIS OF T-7A MOBILE HOME

To evaluate the remaining useful life of the T-7A unit, field tests (described in Task VI report) were performed after each test run (activity) to estimate the effective flexural ($\overline{EI}$) and torsional stiffness ($\overline{J}$). In addition, the damping coefficients (C_D) and apparent frequency (f) were also evaluated and are given in Table 6.

Using these data, the root mean square (RMS) acceleration was evaluated (for each activity) for the front and rear sections of the T-7A. These values are given in Table 7. Using these values along with "base" values defined in the Volume 4 final report*, the predictive trip degradation (PTD) and remaining useful life (RUL) were evaluated (Table 8). As shown, estimated total degradation for the front and rear sections of the T-7A is 40 and 14 percent, respectively. At approximately the same mileage test unit T-1 had degraded 24 percent in the rear.

---

* Correlation of test data with dynamic predictive and finite element analysis.

TABLE 6.
T-7A STIFFNESS DATA FOR RUL ANALYSIS*

Mileage	$(\overline{EI})$		$\overline{J}$	
	Front	Rear	Front	Rear
0	$7.2\ (10^{10})$	$7.7\ (10^{10})$	$6.4\ (10^{6})$	$2.8\ (10^{6})$
500	$3.6\ (10^{10})$	$5.7\ (10^{10})$	$6.0\ (10^{6})$	$2.4\ (10^{6})$
1000	$2.4\ (10^{10})$	$5.1\ (10^{10})$	$5.4\ (10^{6})$	$2.2\ (10^{6})$
1500	$2.3\ (10^{10})$	$4.5\ (10^{10})$	$5.0\ (10^{6})$	$1.9\ (10^{6})$

$C_{DR} = 0.05$ $f_R = 2.56$ Hz

$C_{DF} = 0.14$ $f_F = 2.50$ Hz

Average travel speed; V = 45 mph

*Selected values from smooth curve fitted to actual data.

TABLE 7.
PREDICTED T-7A ACCELERATION RESPONSE

Activity	Trip Distance (miles)	RMS Vertical Acceleration (G's)	
		Rear Location	Front Location
1	500	0.13	0.32
2	500	0.15	0.28
3	500	0.16	0.27

TABLE 8.
PREDICTED DEGRADATION: T-7A MOBILE HOME

Activity	Trip Distance (miles)	Total Distance (miles)	PTD (%)		RUL %	
			Rear	Front	Rear	Front
1	500	500	2.6	16.7	97.4	83.3
2	500	1000	5.0	12.0	92.4	71.3
3	500	1500	6.5	10.9	85.9	60.4

V. FINITE ELEMENT MODEL

A. Development

The computer program ANSYS was used to simulate critical dynamic and stationary load conditions of the mobile home through finite element analysis. The finite element theory was applied to measure stresses or loads in the gypsum board interior mobile home subjected to various forces imposed by transportation and setup and takedown. Results of this analysis were compared to that of plywood interior units. (This finite element analysis of a gypboard interior mobile home follows the previous analyses described in Volumes 1 and 4 of SwRI's final report to HUD on mobile home research.)

The first step was the geometric modeling of the test unit using components with mechanical properties that simulate a gypsum board interior unit. The computer graphic model is presented in Figures 15 and 16 . As with the previous analysis on plywood interior units, the computer-calculated deflection under static 1-g loading was compared to the actual measured deflection of a field test. The flexural modulus E of the gypsum wall panels was manipulated until agreement was reached between calculated deflections from the computer program and the field measurements. A value of 10,000 psi for the gypboard modulus produced satisfactory results: 0.44-in. deflection of the right I-beam's rear and which corresponds to about that of the unit when new.

Once a satisfactory model was developed, it was subjected to three simulated load situations, detailed as follows:

- Load Case 1 - Gravity load run to generate the baseline stresses and deformations for the unit under gravity loads of the structure and its furnishings.
- Load Case 4 - Gravity load of the structure and its furnishings and a concentrated up load of 4000 lb acting on the rear end of the right longitudinal I-beam (Nodal Point 79 in Figure 15). This load case simulates on-site installation where the unit is jacked up and set on blocks.

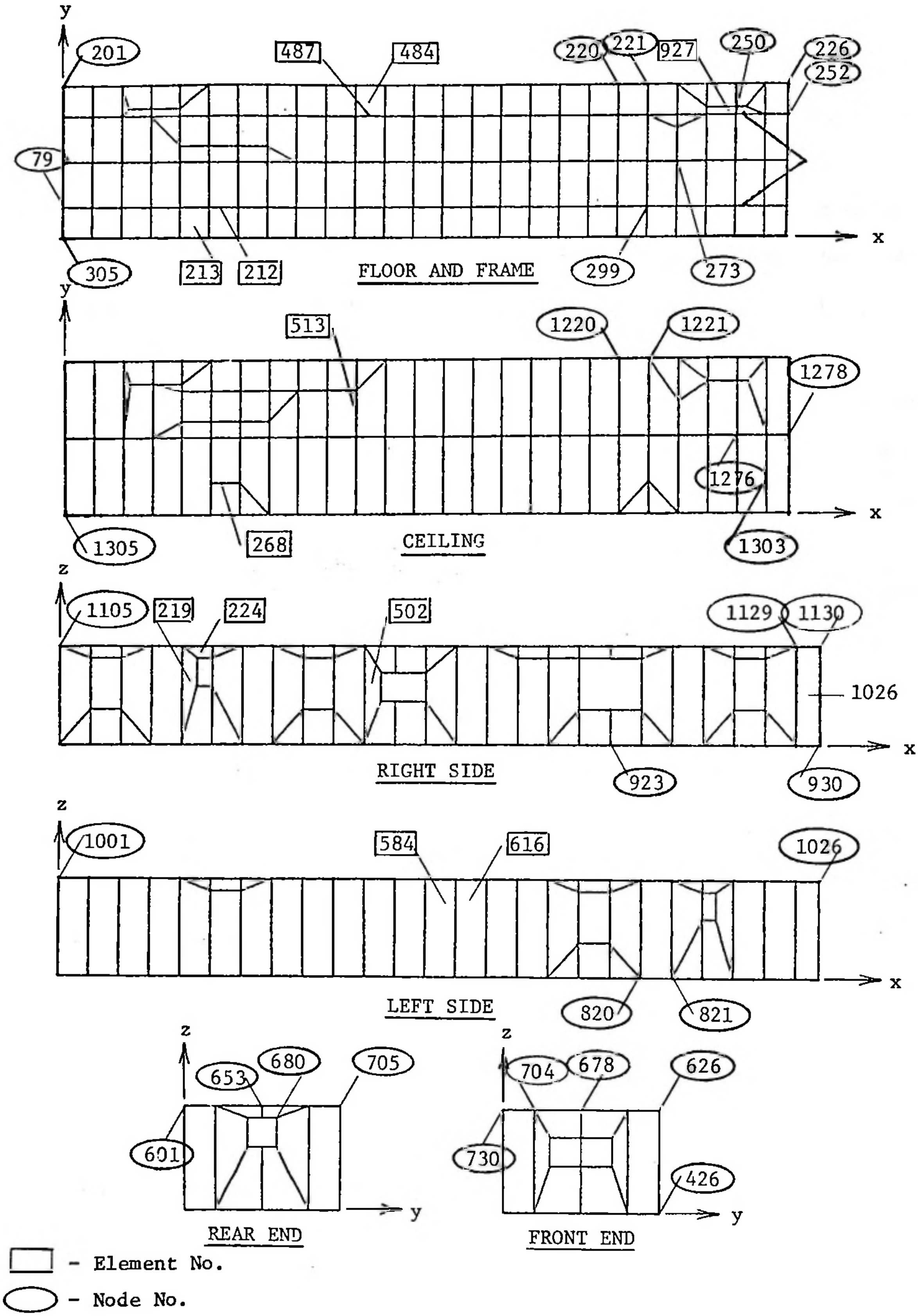
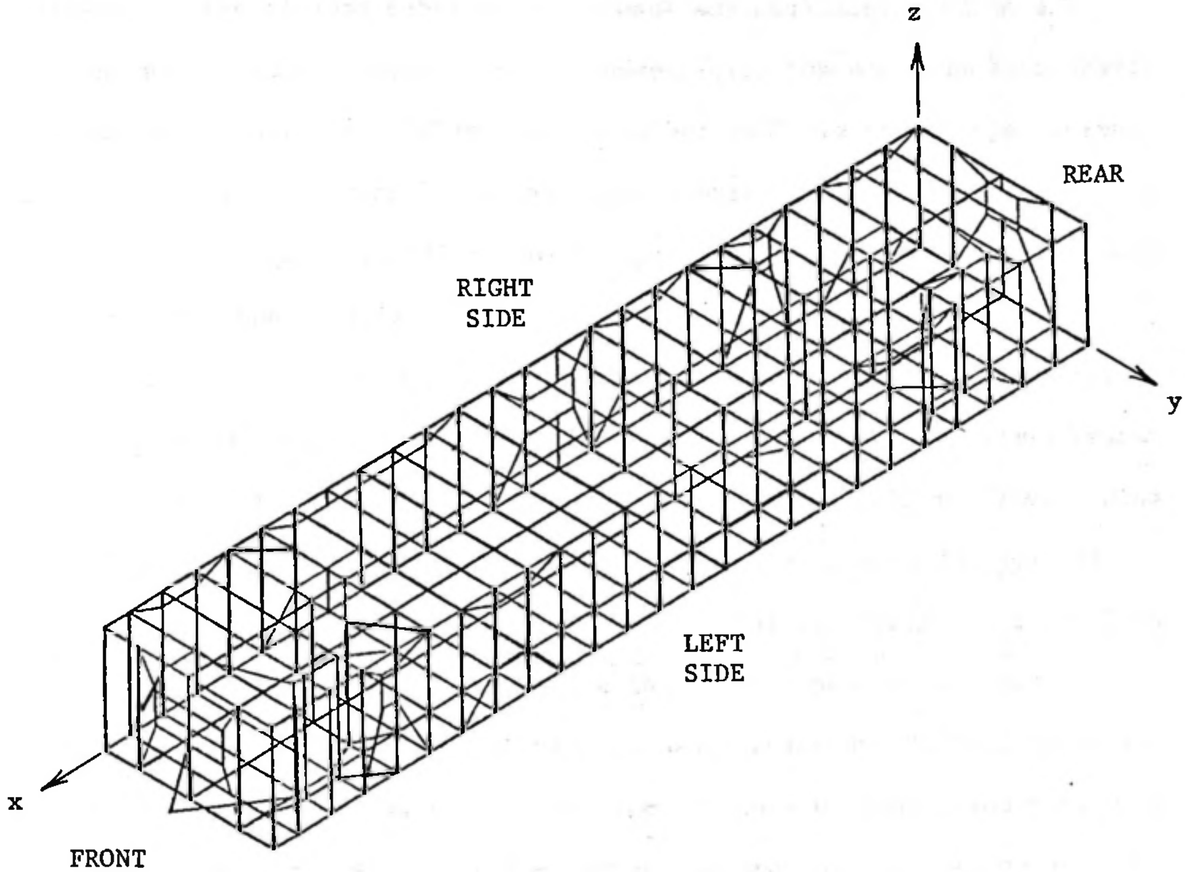


FIGURE 15 . COMPUTER GRAPHIC MODEL OF T-7A



Note: Positive axes directions are indicated.

FIGURE 16 . ISOMETRIC VIEW OF COMPUTER GRAPHIC MODEL OF T-7A

- Load Case 5 - Gravity loads of the structure and its furnishings and equivalent static loads from dynamic analysis of previous SwRI mobile home investigations for HUD. This load case represents a probabilistic "worst case" condition once every 1000 miles traveled over a paved, secondary road.

B. Stress and Displacement

The ANSYS output from the load cases included tensile and compressive stress contour plots and displacement plots. Stress contour plots show lines of equal stress. They indicate areas of high tensile or compressive stress and areas in which stress concentrations occur. Displacement plots show resulting deflections exaggerated to facilitate analysis.

Figure 17 shows the maximum (tensile, if positive) and minimum (compressive, if negative) stress contour plots of the floor for all three load cases. Dashed lines indicate neutral stress lines. This figure also contains the floor displacement plots for each load case. Similarly, Figures 18 through 22 present stress contour plots and displacement plots of ceiling, right sidewall, left sidewall, rear end wall, and front end wall.

In addition to the plotting of stresses and displacements, the computer program ANSYS tabulates these values for each element and node. For each load case, Table 9 presents maximum tensile and compressive stresses of the four primary mobile home components--floor panels (particle board), wall panels (gypsum board), roof trusses (lumber), and I-beam (steel). Stresses are all in units of psi. Elements are included and are indicated in Figure 15. Values for test unit T-1 from previous analysis are included for comparison.

Maximum deflections in each direction of each exterior surface for each load case are presented in Table 10. Node locations are indicated in Figure 15. This table also includes values from the analysis of T-1.

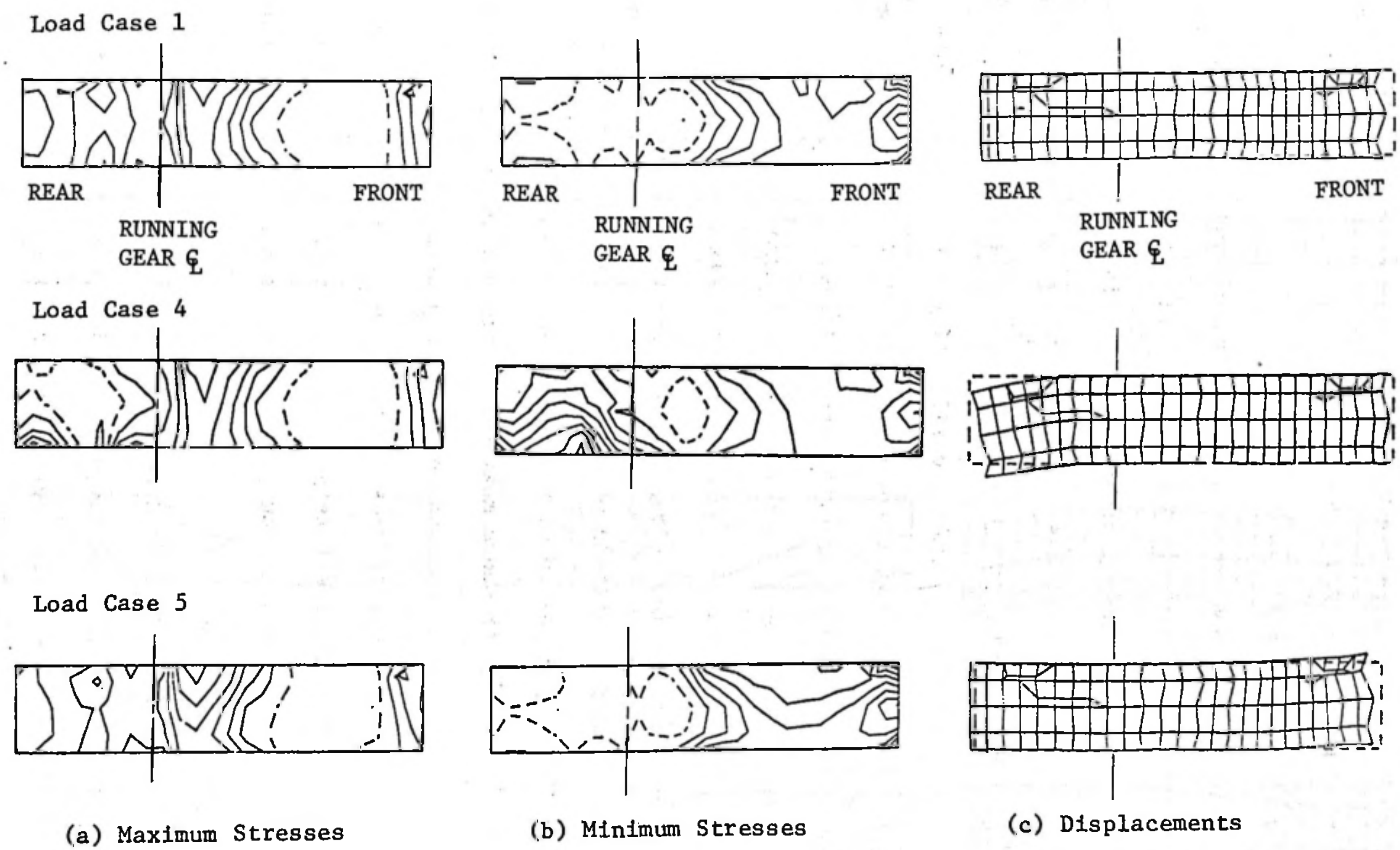


FIGURE 17. T-7A STRESS AND DISPLACEMENT PLOTS-FLOOR

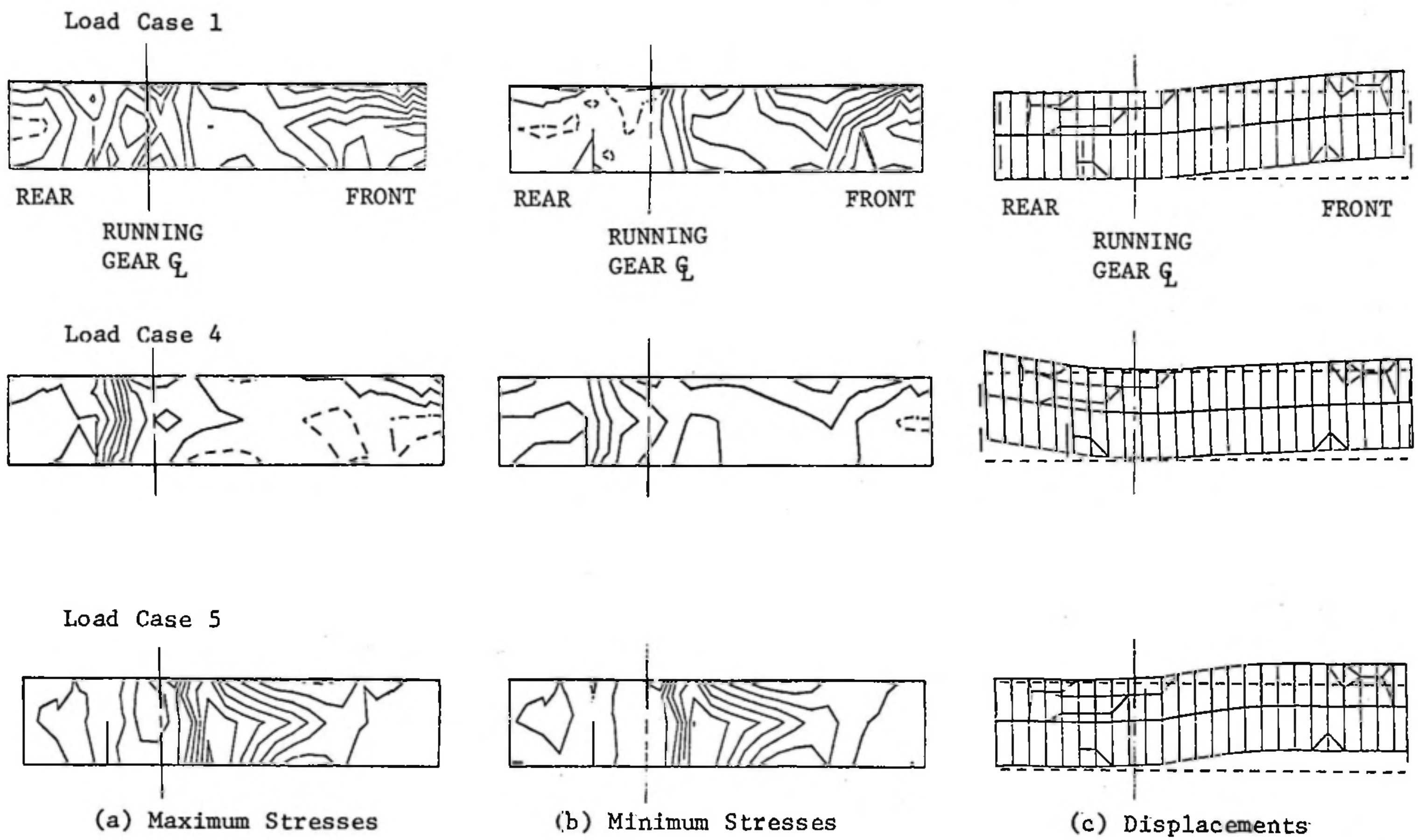
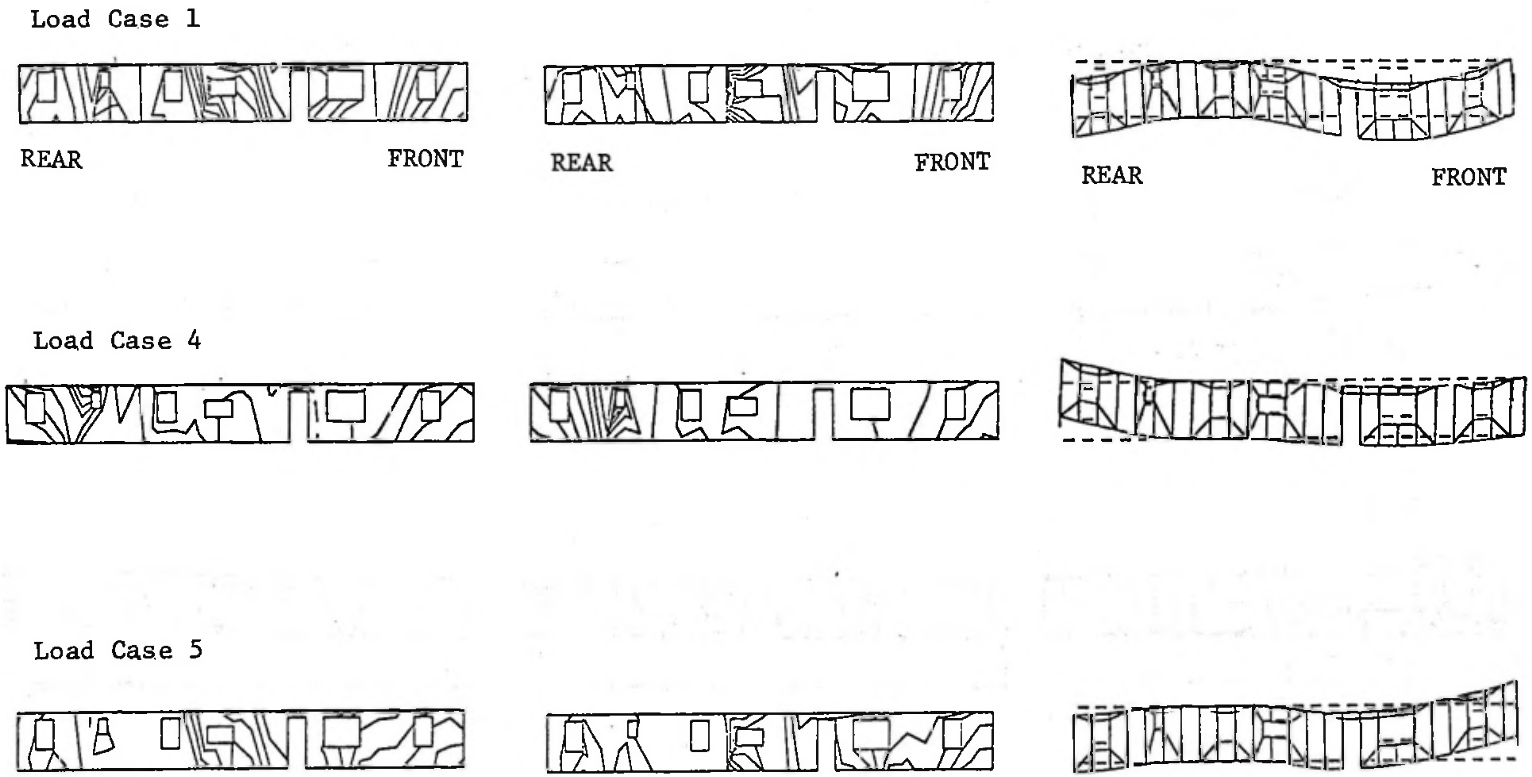


FIGURE 18. T-7A STRESS AND DISPLACEMENT PLOTS-CEILING



(a) Maximum Stresses (b) Minimum Stresses (c) Displacements

FIGURE 19. T-7A STRESS AND DISPLACEMENT PLOTS-RIGHT SIDE

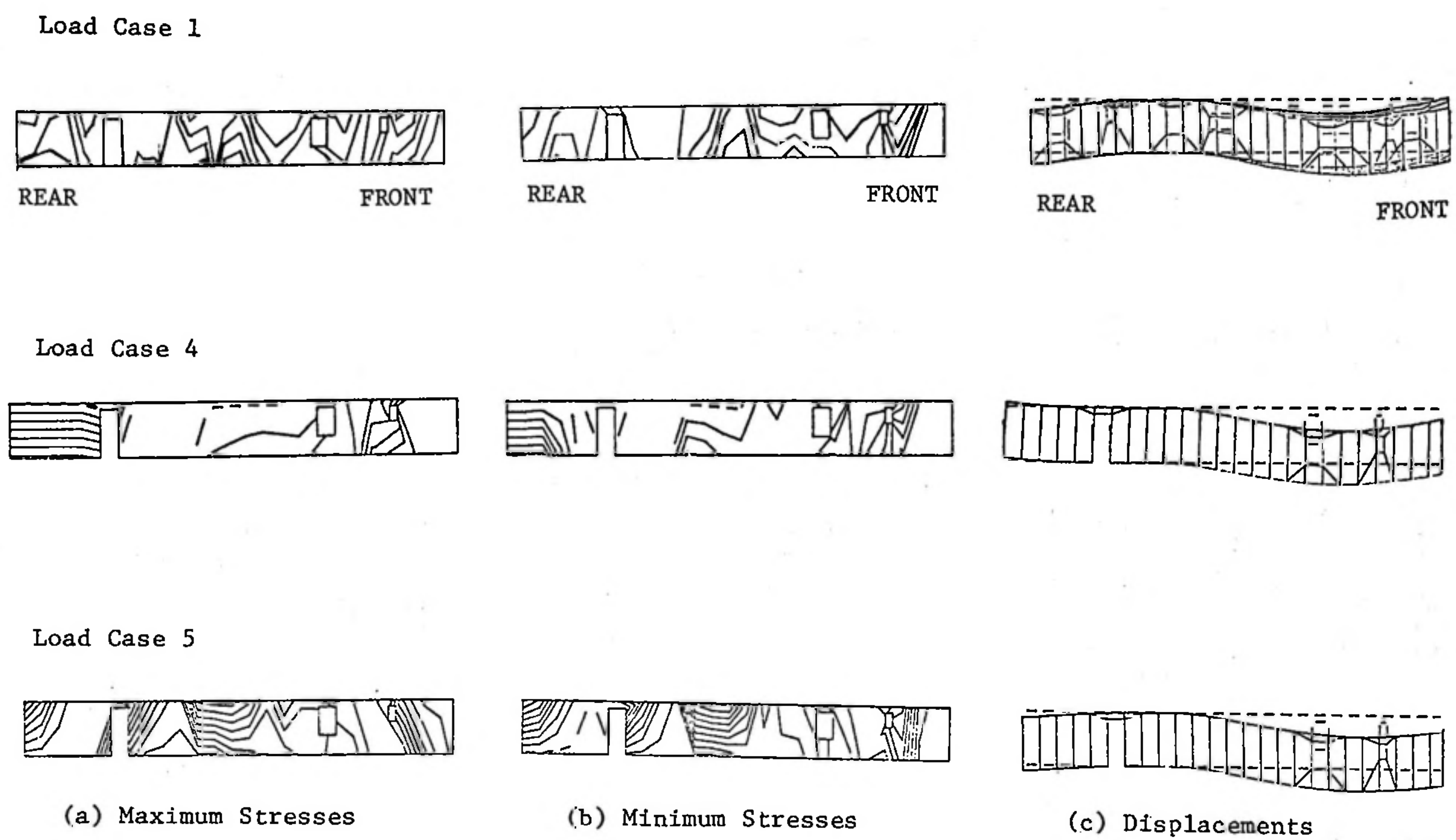
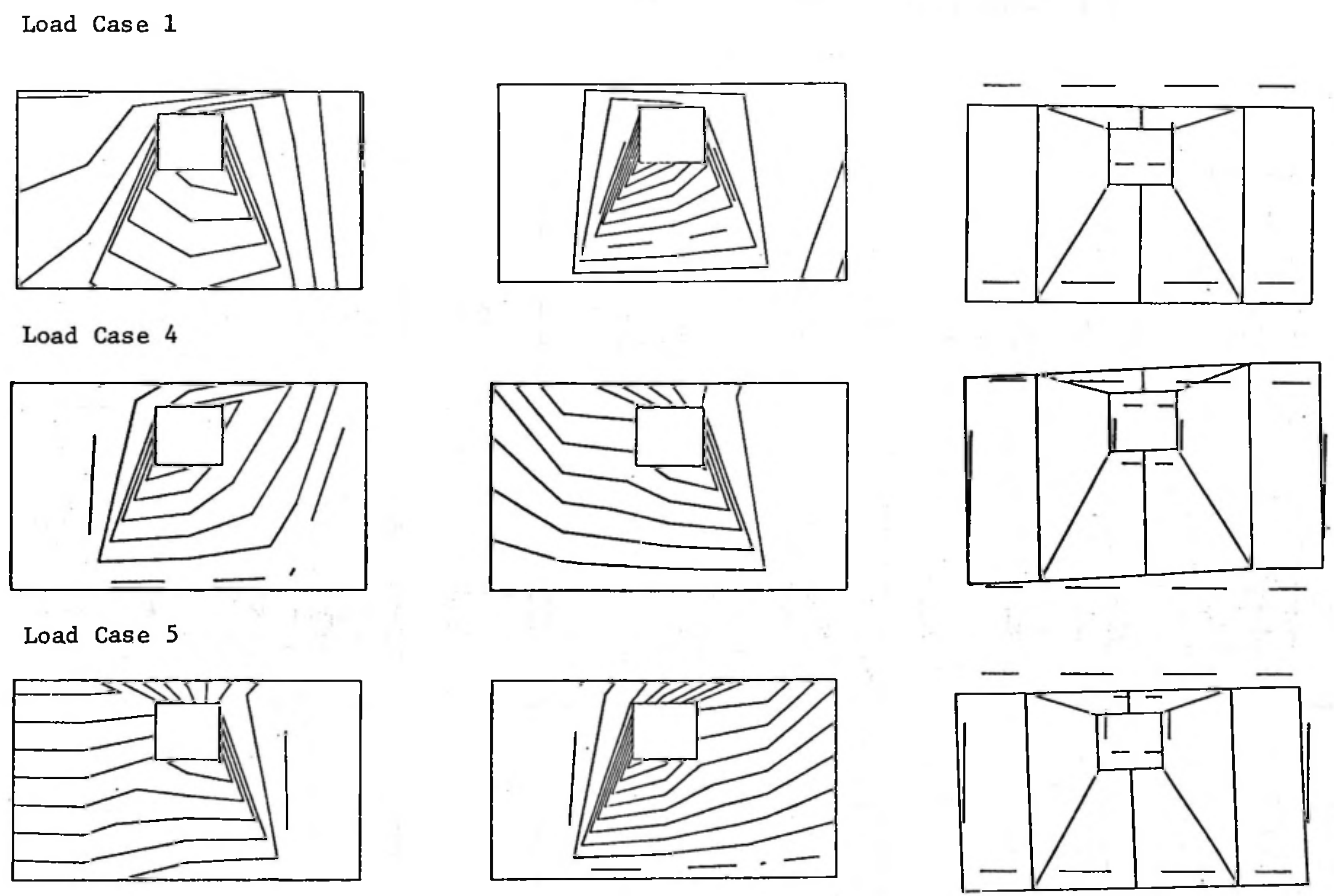


FIGURE 20. T-7A STRESS AND DISPLACEMENT PLOTS-LEFT SIDE



(a) Maximum Stresses (b) Minimum Stresses (c) Displacements

FIGURE 21. T-7A STRESS AND DISPLACEMENT PLOTS-REAR END WALL

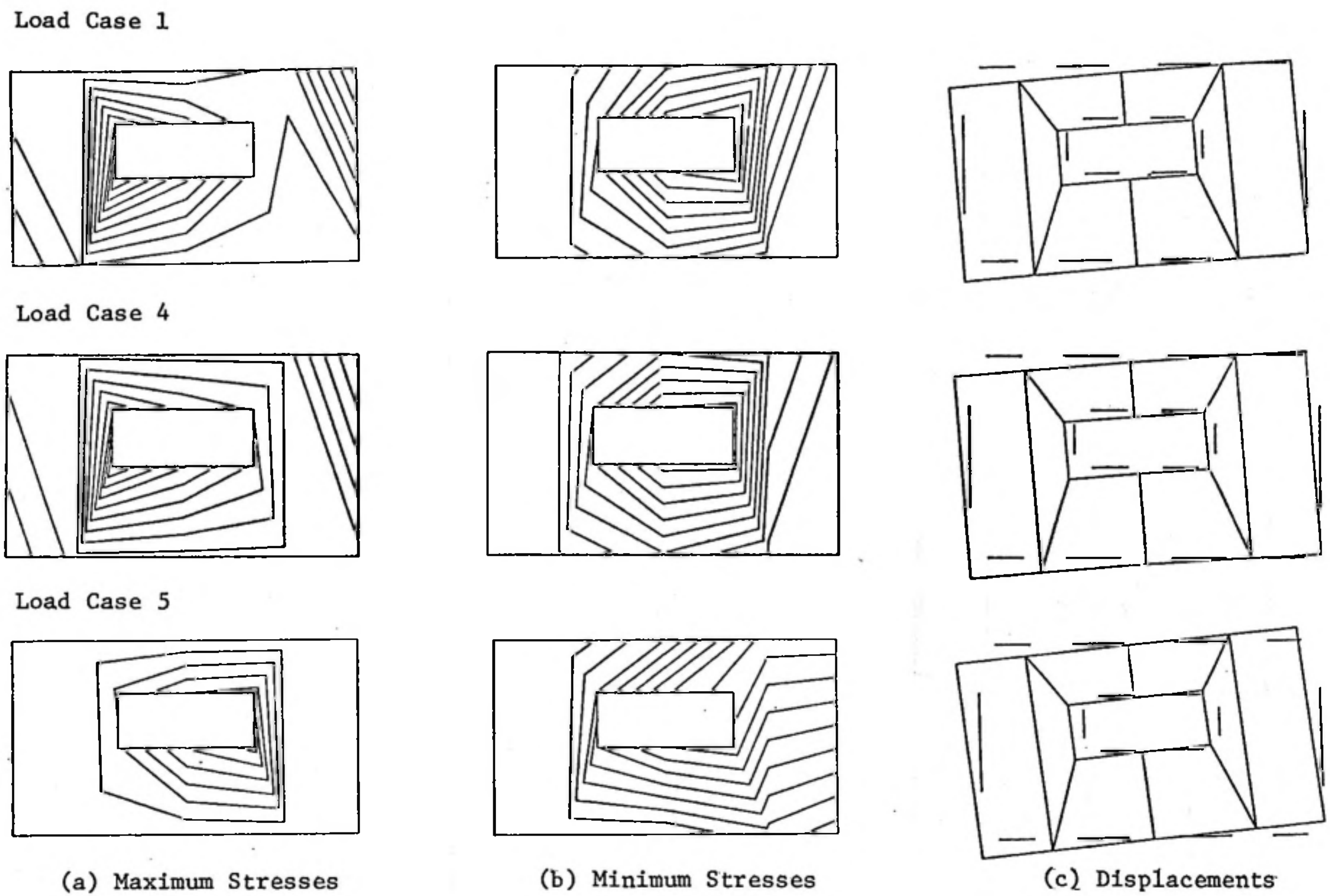


FIGURE 22. T-7A STRESS AND DISPLACEMENT PLOTS-FRONT END WALL

TABLE 9. T-7A AND T-1 MAXIMUM AND MINIMUM STRESSES

T-7A Max. Stress / Element Number

Mobile Home Component	LOAD CASE 1		LOAD CASE 4		LOAD CASE 5		T-1 MAXIMUM TENSILE OR COMPRESSIVE STRESS* LOAD CASE 5	
	TENSILE	COMPRESSIVE	TENSILE	COMPRESSIVE	TENSILE	COMPRESSIVE	TENSILE	COMPRESSIVE
*FLOOR PANELS	113./484	119./927	119./484	167./213	446./484	414./927	180.	282.
WALL PANELS	17./616& 1026	18./502	32./224	35./219	83./616	80./584	722.	658.
ROOF TRUSSES	250./513	226./513	209./268	221./268	1337./513	1172./513		
LONGITUDINAL I-BEAM	9680./487	13,000./487	18,297./212	13,242./487	38,884./487	55,806./487		

NOTES:

- Stresses in Floor and Wall panels are membrane stresses.
- Truss and I-beam stresses are maximum fiber stresses.

*From SwRI, "Mobile Home Research: Analytical Evaluation of Transportation Effects on Mobile Homes," Vol 1, Part 4, Aug 1978, pp 29, 38.

TABLE 10. T-1 AND T-7A MAXIMUM DISPLACEMENT

Key: T-7A Displacement (in.) / Node Number

Mobile Home Component	Load Case 1			Load Case 4			Load Case 5		
	Long.*	Lat*	Vert*	Long.	Lat	Vert	Long.	Lat	Vert
Floor	-0.02 / 250	-0.002 / 299	-0.79 / 220	-0.03 / 273	-0.02 / 201	1.3 / 305	-0.06 / 252	0.03 / 226	-4.3 / 221
Ceiling	-0.07 / 1276	0.20 / 1278	-0.79 / 1220	0.16 / 1305	0.46 / 1305	1.3 / 1305	0.20 / 1303	3.3 / 1303	-4.3 / 1221
Right Side Wall	-0.06 / 1130	0.20 / 1130	-0.51 / 923	0.16 / 1105	0.46 / 1105	1.3 / 1105	-0.21 / 1130	3.3 / 1129	2.0 / 930
Left Side Wall	-0.06 / 1001	0.20 / 1026	-0.79 / 820	0.11 / 1001	0.45 / 1001	-0.82 / 820	0.18 / 1001	3.3 / 1024	-4.3 / 821
Rear End Wall	-0.06 / 653	-0.01 / 705	-0.41 / 680	0.16 / 705	0.46 / 705	1.3 / 705	-0.18 / 601	0.54 / 653	-1.21 / 601
Front End Wall	-0.07 / 678	0.20 / 678	-0.33 / 626	0.07 / 730	0.24 / 678	-0.37 / 626	0.20 / 704	3.3 / 678	-2.9 / 426

*Longitudinal, Lateral, and Vertical correspond to graphic model coordinates x, y, and z. Directionality is defined in Figure 16.

T-1 DISPLACEMENTS (in.)*

Mobile Home Component	Load Case 1		Load Case 4		Load Case 5	
	Lateral	Vertical	Lateral	Vertical	Lateral	Vertical
Floor	-0.010	-1.210	0.027	-0.803	-1.180	-4.159
Ceiling	0.230	-1.210	0.181	-0.803	-2.856	-4.160
Right Sidewall	0.230	-0.969	0.181	-0.496	-2.852	-4.160
Left Sidewall	0.228	-1.210	0.176	-0.803	-2.856	1.191
Rear Sidewall	-0.105	-0.969	0.181	0.308	-1.959	-3.650
Front Sidewall	0.230	-0.712	0.078	-0.103	-2.856	-3.373

*From SwRI, "Mobile Home Research: Analytical Evaluation of Transportation Effects on Mobile Homes," Vol 1, Part 3, August 1978, p46.

C. Discussion

The stress contour and displacement plots and related tables can be useful in several ways:

- For each load case, areas of high stress, high stress gradients, and large displacement are easily located;
- The areas of changing stress or displacement under varying load conditions are also located;
- In comparing plots of various units, the effects of materials and layout can be analyzed.

As with similar analyses on previous test units, areas of high stress concentration in T-7A exist at locations of maximum bending along the unit, around doors and windows, and particularly at the corners of these openings. In Load Cases 1 and 5, maximum bending stresses generally occurred in the box structure around the axles. This agrees with the maximum deflections being near the midpoint of the axle-to-hitch span. Load Case 4 maximum bending was rear of the axles with the right rear corner registering the greatest deflections and steepest stress gradients. Stress contours and displacements plots for T-1, a plywood interior unit, exhibit the same areas of concern.

The stress values of Table 9 show more closely related floor stresses for T-7A and T-1 under Load Case 5 than their corresponding wall stresses. However, the significance of these numbers, their similarities, and their differences should be evaluated knowing the full scenario.

Test units T-1 and T-7A differ in too many ways to link interior wall material to a particular behavior. For instance, T-1 has only 10-in. I-beams with longitudinal floor joists while T-7A has 12-in. I-beams and transverse joists.

The difference between the wall stresses of T-1 and T-7A has at least one explanation. In tuning each model to match actual data, the flexural moduli of the walls of each unit were chosen as 50 ksi for T-1 and 10 ksi for T-7A. With a smaller modulus, the interior wall material of T-7A allowed their studs to take a greater proportion of the load than in T-1 resulting in lower wall stresses.

The displacement values of Table 10 also must be reviewed with regard to the differing constructions of T-1 and T-7A. What can be said is that for the two mobile home designs the following relations may be expected, based upon the finite element analysis:

- T-1 has greater sag than T-7A under static conditions;
- T-7A has greater bending stiffness; T-1 has greater torsional stiffness;
- T-7A has greater lateral deflections but T-1 has slightly greater vertical deflections in a severe dynamic condition.

The first two statements are supported by actual data but the last is difficult to verify.

VI. DISCUSSION OF RESULTS

Test Mobile Home T-7A degraded during the Condition I and II transport cycles. The degree of degradation was significant and was indicated by the numerous visual indicators presented in the previous section. The stiffness measurements indicate the same trend with the initial stiffness being lower. However, the rate of degradation for T-7A was slightly greater than T-1, the plywood paneled home.

Dynamic and particularly stationary test data indicate the gradual loosening of the test unit as mileage increased. Though not dramatic, the dynamic recordings of the lateral and vertical accelerations, expressed in rms values, tend to decrease as the unit ages. Similarly, the floor/wall deflections increased.

The total number of significant vibration occurrences of the wall and I-beam deflections increase substantially with unit aging. Significant vertical accelerations occur more frequently as well, further proof of the unit's loosening or stiffness loss.

Strongest support of the pattern of T-7A's loss of structural integrity are its stiffness histories. Apparent vertical bending stiffnesses of the front and rear sections decreased asymptotically to a "bottomed-out" value, resembling the patterns of other test units. The greatest and most rapid decrease of both bending and torsional stiffnesses was suffered by the front section. The little difference between T-7A's front and rear torsional stiffnesses throughout its testing lifetime distinguished T-7A from the plywood paneled units.

Apparent stiffness values at zero mileage for T-7A indicate that the unit is stiff enough in the vertical bending mode but not in the torsional mode. That is, the apparent vertical bending stiffnesses exceed the minimum values recommended by SwRI*, but the apparent torsional stiffnesses are less than the recommended minimum values. However, the rate of decrease of the vertical bending stiffnesses was greater for T-7A than T-1. Torsional stiffnesses of T-7A compared to T-1 were as much as 50 percent lower for the rear section and 80 percent lower for the front section.

In consideration of the more rapid decline of stiffness of this gypsum board interior mobile home with respect to a plywood interior unit, it may be necessary to change the design of the gypsum board interior mobile home in order to provide substantial initial stiffness levels for the gypsum board construction.

Another critical mode during transportation is the repetitive loadings supplemented by the constant vibration. The loads and vibrations are the result of the dynamics generated by highway travel. These dynamics associated with both the vertical bending and torsional modes result in significant and repetitive input loads to the structure. The structure, especially the joints, is further damaged by the 5-10-Hz vibration found throughout the mobile home during the transportation mode. Tests conducted by U.S. Gypsum Association indicate that these types of loads prove detrimental to the gypsum board interior when it is installed as load-absorbing paneling. Mobile home design should minimize the load inputs and deflections of the gypsum board by possibly including exterior wall panels which can absorb the loads and relieve the gypsum board of as much load and deflection as possible.

The gypsum board interior test mobile home performed better than expected in that only a few areas suffered severe damage such as the

* See Volume 5 of SwRI's "Mobile Home Research: Recommended Revisions to HUD Mobile Home Construction and Safety Standard."

gypsum board popping loose, compression failures, glue lines pulling loose, and attachments failing. However, it is obvious that the foam gusseting applied to the ceiling gypboard must have a significant effect because none of the ceiling panels suffered any damage whatsoever. Also, the normal 1/4-in. wide PV glue lines are not adequate because they are attached only to the paper in a localized manner. The recommendations in Section VII provide possible solutions to these problems.

VII. RECOMMENDATIONS

The recommended changes in design of the structural box for mobile homes that utilize gypsum board interior paneling are:

- The concentrated as well as the total load input to the gypsum board paneling should be reduced as much as possible.

- Experience gained from the application of the foam gusseting from the gypboard to the wood structure should be applied to the walls, shear walls, and partitions.

- Method of reducing loading on the gypsum board are:

  - Temporary stiffeners applied during the transportation modes.

  - Increasing the structural integrity and stiffness of the wall and roof sections by installing exterior plywood paneling under the aluminum siding. In this manner the plywood will take the predominant portion of the structural loading, thereby reducing loading on the gypboard. This approach would also increase the structural stiffness in both the torsion and vertical modes whereby the unit would then meet the recommended minimum EI and GJ values.

- The application of the plywood exterior paneling would also permit the use of the 10-in. I-beams rather than the 12-in. I-beams used on T-7A. This would affect a significant cost item.

- Temporary stiffeners could still be considered with the new design to further reduce the loading on the gypboard and minimize torsion and vertical deflection.

APPENDIX A

VERTICAL BENDING AND TORSIONAL STIFFNESS TEST DATA

TABLE A.1 T-7A TORSION TEST DATA*- FRONT LEFT

Prior to Trip 1 / Acc. mileage 0

Load (lb)	Defl. (in.)
470	0.05
0	0
-580	-0.05
-1170	-0.09
-1750	-0.13
-2330	-0.18
-2920	-0.22
-3150	-0.26
$Avg(\overline{GJ})_{FL}=2.28(10^8)\,lb\text{-}in.^2$	

After Trip 1 / 325 miles

Load (lb)	Defl. (in.)
-590	-0.06
-1400	-0.12
-1990	-0.16
-2570	-0.22
-3270	-0.27
$Avg(\overline{GJ})_{FL}=2.10(10^8)\,lb\text{-}in.^2$	

After Trip 2 / 525 miles

Load (lb)	Defl. (in.)
-580	-0.05
-1170	-0.10
-1750	-0.17
-2330	-0.23
-3150	-0.33
$Avg(\overline{GJ})_{FL}=2.06(10^8)\,lb\text{-}in.^2$	

After Trip 3 / 725 miles

Load (lb)	Defl. (in.)
290	0.04
0	0
-590	-0.06
-1170	-0.14
-1750	-0.23
-2340	-0.30
-2920	-0.37
-3620	-0.45
$Avg(\overline{GJ})_{FL}=1.51(10^8)\,lb\text{-}in.^2$	

After Trip 4 / Acc. mileage 999

Load (lb)	Defl. (in.)	
590	0.07	
1170	0.15	
0	0	0
-580		-0.07
-1160		-0.17
-1750		-0.29
-2330		-0.39
-2910		-0.47
-3380		-0.55
$Avg(\overline{GJ})_{FL}=1.19(10^8)\,lb\text{-}in.^2$		

After Trip 5 / 1270 miles

Load (lb)	Defl. (in.)	
820	0.13	
0	0.04	0
0		0
-590		-0.10
-1170		-0.21
-1750		-0.28
-2570		-0.42
$Avg(\overline{GJ})_{FL}=1.16(10^8)\,lb\text{-}in.^2$		

After Trip 6 / 1538 miles

Load (lb)	Defl. (in.)	
460	0.05	
0	0.02	0
-400		-0.06
-980		-0.17
-1560		-0.26
-2150		-0.35
-2730		-0.44
-3080		-0.49
$Avg(\overline{GJ})_{FL}=1.24(10^8)\,lb\text{-}in.^2$		

* Refer to Vol. 6 concerning $\overline{GJ}$ apparent torsional stiffness.

TABLE A.2 T-7A TORSION TEST DATA*- FRONT RIGHT

Prior to Trip 1 / Acc. mileage 0

Load (lb)	Defl. (in.)	
580	0.05	
1160	0.10	
1750	0.13	
2330	0.17	
2680	0.21	
0	0.02	0
-290		-0.02
-880		-0.07
$Avg(\overline{GJ})_{FL}=2.40(10^8)$ lb-in.^{2}		

$Avg(\overline{GJ})_F=2.34(10^8)$ lb-in.^{2}

After Trip 1 / 325 miles

Load (lb)	Defl. (in.)	
590	0.06	
1170	0.13	
1750	0.19	
2340	0.22	
2920	0.22	
0	0	0
-580		-0.07
-930		-0.11
$Avg(\overline{GJ})_{FL}=1.90(10^8)$ lb-in.^{2}		

After Trip 2 / 525 miles

Load (lb)	Defl. (in.)	
590	0.06	
1170	0.12	
1750	0.18	
2340	0.25	
2920	0.31	
0	0	0
-580		-0.05
$Avg(\overline{GJ})_{FL}=1.92(10^8)$ lb-in.^{2}		

After Trip 3 / 725 miles

Load (lb)	Defl. (in.)	
590	0.07	
1170	0.19	
1750	0.26	
2330	0.36	
2920	0.45	
3500	0.55	
0	0.06	0
-190		-0.03
-540		-0.17
$Avg(\overline{GJ})_{FL}=1.25(10^8)$ lb-in.^{2}		

After Trip 4 / Acc. mileage 999

Load (lb)	Defl. (in.)	
590	0.07	
1170	0.15	
1750	0.23	
2340	0.33	
2920	0.40	
3620	0.48	
0	0.08	0
0		0
-700		-0.12
$Avg(\overline{GJ})_{FL}=1.42(10^8)$ lb-in.^{2}		

After Trip 5 / 1270 miles

Load (lb)	Defl. (in.)	
580	0.06	
1160	0.17	
1750	0.24	
2330	0.35	
2910	0.43	
3030	0.47	
0	0.06	0
-180		-0.03
-770		-0.11
$Avg(\overline{GJ})_{FL}=1.38(10^8)$ lb-in.^{2}		

After Trip 6 / 1538 miles

Load (lb)	Defl. (in.)	
590	0.17	
1170	0.25	
1750	0.36	
2340	0.45	
2920	0.61	
0	0.06	0
0		0
-350		-0.07
$Avg(\overline{GJ})_{FL}=.884(10^8)$ lb-in.^{2}		

* Refer to Vol. 6 concerning $\overline{GJ}$ apparent torsional stiffness.

TABLE A.3 T-7A TORSION TEST DATA*– REAR LEFT

Prior to Trip 1 / Acc. mileage 0

Load (lb)	Defl. (in.)	
580	0.03	
1050	0.07	
0	0.01	0
0		0
-580		-0.04
$Avg(\overline{GJ})_{FL} = 2.29(10^8)$ lb-in.^{2}		

After Trip 1 / 325 miles

Load (lb)	Defl. (in.)	
580	0.06	
700	0.06	
0	0	0
580		-0.05
1050		-0.10
$Avg(\overline{GJ})_{FL} = 1.47(10^8)$ lb-in.^{2}		

After Trip 2 / 525 miles

Load (lb)	Defl. (in.)	
460	0.05	
0	0	0
-820		-0.08
$Avg(\overline{GJ})_{FL} = 1.40(10^8)$ lb-in.^{2}		

After Trip 3 / 725 miles

Load (lb)	Defl. (in.)	
590	0.06	
700	0.09	
0	0	0
-580		-0.05
-1160		-0.09
-1630		-0.14
$Avg(\overline{GJ})_{FL} = 1.55(10^8)$ lb-in.^{2}		

After Trip 4 / Acc. mileage 999

Load (lb)	Defl. (in.)	
580	0.05	
1160	0.09	
1750	0.15	
0	0	0
-590		-0.06
-1170		-0.12
$Avg(\overline{GJ})_{FL} = 1.83(10^8)$ lb-in.^{2}		

After Trip 5 / 1270 miles

Load (lb)	Defl. (in.)	
580	0.08	
1160	0.14	
1750	0.19	
0	0.04	
0		0
$Avg(\overline{GJ})_{FL} = 1.19(10^8)$ lb-in.^{2}		

After Trip 6 / 1538 miles

Load (lb)	Defl. (in.)	
470	0.08	
0	0.06	0
0		0
-590		-0.07
-1170		-0.12
-1520		-0.17
$Avg(\overline{GJ})_{FL} = 1.16(10^8)$ lb-in.^{2}		

* Refer to Vol. 6 concerning $\overline{GJ}$ apparent torsional stiffness.

TABLE A.4 T-7A TORSION TEST DATA*– REAR RIGHT

Prior to Trip 1 / Acc. mileage 0

Load (lb)	Defl. (in.)
580	0.03
810	0.04
0	0
0	0
-580	-0.02
-930	-0.04

$Avg(\overline{GJ})_{FL} = 3.24(10^8)\,lb\text{-}in.^2$

$Avg(\overline{GJ})_{R} = 2.77(10^8)\,lb\text{-}in.^2$

After Trip 1 / 325 miles

Load (lb)	Defl. (in.)	
580	0.05	
0	0	0
0		0
-580		-0.05

$Avg(\overline{GJ})_{FL} = 1.57(10^8)\,lb\text{-}in.^2$

After Trip 2 / 525 miles

Load (lb)	Defl. (in.)	
590	0.05	
1050	0.08	
0	0	0
-580		-0.08

$Avg(\overline{GJ})_{FL} = 1.54(10^8)\,lb\text{-}in.^2$

After Trip 3 / 725 miles

Load (lb)	Defl. (in.)	
580	0.05	
1160	0.12	
1280	0.14	
700	0.08	
0	0.05	0
0		0
-580		-0.06

$Avg(\overline{GJ})_{FL} = 1.40(10^8)\,lb\text{-}in.^2$

After Trip 4 / Acc. mileage 999

Load (lb)	Defl. (in.)	
590	0.06	
700	0.08	
0	0.02	0
0		0
-580		-0.05
-1400		-0.12

$Avg(\overline{GJ})_{FL} = 1.51(10^8)\,lb\text{-}in.^2$

After Trip 5 / 1270 miles

Load (lb)	Defl. (in.)	
470	0.05	
0	0	0
-820		-0.06
-1400		-0.10
-1750		-0.15

$Avg(\overline{GJ})_{FL} = 1.75(10^8)\,lb\text{-}in.^2$

After Trip 6 / 1538 miles

Load (lb)	Defl. (in.)	
580	0.07	
1170	0.12	
1750	0.19	
0	0.01	0
-580		-0.07
-1050		-0.12

$Avg(\overline{GJ})_{FL} = 1.25(10^8)\,lb\text{-}in.^2$

* Refer to Vol. 6 concerning $\overline{GJ}$ apparent torsional stiffness.

TABLE A.5 T-7A VERTICAL BENDING TEST DATA

Prior to Trip 1 — Accumulated Mileage - 0 mi

ADDED LOAD (lb)	Deflection (in.)	
	Front	Rear
0	0.0	0.820
190	0.020	0.930
267	0.024	1.000
517	0.050	1.137
767	0.082	1.278
1017	0.110	1.430
1267	0.140	1.608
Avg. $\overline{EI}$ (in.^{4})	7.23 (10^{10})	7.71 (10^{10})

After Trip 1 — 325 mi

ADDED LOAD (lb)	Deflection (in.)	
	Front	Rear
0	0.053	0.050
185	0.076	0.168
263	0.080	0.240
513	0.105	0.360
763	0.130	0.573
1013	0.155	0.690
1263	0.180	0.855
Avg. $\overline{EI}$ (in.^{4})	4.65 (10^{10})	6.30 (10^{10})

After Trip 2 — 525 mi

ADDED LOAD (lb)	Deflection (in.)	
	Front	Rear
0	0.095	0.725
190	0.120	0.810
267	0.125	0.855
517	0.140	0.975
867	0.165	1.150
1117	0.180	1.230
1367	0.210	1.390
Avg. $\overline{EI}$ (in.^{4})	3.25 (10^{10})	8.85 (10^{10})

After Trip 3 — 725 mi

ADDED LOAD (lb)	Deflection (in.)	
	Front	Rear
0	0.105	1.409
190	0.135	1.547
267	0.150	1.635
517	0.170	1.652
767	0.195	1.775
1017	0.220	1.930
1267	0.250	2.070
Avg. $\overline{EI}$ (in.^{4})	2.78 (10^{10})	4.92 (10^{10})

After Trip 4 — 999 mi

ADDED LOAD (lb)	Deflection (in.)	
	Front	Rear
0	0.130	1.730
180	0.170	1.860
257	0.185	1.930
507	0.210	2.075
757	0.235	2.210
1007	0.265	2.360
1257	0.300	2.520
Avg. $\overline{EI}$ (in.^{4})	2.25 (10^{10})	4.75 (10^{10})

After Trip 5 — 1270 mi

ADDED LOAD (lb)	Deflection (in.)	
	Front	Rear
0	0.130	1.300
185	0.160	1.410
262	0.175	1.470
512	0.205	1.600
762	0.235	1.750
1012	0.265	1.890
1262	0.300	2.040
Avg. $\overline{EI}$ (in.^{4})	2.35 (10^{10})	5.40 (10^{10})

After Trip 6 — 1538 mi

ADDED LOAD (lb)	Deflection (in.)	
	Front	Rear
0	0.025	1.790
225	0.050	1.960
302	0.065	2.045
552	0.090	2.200
802	0.115	2.375
1052	0.140	2.545
1302	0.175	2.750
Avg. $\overline{EI}$ (in.^{4})	2.55 (10^{10})	4.41 (10^{10})

Transportation Safety Test
Program

TRANSPORTATION SAFETY TEST PROGRAM

Prepared By

C.R. Ursell, II

W.W. Raine

TABLE OF CONTENTS

INTRODUCTION

The research contained herein was conducted for HUD, Office of Policy Development and Research, to study the effects of transportation on mobile homes, with regard to safety performance. Southwest Research Institute performed in-transit and static tests on mobile homes which reflected a representative cross-section of mobile home transportation related effects. Single- and double-wide, new and used mobile homes were purchased and transported over a variety of road conditions, instrumented with accelerometers, strain gages, and deflection devices. Together with inspections, the summarized test data was evaluated for purposes of recommending improved design criteria for the design of mobile homes per Subparts D, E, and J of the HUD Mobile Home Construction and Safety Standard.

Testing was performed on critical components and sub-assemblies of the mobile homes. Tested and evaluated were the A-frame and hitch coupler, running gear, and brake wire systems. Also investigated were temporary stiffening of mobile homes and reuse of the running gear.

ALUMINUM &
COPPER BRAKE WIRE

I. OBJECTIVES

During the course of a previous mobile home transportation study, deficiencies of the electrical brake system were reported. As a result of these reported deficiencies, SwRI recommended to HUD that further investigation be directed in areas regarding existing and similar electrical brake systems on mobile homes.

The resulting report herein compares copper and aluminum brake wiring as used in two different brake system configurations. The objective is to present their respective performance characteristics and either endorse the existing system or recommend design modifications for a better system.

II. INTRODUCTION

Every mobile home/tractor brake system is required to undergo and pass a dynamic test, which SwRI refers to as the "20/40 stop test", according to U.S. Department of Transportation regulations. The test requires that a combined mobile home/tractor unit traveling 20 mph stop in 40 ft. It is possible, however, to pass the test with inadequate mobile home brakes if the tractor can provide the required stopping energy. Under this condition, the risk of an unstable stop is increased. Without the mobile home "dragging" the two units, especially during emergency stops, jackknifing or other unsafe stops may easily occur.

It has been the experience of SwRI that the 20/40 stop test can be passed without mobile home brakes. Successful tests were made with mobile home brakes contributing little if any braking. It was also observed that some stops were not straight when mobile home brakes were used; that is, the tractor had to steer to maintain the mobile home direction in a straight line. This may be the result of asymmetrical braking effectiveness provided by a particular brake wire configuration.

The importance of mobile home electrical brake systems warrants investigation of the effectiveness of the various systems. In particular, controversy exists over the comparative advantages and disadvantages of aluminum and copper wire systems used in brake and electrical systems.

The decision to use a particular wire system is not based simply on a comparison of cost and conductivity. In addition to the latter, several other items must be considered, such as corrosiveness, gage size and flexibility. For instance, consider aluminum wiring: to achieve maximum conductivity, aluminum wire can be used in a solid bar, but this reduces its flexibility; moreover, aluminum wire increases in temperature with current flow which increases the wire's resistance as well (in this case reducing braking efficiency).

This report investigates not only the use of aluminum and copper conductors, but also, the performances of two brake wiring configurations. The method generally in use is a "runaround system", which distributes an uneven braking signal among the brakes. Unbalanced braking can produce asymmetrical stops that can lead to jackknifing. To solve this problem, a spider wiring system that distributes an equal braking signal may be substituted.

III. TEST SPECIMEN

From various test mobile homes used by SwRI for previous research for HUD, the single-wide mobile home designated T-1 was selected as the test specimen and was towed by a 1968 truck weighing 8,950 lbs.* T-1 was equipped with 20-percent,† 12- x 2-in. electric brakes on two of the three front axles. The tires were 10 ply 700 x 14.5 inflated to 70 psi. The axles were mounted on single-leaf, slider spring systems with equalizers.

For this study, T-1 used three different brake wiring systems, two of which consisted of copper wire and differed only in the method of power distribution to the brakes. The third was an aluminum wire system. The system originally installed in the mobile home was the No. 3 aluminum "runaround" or "C" configuration. As the name implies, the runaround system supplies power to the brakes beginning with the front brake on one side progressing to that side's next rear axle, across to the other rear, and finally to the remaining front brakes. Generally, this configuration is uneven with the first brake in the series connection receiving the greatest power. The other wiring configuration investigated in this study was the "spider" system. In this system, the distribution of power to the brakes is more even because it provides a central distribution point and the lengths of the lead wires can be made equal. The system consists of a main lead that branches off into four leads, each of which controls a different brake.

---

*Refer to Task III, Volume I, Part I for T-1 history.
†See page 9 of this report for explanation of 20-percent effective brakes.

Fourteen-gage stranded copper wire with 0.035-in. of plastic insulation was tested in both the runaround and spider wiring configurations. Connections between main brake wire and individual leads to the brakes were made with wire nuts. The connection at the tractor was the twisted and taped method.

IV. TEST SETUP AND PROCEDURES

The testing of this effort consisted of two types of work:

- 20/40 stop tests according to U.S. Department of Transportation Regulations;
- Electric brake wire voltage measurements.

A. Stop Tests

The 20/40 stop test is a standard test for determining the performance of mobile home/tractor brake systems for compliance with Subpart "J" "Transportation" of the HUD Mobile Home Construction and Safety Standards, which states, "Brakes on towing vehicle and mobile home should be such that the maximum stopping distance from a velocity of 20 mph does not exceed 40 feet." The mobile home/tractor test combination was subjected to the 20/40 stop test, equipped with both runaround and spider brake wiring systems. Stops were made both uphill and downhill on a 2.14-percent grade and on a flat grade of standard asphalt, Class 2 pavement. As the tractor's front bumper crossed the zero footage mark, a flagman signaled the driver to apply his brakes. Some driver reaction time was included in the measurements; however, because he was anticipating the action, the driver's reaction time was considered to contribute only about 3 ft to the actual stopping distance (about 1/10 of a second travel at 20 mph). Films of the stops were made for future reference. (Refer to Figure 1 for 20/40 stop test procedures.)

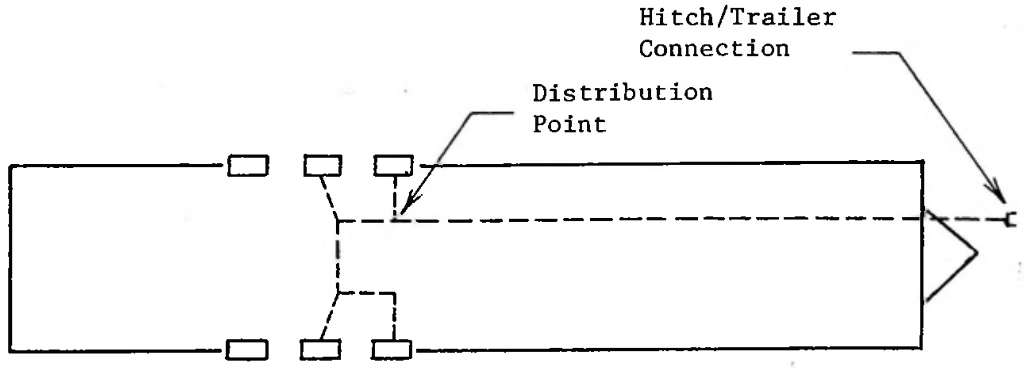
B. Brake Wire Voltage Tests

The electric brake wire voltage measurements were made between ground and various points along the mobile home brake system with the brakes manually applied. The points of interest, as indicated in Figure 2, were on each side of the hitch/trailer connection, at the distribution point, and at each brake connection point. This test was done for both aluminum and copper wiring of both runaround and spider brake wiring systems.

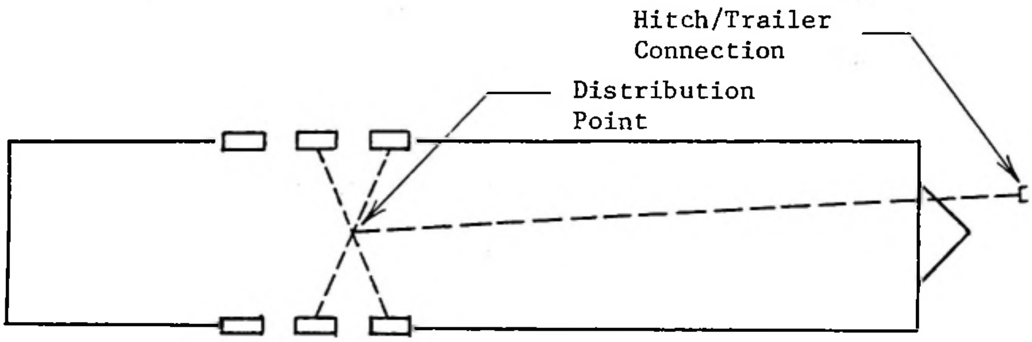
FIGURE 1.

20/40 STOP TEST PROCEDURES

1. Calibrate speedometer.
2. Install fifth wheel, left side of tractor.
3. Instrument tractor brakes with thermocouples.
4. Weigh tractor and mobile home, set tire pressure at 60 psi.
5. Adjust brakes on mobile home and tractor.
6. Paint white stripes across selected test road, 40-ft apart.
7. Install flag/poles at each white stripe right side of road.
8. Setup 16-mm movie camera at front white stripe off left shoulder.
9. Setup walkie-talkie on tractor C.B. channel.
10. Record ambient temperature.
11. Check fore/aft level of mobile home for equal weight on each axle.
12. Provide 800 ft minimum for acceleration to 20 mph.
13. Prepare camera.
14. Set signal flagman with walkie-talkie at first pole/stripe.
15. Driver accelerates to 20 mph and stabilizes speed. Turn on recorder. Turn on movie camera and pan through complete stop operation.
16. The driver, 40 ft prior to first line, places foot on brake pedal.
17. At signal from flagman (who drops flag and into walkie-talkie shouts "now") when bumper crosses first stripe, driver applies maximum brake and steers into a straight line for mobile home as necessary.
18. Measure tire skid marks on tractor.
19. Measure distance from first white stripe to front of bumper.
20. Record these data with temperature.
21. Note degree of angle of tractor to control stop.
22. Note any skid of tractor and mobile home tires.
23. Record weight of units.



"RUNAROUND" OR "C"
CONFIGURATION



"SPIDER" CONFIGURATION

FIGURE 2. MOBILE HOME BRAKE WIRING CONFIGURATIONS

V. TEST RESULTS

A. Stop Tests

The data of Tables 1 and 2 represent the results of several 20/40 stop tests with T-1. The tables present each run's stopping distance and the average and range of the distances under each grade condition (uphill, downhill, and level). The stops were accomplished using copper and aluminum runaround systems as well as two stops on level grade, indicated by "*", using a copper spider system. The initial stop test data (Table 1) reflect the performance of the factory furnished 20-percent effective brake system. The second set of stop test data (Table 2) reflect the performance of the SwRI new replacement brake components, which are estimated to be in the 30- to 35-percent effective range.

Brake effectiveness is an expression derived from the basic gravitational formulas for deceleration rates and stopping distances. In basic terminology, brake effectiveness is a stopping distance factor expressed in percent of gravitational g's as a brake constant.

Appendix A of this report contains a procedure and a report of Test No. 203, Mobile Home Brake Performance by an axle manufacturer. This is another evaluation of a mobile home brake system tested by the 20/40 stop test for compliance with the federal standard. Data are presented for three conditions: tractor brakes only, trailer brakes only, and both. This report is included to show the correlation of the test results between the manufacturer and SwRI.

B. Brake Wire Voltage Tests

Tables 3 and 4 present the voltages measured between ground and several locations for each type of system. There were three system combinations consisting of either copper or aluminum wire and runaround or spider configurations. The two conditions under which measurements were taken were as follows: manual application of mobile home brakes only (no tractor brakes) and manual application of mobile home brakes in conjunction with the tractor brakes.

Note that for each runaround system, voltages were recorded for only the right front brake. This is the last brake in the distribution path, and consequently, it experiences the greatest voltage drop.

TABLE 1. 20/40 STOP TEST DATA SUMMARY
(Factory Furnished Brakes)

	Distances Recorded in Test (ft)		
	Uphill	Downhill	Level
	38	48	39
	31	50	38
	35		38*
	30		39*
	40		
Avg	34.8	54	38.5
Range	30-40	50-58	38-39
Trailer Brakes Only:		300	200

*All stops that used the copper spider brake system. All other stops used the aluminum runaround brake system.

TABLE 2

MOBILE HOME & TRACTOR

20/40 STOP TESTS

(Replacement Brakes)
35% effective

Date: 4/20/78 (Runs 1-7) HUD Demonstration
4/26/78 (Runs 8-13) SwRI Added tests

MOBILE HOME TEST UNIT: T-1 (14' x 65')

8950# Tractor Weight

3590# Mobile Home Tongue Weight

15540# Mobile Home Axle Weight

4/20/78
Forward Two Axles

Run No.	Brake System Mobile Home: Two front axles, 4 brakes	Stopping Distance (ft)	Left Middle Axle Skid Length (ft)
1 2	Copper Runaround* (w/Tractor brakes)	25 24	21 21
3 4	Aluminum Runaround (w/Tractor brakes)	32 33.5	24.5 22
5 6	Aluminum Runaround (w/o Tractor brakes)	71 78	65.5 59.5
7	Copper Spider (w/o Tractor brakes)	71.5	65.5

4/26/78
All Three Axles on Mobile Home - 6 brakes

8 9	Copper Spider (w/Tractor brakes)	27.5 28
10 11	Copper Spider (w/o Tractor brakes)	39.5 36.5

4/26/78
Rear Two Axles on Mobile Home - 4 brakes

12 13	Copper Spider (w/Tractor brakes)	29.5 27

Weather - 4/20: Cool (58°F) after scattered showers; dry pavement (asphalt)
4/26: Warm (69°F) bright day; dry pavement (asphalt)

Tire pressures before tests - 60 psi

*"Runaround" describes wire from hitch down one side, across and up the other side.

TABLE 3. MOBILE HOME BRAKE WIRE VOLTAGES
(ALUMINUM UNCORRODED/COPPER UNCLEANED)

Connection Points	No. 3 Aluminum Wire (Volts)				14-Gauge Copper Wire (Volts)			
	Spider System		Runaround System		Spider System		Runaround System	
	No*	Yes*	No*	Yes*	No*	Yes*	No*	Yes*
Hitch/Trailer Connection:								
Tractor Side	11.220	11.410	11.230	11.247	11.099	11.099	11.103	11.105
Trailer Side	11.050	11.213	11.050	11.150	10.976	10.984	10.940	10.980
Distribution Point	9.155	8.620	8.250	8.660	9.150	9.020	8.590	8.965
Brake Connection Points								
Left Front	8.786	8.559			8.663	8.970		
Left Rear	8.780	8.559			8.661	8.970		
Right Front	8.785	8.552	8.200†	8.170	8.663	8.970	8.401†	8.536†
Right Rear	8.785	8.555			8.663	8.970		

*Indicates whether or not tow tractor brakes were applied in addition to mobile home brake actuator.

†Voltage at brake connection with greatest lead wire (last brake to receive signal).

TABLE 4. MOBILE HOME BRAKE WIRE VOLTAGES
(ALUMINUM CORRODED/COPPER UNCLEANED)

Connection Points	No.3 Aluminum Wire (Volts)				14-Gauge Copper Wire (Volts)			
	Spider System		Runaround System		Spider System		Runaround System	
	No*	Yes*	No*	Yes*	No*	Yes*	No*	Yes*
Hitch/Trailer Connection:								
Tractor Side	11.220	11.410	11.230	11.247	11.10	11.099	11.103	11.105
Trailer Side	10.20	10.51	9.77	9.96	10.99	11.01	10.88	10.92
Distribution Point	7.88	7.29	7.08	7.46	10.33	10.27	9.75	9.97
Brake Connection Points								
Left Front	7.95	7.71			8.89	9.11		
Left Rear	7.90	7.72			8.88	9.11		
Right Front	7.95	7.68	7.70†	7.52†	8.89	9.11	8.66†	8.89†
Right Rear	7.95	7.69			8.90	9.11		

*Same as Table 3 indicates whether or not tow tractor brakes were applied in addition to mobile home actuator.

†Voltage at brake connection with greatest lead wire (last brake to receive signal)

First voltage tests on the No. 3 aluminum runaround configuration indicated a significant drop across the connection between the chassis and tractor wiring. Inspection revealed that the surface of the aluminum wire was corroded. The soft aluminum wire oxidizes very rapidly when exposed to the atmosphere. Once the wires were cleaned, the voltage drop across the connection was significantly reduced. The tow tractor had a 12-volt electrical system with a minimum power draw because the unit was towed during the daylight hours. Therefore, a maximum power supply was available for the brake system. Later, No. 8 copper wire was installed from the tractor battery to the hitch junction. The measured voltages of both the aluminum and copper brake configurations at various points are presented in Tables 3 and 4.

VI. SUMMARY

The primary problems encountered with mobile home aluminum brake wire are the same problems encountered with the aluminum interior wiring: (1) Corrosion developing from normal oxidation and heat caused by electric current; (2) inadequate terminal connections; and (3) installation problems. The stranded aluminum wire tested, which was one wire diameter larger than the copper wire, was not comparable to the performance of the copper wire. (Refer to Tables 2, 3, and 4) The latter problems were aggravated by the galvanic action caused by dissimilar metals. Humidity, road film, and particularly salt, when added to wet roads, accelerated the initiation of the galvanic action to a large degree. Thus, when using aluminum instead of copper wire, the performance of the mobile home brake system can be reduced 20 percent regardless of the wiring configuration due to rapid oxidation of the surface contact area. Table 3 presents the comparative voltage data resulting from testing new aluminum wire with cleaned and polished terminals and large clamped areas at the terminations as opposed to copper brake wire installed without cleaning and standard one-way terminations. Table 4 presents the voltage data resulting from testing corroded aluminum wire against rusty contact areas and alligator clips from the tractor to the mobile home brake wire as opposed to copper brake wire installed as before. The voltage reduction with the aluminum wire is significant when compared to the standard copper wire installation. In addition to the voltage tests, the 20/40 stop tests also proved aluminum wire less effective than the copper wire by approximately 10 to 15 percent.

Testing of aluminum and copper brake wire systems also revealed that the common "runaround" wire configuration used in many systems causes unsteady braking due to the nature of its distribution of power. On the other hand, the "spider" configuration, also investigated in this study, demonstrated stable braking because of its centralized power distribution. Hence, the use of the "spider" configuration in a brake wire system provides a more uniform and effective braking capability.

During the latter voltage tests, it was noted that the brake lights were so dim that they could not be seen in the bright sunlight by a person following the unit in a vehicle 100 feet away. The other test mobile home experienced the same problem. The cause of the low voltage was the long run (69 feet) of taillight and brake light wire from the hitch to the rear wall as well as the small size of the wire used and the poor ground connection from mobile home to tractor via only the ball hitch. In essence, the taillight assemblies did not have adequate voltage to meet the illumination criteria of FMVSS No. 108. A heavy, well grounded jumper wire from the hitch coupler frame to the tractor frame improved the voltage increasing the brightness of the taillight, but the brightness was still considered inadequate. Finally, with 10 volts at the taillight, the brightness was increased by a factor of four.

Under the 20/40 stop test the T-1 with an empty weight of 16,000 and an additional 4,000 lb of furniture totaling 20,000 lb could be stopped with the lightweight SwRI tow tractor within the required 40 ft. The unit could also be stopped within the required 40 ft using only the tractor brakes. There was a difference of only 0.5 to 1.0 ft in the stopping distance with and without the mobile home brakes that were classed as 20-percent effective. The brakes were then overhauled using locally purchased replacement parts and coordinated with the axle manufacturer that analyzed and interpreted the parts assembled along with test results. The axle manufacturer reported that the lining material, heavier coil and anvil, and slightly heavier brake drums resulted in a 30- to 35-percent effective brake assembly. As noted during a demonstration program for HUD and Industry at SwRI, the wheels could be "locked-up" with this repaired brake assembly.

To conclude, the 20-percent effective brakes apparently do not provide significant or adequate stopping or steering force for the mobile home, as indicated by the SwRI tests, especially during panic stops. It is recommended that a 30- to 35-percent effective brake system be used to increase safety, stopping capability and control, especially if reuse of the brake and axle is contemplated. If aluminum wire is used for mobile home brakes, proper instructions for cleaning, clamping, and inspection must be provided the transporters.

VII. RECOMMENDATIONS

The tests conducted indicate that at least 10.75 volts must be maintained at the tractor-to-mobile home hitch brake connection throughout the stop to achieve at least 20-percent effective braking. Therefore, it is recommended that the system be designed to achieve, as a minimum, 10.75 volts at the brake wire connection at the tractor-to-mobile home hitch on all electric brake systems.

In view of the results generated by the stop tests during this program, the 20-40 stop test should be revised to develop a three part data package for a more realistic approach to determining the exact capability of the combined brake systems of the tow tractor and mobile home. The following is the recommended wording for the standard:

Running Gear:

Conduct 20-40 Stop Tests

Purpose: To establish effectiveness of mobile home braking system for control and stops

Equipment: Two motion picture cameras

Tape (100 ft)

Marking paint for asphalt and wheel/tires

Level road, 40-ft wide, 1/4 mile long

C.B. radio or walkie talkie communications

Fifth wheel or calibrated speedometer for speed control

Weight of mobile

Weight of tow tractor

Test Procedure: Select a level, smooth stretch of asphalt highway or road which can be used for test. Consider areas at each end for turn-around purposes. Select a test section at one end and paint two parallel lines across the road 40-feet apart. Use a contrasting color. Paint 90 degree radial lines on the wheel and tires of the tow tractor and also on the mobile home wheels and tires. Paint only on the side that will be facing the cameras. Set up one motion picture camera at the second 40-ft mark with adequate field of view for tractor and both 40-ft marks. Set up the second motion picture camera to key on the mobile home wheels. An automatic or remote control brake application system can be used if desired. In order to include the operators reaction time, a communication system can be used where the ground operator stands on the first line and voices the signal to the driver to apply the brakes when he crosses the first stripe. Determine if both the tractor and mobile home brakes produced a skid. Measure the skid distance. Determine the stopping distance (including reaction time) from the first mark. Measure the tractor skid marks for actual stopping distance, less reaction time. Determine if the skid is straight forward (does tractor have to control the mobile home). (i) Conduct three tests in accordance with the above and use the cameras on each stop. Average the results. (ii) Conduct three additional tests in accordance with the above using or applying only the tractor brakes. Average the results. (iii) Conduct three additional tests in accordance with the above using or applying only the mobile home brakes. The mobile home and tractor must stop within the 40-foot marker for items (i) and (ii). The stopping distance for (iii) must not be greater than 80 feet.

The basic configuration of tow tractor/trailer combinations requires that brakes be installed on both the tractor and trailer for adequate stopping capabilities. The trailer brakes are applied first, thereby "dragging" the trailer while the tractor is free to use its brakes to "control" the stop. The 35-percent effective brakes tested on mobile homes by SwRI permitted this kind of controlled stopping capability. Hence, it is recommended that consideration be given to the use of 35-percent effective brakes on mobile homes. This recommendation is also made in view of the potential reusability of running gear systems.

Lastly, it is important that taillight assemblies have adequate voltage to meet the illumination criteria of FMVSS No. 108.

APPENDIX A

Brake Test

AN AXLE COMPANY BRAKE TEST

PRODUCT ENGINEERING

DATE: May 24, 1974

TEST NO: 203

PROJECT REF: 1-33

USAGE: Mobile home

SUBJECT: 12 x 2 Mobile Home Weld-On Brake Performance

OBJECTIVE: Test the mobile home brake for compliance to paragraph B.9.1. of the appendix to Section B of ANSI Standard A119.1, which states, "Brakes on tractor and mobile homes should be such that the maximum stopping distance from a velocity of 20 mph does not exceed 40 feet (U.S. Department of Transportation Regulations).

CONCLUSION: The combination of vehicles as specified meets the test requirement with the trailer brakes operating.

DISCUSSION: The data summary gives the results of the test. Distance includes the range and average of the three stops. Calculated deceleration is derived from the average distance and would, therefore, include brake system reaction time. Observed deceleration, while not recorded, was naturally higher and easily met the 43.5% retarding force D.O.T. requirement. Retarding force is the total developed by the brakes used for that particular mode of the test, again calculated from the average stopping distance.

Equivalent deceleration is derived from the retarding force and is simply the deceleration rate either vehicle should be able to attain alone, when it does not have to stop the other vehicle. The most useful number here is the value for mode 2, trailer brakes only. The trailer brakes would be capable of 6.9 fps or .21G if stopping the trailer gross axle weight rating (GAWR).

EQUIPMENT: Towing Vehicle - 1972, weight is 7630 lbs.
Front Brakes 14" x 2 1/2" two leading shoes
Rear brakes 15" x 5" twinplex
Hydraulic with vacuum power assist

Test Vehicle - Mobile home simulation trailer, 13,050 lbs.
Brakes 12" x 2" electric - tandem axles

Test personnel weight is 435 lbs.

The GVW is 21,115 lbs, weight per trailer axle was 6000 lbs.

Axles = Ai 81 1/2 - 64 1/4 S.C. over
Backing plates = P36-39
Hubs = 8-182
Linings = production
Links = P40-69

May 24, 1974

EQUIPMENT, Cont.

Magnets = small case C.R.
Rims = TL-600
Springs = mono-leafs
Tires = 8 x 14.5 12 ply 95 psi

INSTRUMENTATION: Shotgun
Tape measure
Calibrated speedometer

TEST PROCEDURE: Burnish - 50 snubs 30-10 mph, 10fps^2

Effectiveness - 3 full stops from 20 mph each for:

1. Truck brakes only
2. Trailer brakes only
3. All brakes

Measure distance to stop from point of initial brake application.

DATA SUMMARY: (Also, see graph A)

Mode	Distance in ft. Range	Distance in ft. Ave.	Calculated Decel in fps^2	Retarding Force in lbs.	Equivalent Decel in fps^2	Equivalent Decel in G's
1	38 to 42	40.0	10.8	7056	24.9	.77
2	100 to 117	109.0	3.91	2564	6.9	.21
3	29 to 33	31.6	13.6	8925	13.6	.42

SUBMITTED BY:__________ APPROVED BY:__________

TEMPORARY STIFFENERS

I. OBJECTIVES

Conjecturing that temporary stiffeners, such as tension cables, could reduce transportation-induced deflections in mobile homes, SwRI conducted investigations on temporary stiffening of the mobile home structural box during the transportation phase for purposes of retarding related deterioration.

The resulting report compares quantitative characteristics of a mobile home with and without temporary stiffeners. The objective is to present the effects of the stiffeners on those characteristics associated with degradation and, consequently, to recommend for or against their use as well as present the methods of application.

II. INTRODUCTION

The stiffness method investigated in this task involved the use of vertical lift cables tensioned to resist vertical sagging and/or deflection resulting from static and dynamic loads. The latter vertical lift cables were externally mounted on each side. For resistance to torsional deflection, tensioned cables were mounted extending from each wall/floor junction to its opposite wall/ceiling junction. These cross-cables were spaced along the mobile home's open span at distances dependent upon the length of the span. The external lift cables extended along each outside wall with attachments to the longitudinal I-beams at the rear and at a point midway between the axles and hitch coupler in the front section. From each of these points the cable extended diagonally to a tie or support point at the roof line over the axles.

The test program for this effort consisted, in part, of collecting data from several transducers located on an in-transit test unit, with and without temporary stiffeners tensioned to absorb loads. Analytical comparisons of the data from each accelerometer, strain gage, and deflection transducer of interest were made between runs. Also, apparent torsional and bending stiffnesses were calculated based upon SwRI's recommended mobile home static Torsion Test and Vertical Bending Deflection Test.*

The results of these tests were used in recommending temporary stiffening methods for various mobile home types including retrofitting existing mobile homes and designing adequate anchor points for new mobile homes.

---

*Refer to Task III, Vol. 1, Part I for description of test procedures.

III. TEST SPECIMEN

From test units used by SwRI in the previous mobile home study for HUD, T-1* was selected to be used in this modification. SwRI decided to test a single-wide unit rather than half of a double-wide on the basis that if appreciable results were achieved with a single-wide, then a double-wide, which has less torsional regidity, would benefit even more. This particular single-wide test unit was chosen because it had been subjected to documented miles of travel, evident in its torsional and bending stiffnesses. Both stiffnesses were greatly reduced from the measured values recorded when the unit was new.

IV. TEST SETUP AND PROCEDURE

The testing consisted of two work efforts listed as follows:

(1) In-Transit testing involving data retrievel from instrumented mobile home to measure and analyze the dynamic factors associated with torsion and vertical bending;

(2) Static testing of mobile home to measure its effective torsional and bending stiffnesses with and without temporary stiffeners.

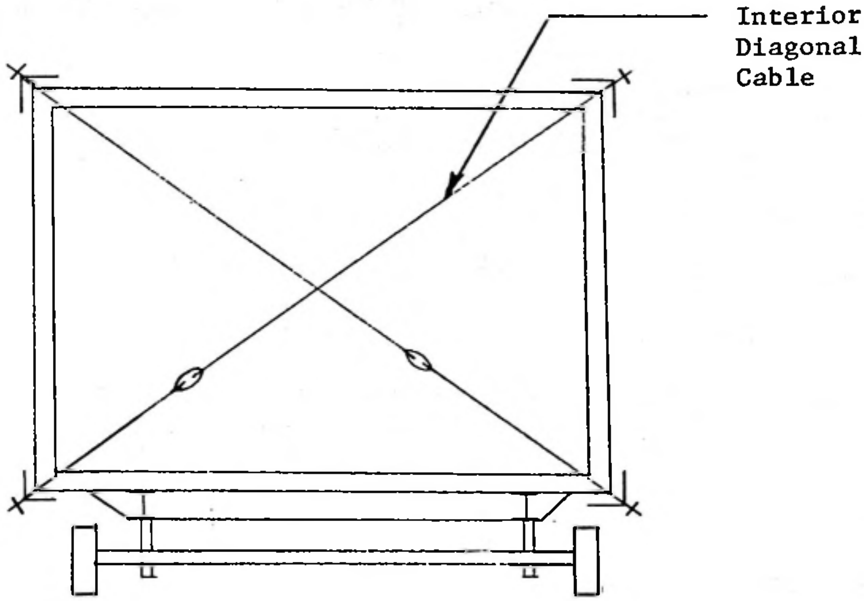
The two work efforts were performed both with and without tensioning of temporary stiffeners in order to compare the data for each case. The temporary stiffeners installed were the tension cable type. (See Figure 1.) Inside the mobile home were diagonal cross-cables extending from each wall/floor interface to the opposite wall/ceiling interface. Anchoring was accomplished with eyebolts that penetrated the walls and fastened to large angle pressure plates on exterior corners to distribute the loads. Turnbuckles were used to accomplish the tensioning. There were two pair of torsion cross-cables spaced evenly in the long open span of the living room and adjoining kitchen area.

Exterior lift cables extended longitudinally, one each side, from the lower rear corner upward to the roof wall intersection over the axles and down to the longitudinal I-beam at a point midway between hitch coupler and axles. Angle plates on exterior corners distributed the compression loads exerted by the cable on the lower corners where the cable turned under the floor to anchor points on the I-beam. At the upper point of the cables along the roof line, eyes were attached to the same angle plates used to anchor the interior cables.

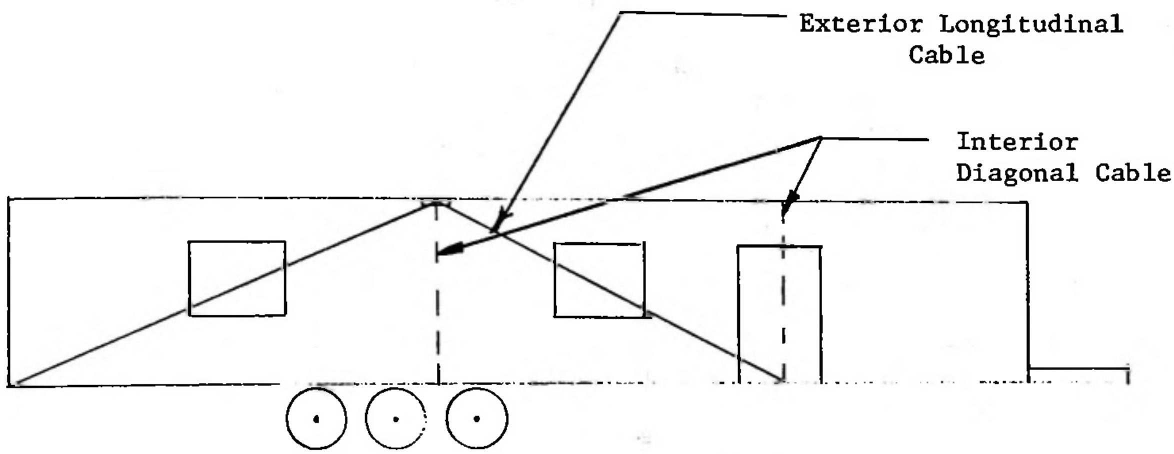
For the dynamic testing, the instrumentation consisted of strategically located accelerometers and strain gages.

---

*Refer to Task III, Vol. 1, Part I for T-1 history.



Cross-Section



Side View

FIGURE 1. TEMPORARY STIFFENERS

The accelerometers were located on the end walls at upper and lower, right and left corners, and on the floor over the axle as diagrammed in Figure 2. The orientation of each transducer (indicated in the figure) was either vertical, longitudinal (fore/aft), or lateral (side-to-side). This combination of transducers provided appropriate data for the determination of torsional and vertical accelerations.

The transducer low-level signals were displayed by a strip chart recorder after having been conditioned and amplified. The typical signal conditioner, shown in Figure 3, adjusts the voltage applied to the transducer, balances the bridge, and amplifies the output. The strip chart recorder used was a multichannel Honeywell visicorder or light beam oscillograph. It produced a chart with output signals of six transducers recorded simultaneously.

Dynamic data were collected as the mobile home was towed over four selected stretches of road that represented significant and varied conditions. These four roads were considered typical road conditions over which mobile homes routinely travel.

The static testing consisted of mobile home torsion and bending deflection tests in accordance with SwRI recommended test procedures. These procedures are presented in Task IV, Vol. 1, Part I. In addition to the leveled mobile home, the tests required a calibrated load jack, a dial micrometer, 1000-lb portable weights, and a plumb line pendulum. The torsion test measured angular deflection of the mobile home structure as a function of vertical uploading on each front and rear lower corner. These data developed an effective torsional stiffness. The deflection test measured vertical deflection of the rear wall and at the midpoint of axle and coupler span as a function of vertical down-loading at each point. The rear end of the box structure

ACCELEROMETER
LABELING CODE

1ST LETTER	2ND LETTER	3RD LETTER
U - UPPER L - LOWER	R - RIGHT L - LEFT C - CENTER	R - REAR F - FRONT

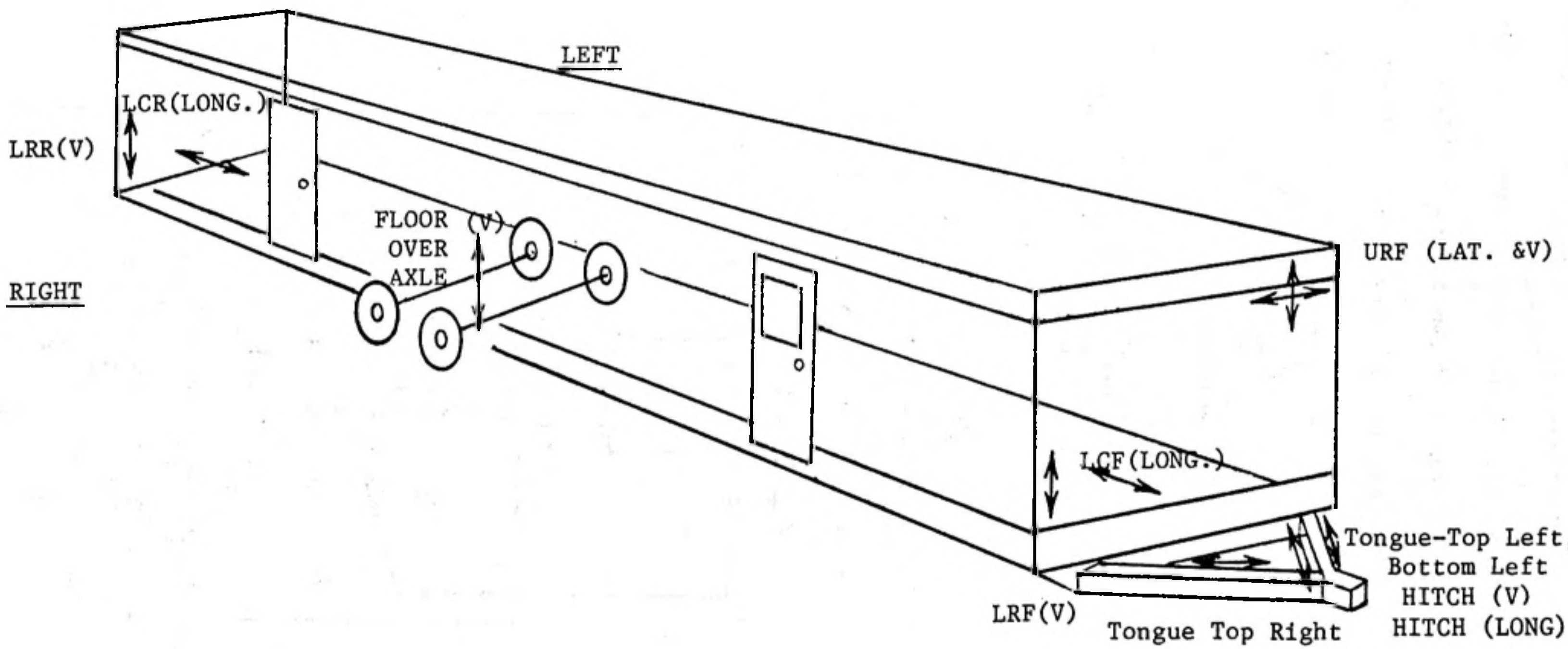


FIGURE 2. ACCELEROMETER AND STRAIN GAGE

LOCATIONS

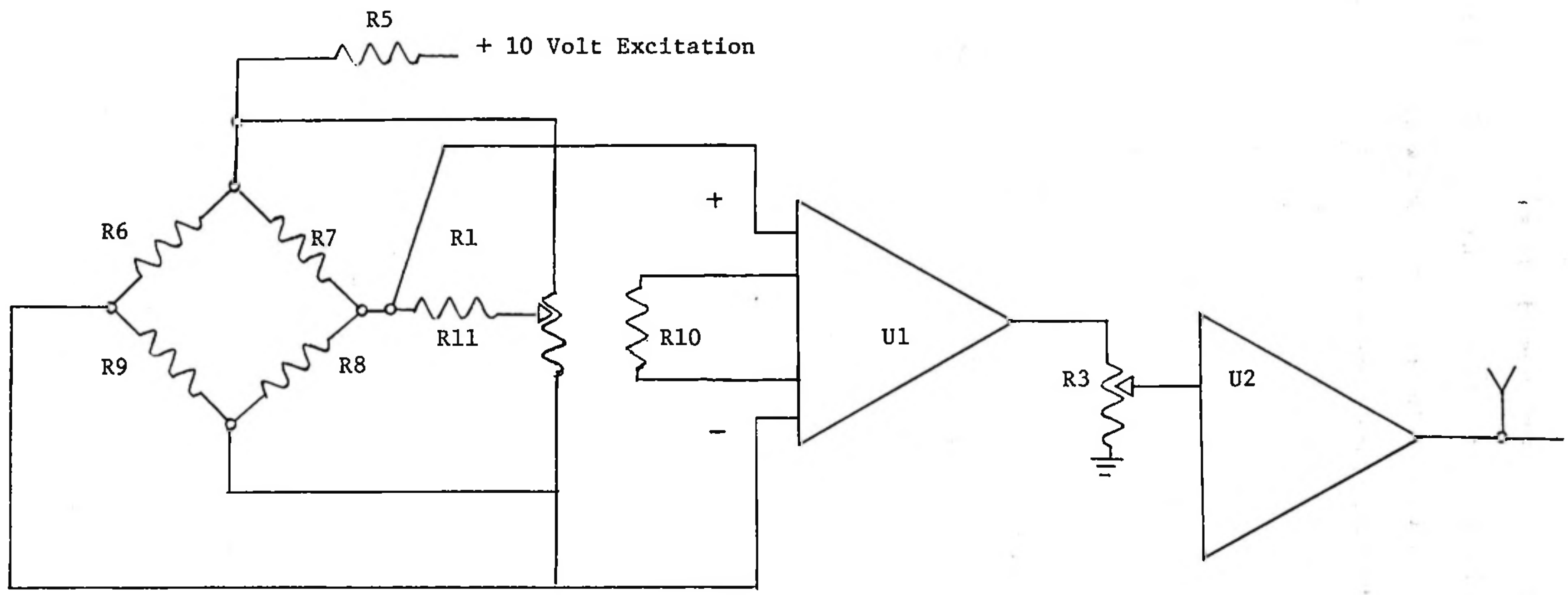


FIGURE 3. SIGNAL CONDITIONER

was supported by cantilever and the front was simply supported. These load-versus-deflection data developed an effective bending stiffness. These two stiffness values were compared for the two cases with and without tensioned temporary stiffeners to determine approximate in-transit effects related to stiffness in torsion and vertical bending.

V. INTRODUCTION OF DYNAMIC DATA

The raw data traces and summary tables for this study are available from SwRI. From the data in the summary tables, Table 1 was compiled. This table presents values of maximum peak-to-peak units for all the transducers monitored. Values are assembled for each condition of the temporary stiffeners, loose or tight, corresponding to each of the four road events.

The values referred to as "Average Maximum Peak-to-Peak Unit" were derived as follows: Significant maximum and minimum peaks in both the positive and negative directions were selected from the original data traces and tabulated. This was performed for each transducer signal recorded during each road event. Usually, the road event occurred three times for each transducer under each cable condition. Averaging these three maximum signals and summing those for positive and negative directions produced the average maximum peak-to-peak values. These values are consequently comparable only horizontally in Table 1; that is, with this table, comparison between the effects of the cables can be made only for a particular transducer and a particular road event.

To further facilitate the analysis of temporary stiffening effects, Figure 1 specifies under which cable condition each transducer exhibits a signal greater by 10 percent or more for at least three road events. Also indicated are the cable conditions which excite the other transducers to some degree.

TABLE 1.

DYNAMIC DATA SUMMARY

Transducer Location *	$\overline{RC}$ †	Avg. Max. Peak-to-Peak g's		Greater by 10% or More	
		Without**	With**	Without**	With**
URF(V)	1.1	0.90	0.87		
	1.2	1.18	1.30		X
	1.3	1.40	1.74		X
	1.4	2.14	2.31		X
LRF(V)	1.1	0.36	0.37		X
	1.2	0.50	0.56		X
	1.3	0.73	0.80		X
	1.4	1.13	0.95	X	
FOA(V)	1.1	0.74	0.75		
	1.2	1.44	1.34		
	1.3	2.44	1.61		
	1.4	2.84	2.29	X	
LRR(V)	1.1	0.61	0.53	X	
	1.2	0.98	1.08		X
	1.3	2.18	2.58		X
	1.4	1.72	1.57	X	

*Refer to Figure 2.
†Road condition factor as defined in Task I, Volume I.
** With or without temporary stiffeners.

TABLE 1. (Cont'd)

Transducer Location *	$\overline{RC}$ †	Maximum Peak-to-Peak Units		Greater by 10% or More	
		Without**	With**	Without	With
URF (Lat) (g's)	1.1	0.27	0.12	X	
	1.2	0.52	0.21	X	
	1.3	0.81	0.20	X	
	1.4	0.72	0.33	X	
HITCH- (Long.)	1.1	621	649		
(lb)	1.2	1243	1288		
	1.3	734	863		X
	1.4	2162	1347	X	
ULR (Lat) (g's)	1.1	0.12	0.87		X
	1.2	0.26	1.23		X
	1.3	0.92	1.62		X
	1.4	0.48	2.23		X
LCR (Long.)(g's)	1.1	0.12	0.16		X
	1.2	0.24	0.26		
	1.3	0.41	0.38	X	
	1.4	0.47	0.43	X	

See notes on first page of Table.

TABLE 1. (Cont'd)

Transducer Location *	$\overline{RC}$ †	Avg. Max. Peak-to-Peak lbs.		Greater by 10% or More	
		Without**	With**	Without	With
Hitch -	1.1	2422	2898		X
Vertical Force	1.2	5601	6214		X
	1.3	13110	13696		X
	1.4	8326	7527	X	
Tongue S.G.	1.1	1439	2469		X
Top Right	1.2	2440	3745		X
	1.3	3760	11501		X
	1.4	6347	6013		
Tongue S.G.	1.1	1962	2254		X
Top Left	1.2	4032	4875		X
	1.3	10478	10634		X
	1.4	6946	6013	X	
Tongue S.G.	1.1	1640	2025		X
Bottom Left	1.2	3373	3921		X
	1.3	8561	8932		X
	1.4	5733	5062	X	

See notes on first page of Table.

VI. INTRODUCTION OF STATIC DATA

Data from the static tests on the mobile home, with and without temporary stiffeners, provided comparison of the box structure stiffness relative to the cable tensions. The two tests conducted were the torsion test and the bending deflection test. (See Task VII for procedure.)

A. Torsion Test

The torsion test determined the relationship between the torsional moment applied about the longitudinal axis of a mobile home and the resulting angular deflection. That relationship is expressed as $\bar{J}$, the effective torsional stiffness. The dynamic analysis conducted under Task I of this project developed formulae through regression analysis for the front and rear $\bar{J}$'s of a single-wide mobile home as follows:

$$J_R = 851.1 \quad P_R h_R W_R^{-.391} / \ell_R$$

$$J_F = 2448.0 \quad P_F h_F W_F^{-.277} / \ell_F$$

where subscripts R and F denote rear and front, respectively, and the following definitions apply:

P_R, P_F– applied loads at the lower corner of the mobile home (lb);

h_R h_F– distances from the center of rotation to the point of loading (in.);

W_R W_F– measured lateral displacements of pendulum attached to mobile home (in.);

ℓ_R ℓ_F– pendulum lengths (in.).

The applied moment is the product of the load at a corner (P_R or P_F) and the distance from the center of the mobile home to the point of application (h_R or h_F). Rather than angular deflection, the formulae use the displacement of a pendulum with respect to the twisted mobile home end wall. Other formulae were derived for double-wide mobile homes.

Data collected from the test unit are presented in Tables 2 and 3 with the computed $\overline{J}$'s for each cable condition and each mobile home end. The pendulum deflections x_f and x_r are measured from the maximum deflection at zero upward load on each corner.

B. Vertical Bending Test

The vertical bending test was performed to relate vertical deflection of the box structure to the applied load for both cable conditions, loose and tight. At each of two points, one midway between axle and hitch, the other at the rear of the mobile home, vertical down loads were applied and deflections were measured. The collected data were put into formulas for front and rear effective $(\overline{EI})$'s, Equations 3 and 4.

$$(\overline{EI}) = 36\ell_f^{\,3}(P/y)_f \tag{3}$$

$$(\overline{EI}) = 575\ell_r^{\,3}(P/y)_r(1 + \ell_f/\ell_r) \tag{4}$$

where,

ℓ_f = length from front to middle supports (ft);

ℓ_r = length from middle to rear supports (ft);

P = loads (lb);

y = deflection of mobile home (in.).

Data collected during this test are presented in Table 4 along with the computed $\overline{EI}$ for each data pair. Average $(\overline{EI})$'s for each end are included. Zero load and deflection are defined as the unsupported weight of the mobile home with technician and empty barrels in position.

TABLE 2. TORSION TEST RESULTS WITHOUT TEMPORARY STIFFENERS

FRONT END

$$\bar{J}_F = 2448\, P_F h_F W_F^{-.277} / \ell_f$$

$h_F = 48$ in.

$\ell_F = 50$ in.

	P_F(lb)	W_F(in.)	$\bar{J}_F$(in.^{4})
RIGHT SIDE	0	0	-
	580	.25	2.00 (10^6)
	1170	.22	4.18 (10^6)
	1750	.34	5.54 (10^6)
	2330	.53	6.53 (10^6)
	0	.25	-
	-580	-.13	2.40 (10^6)
	-1170	-.19	4.36 (10^6)
	-1750	-.56	4.83 (10^6)
	0	0	-
		Avg. Right $\bar{J}_F$ = 4.26(10^6)	
LEFT SIDE	0	0	-
	590	.16	2.30 (10^6)
	1170	.28	3.91 (10^6)
	1750	.41	5.26 (10^6)
	1870	.44	5.52 (10^6)
	0	0	-
	-580	-.09	2.66 (10^6)
	-1160	-.22	4.15 (10^6)
	-1750	-.34	5.54 (10^6)
	-2330	-.47	6.75 (10^6)
	0	0	-
		Avg. Left $\bar{J}_F$ = 4.51 (10^6)	
		Avg. $\bar{J}_F$ = 4.39 (10^6)	

Note: Tables 2 and 3 present the left and right, front and rear torsion stiffnesses ($\bar{J}$), with and without temporary stiffeners. Note the significant increase in stiffness when the temporary stiffeners are added.

TABLE 2. (CONT')

REAR END

$$\bar{J}_R = 851.1\, P_R h_R W_R^{-.391} / \ell_R$$

h_R = 48 in.
ℓ_R = 50 in.

	P_R(lb)	W_R(in.)	$\bar{J}_R$(in.^{4})
RIGHT SIDE	0	0	-
	590	.19	9.23 (10^5)
	1170	.31	15.1 (10^5)
	1400	.31	18.1 (10^5)
	0	0	-
	-580	-.13	10.5 (10^5)
	-1160	-.19	18.1 (10^5)
	-1630	-.31	21.1 (10^5)
	0	0	-
			Avg. Right $\bar{J}_R$ = 1.54 (10^6)
LEFT SIDE	0	0	-
	580	0	-
	1160	.13	2.10(10^6)
	1400	.19	2.19(10^6)
	0	0	-
	-590	-.09	1.24(10^6)
	-1170	-.16	1.96(10^6)
	-1520	-.22	2.24(10^6)
	0	0	-
			Avg. Left $\bar{J}_R$ = 1.95 (10^6)

Avg. $\bar{J}_R$ = 1.75 (10^6)

TABLE 3. TORSION TEST RESULTS
WITH TEMPORARY STIFFENERS

FRONT END

$$\bar{J}_F = 2448\ P_F h_F W_F^{-.277} / \ell_F$$

h_R = 48 in.
ℓ_F = 50 in.

	P_F(lb)	W_F(lb)	$\bar{J}_F$(in.^{4})
RIGHT SIDE	0	0	-
	590	.13	2.44 (10^6)
	1170	.19	4.36 (10^6)
	1640	.25	5.66 (10^6)
	0	.06	-
	-580	-.06	2.97 (10^6)
	-1160	-.13	4.80 (10^6)
	-1750	-.25	6.04 (10^6)
	2330	-.31	7.57 (10^6)
	0	0	-
		Avg. Right $\bar{J}_F$ = 4.83 (10^6)	
LEFT SIDE	0	0	-
	580	.06	2.97 (10^6)
	1170	.13	4.84 (10^6)
	1750	.25	6.04 (10^6)
	2100	.31	6.83 (10^6)
	0	.06	-
	-580	0	-
	-1170	-.06	5.99 (10^6)
	-1750	-.13	7.24 (10^6)
	-2100	-.19	7.82 (10^6)
	0	0	-
		Avg. Left $\bar{J}_F$ = 5.96 (10^6)	
		Avg. $\bar{J}_F$ = 5.40 (10^6)	

Note: Tables 2 and 3 present the left and right, front and rear torsion stiffnesses ($\bar{J}$), with and without temporary stiffeners. Note the significant increase in stiffness when the temporary stiffeners are added.

TABLE 3. (CONT'D)

REAR END

$$\bar{J}_R = 851.1\ P_R h_R W_R^{-.391}/\ell_R$$

h_R = 48 in.
ℓ_R = 50 in.

	P_R(lb)	W_R(in.)	$\bar{J}_R$(in.^{4})
RIGHT SIDE	0	0	-
	580	.06	1.42(10^6)
	0	0	-
	-580	-.06	1.42(10^6)
	-1170	-.06	2.87(10^6)
	-1750	-.09	3.67(10^6)
	-2330	-.13	4.22(10^6)
	-2450	-.13	4.44(10^6)
	0	0	-

Avg. Right $\bar{J}_R$ = 3.01 (10^6)

	P_R(lb)	W_R(in.)	$\bar{J}_R$(in.^{4})
LEFT SIDE	0	0	-
	590	.03	1.90(10^6)
	1170	.06	2.87(10^6)
	1750	.13	3.17(10^6)
	2340	.19	3.66(10^6)
	2570	.25	3.61(10^6)
	0	.06	-
	580	0	-
	930	-.06	2.28(10^6)
	0	0	-

Avg. Left $\bar{J}_R$ = 2.92(10^6)

Avg. $\bar{J}_R$ = 2.97(10^6)

TABLE 4. VERTICAL BENDING TEST RESULTS

P(lbs.)	Y-WITHOUT TEMPORARY STIFFENERS (IN.)	Y-WITH TEMPORARY STIFFENERS (IN.)	$(\overline{EI})_f$-WITHOUT TEMPORARY STIFFENERS (lb. - in.^{2})	$(\overline{EI})_f$-WITH TEMPORARY STIFFENERS (lb. - in.^{2})
250	.032	.015	$1.01(10^{10})$	$2.16(10^{10})$
500	.067	.040	$.965(10^{10})$	$1.62(10^{10})$
750	.093	.065	$1.04(10^{10})$	$1.49(10^{10})$
1000	.124	.091	1.04	$1.42(10^{10})$
		$(\overline{EI})_f$ Avgs. =	$1.02(10^{10})$	$1.67(10^{10})$

REAR END

P (lbs)	Y-WITHOUT	Y-WITH	$(\overline{EI})_r$ - WITHOUT	$(\overline{EI})_r$ -WITH
250	.270	.297	$2.33(10^{10})$	$2.12(10^{10})$
500	.574	.48	$2.19(10^{10})$	$2.62(10^{10})$
750	.843	.615	$2.24(10^{10})$	$3.07(10^{10})$
1000	1.155	.770	$2.18(10^{10})$	$3.27(10^{10})$
		$(\overline{EI})_r$ Avgs. =	$2.23(10^{10})$	$2.78(10^{10})$

Note: The variation of the individual $\overline{EI}$ factor with load and deflection should be noted because it is a function of road surface condition. The most significant item is the effect on $\overline{EI}$ with and without the addition of the temporary stiffness.

VII. SUMMARY

Temporary cable stiffeners were installed on T-1 in accordance with the theory that the maximum twist (or torsion) occurs in the longest open span(s), as was measured and verified during the road tests. Two pair of diagonal internal cables were installed in the long open span of T-1 between the front wall of the living room and the rear wall of the kitchen. The vertical lift external cables were applied to reduce vertical flexure. Deflection at each of the following attach points is measured in the static test: (1) midway between the hitch and axles and (2) at the rear-most wall. (See Figure 1.) Both internal and external cables were preloaded in order to add some degree of rigidity to the box structure by removing some slack. However, the 1000 lb of tension preloaded in each external cable did not prove to be enough to lift the sagging wall completely to a level position.

The results were definitive as is indicated in Table 5. In addition, this temporary stiffening verifies the validity of torsion and deflection tests because the results indicate the presence of the pretensioned cables and the increase in $\overline{EI}$ and $\overline{J}$, accordingly. The percentage increase is evident by the results noted in Table 5.

Stiffness did not increase in those areas unaffected by the temporary stiffeners. The information recorded by accelerometers on the front wall and over the axle differed little whether or not tensioned cables were added. Also, in making a 90-deg turn with the mobile home, side loads developed on the hitch revealing no increase in stiffness except for a transmission of torsion in the structural box. Yet, the percentage increase in stiffeners in the affected areas was significant, and correlation was good

TABLE 5. SUMMARY OF TEST DATA

Mobile Home Test Unit # T-1

TEST	INSTRUMENTATION	MOBILE LOCATION	A WITHOUT STIFFENING		B WITH STIFFENING		PERCENT INCREASE
Torsion	*	Front L.H.	4.51×10^6		5.96×10^6		32
		Front R.H.	4.26×10^6		4.83×10^6		13
Torsion	*	Rear L.H.	1.95×10^6		2.92×10^6		50
		Rear R. H.	1.54×10^6		3.01×10^6		95
Vertical Deflection	*	Front	1.02×10^{10}		1.67×10^{10}		64
Vertical Deflection	*	Rear	2.23×10^{10}		2.78×10^{10}		25
Accelerometers:							
LRF (V)	Accel	Lower Right Front	1.13	g's	0.95	g's	-16
			0.50		0.56		12
			0.36		0.37		3
			0.73		0.80		10
C.G. (V)	Accel	Floor Over Axle	2.84	g's	2.29	g's	-19
			1.44		1.34		- 7
			0.74		0.75		1
			2.44		1.61		-34
LRR (V)	Accel	Right Rear	1.72	g's	1.57	g's	- 9
			0.98		1.08		10
			0.61		0.53		-13
			2.18		2.58		18
ULR (Lat)	Accel	Left-rear	0.48	g's	2.23	g's	365
			0.26		1.23		373
			0.12		0.87		625
			0.92		1.62		76
Tongue S.G.	Strain Gage	Top R.H. A-Frame	6347	lb	6013	lb	- 5
			2440		3745		53
			1439		2469		72
			3760		11,501		206

between the static and in-transit tests. From the results obtained during the latter testing, it is clear that the addition of tensioned cables is an effective method of temporarily stiffening mobile homes for transportation.

The data contained in this report were developed from tests conducted on a single-wide mobile home. As previously stated, the effects on a half of a double-wide would be more pronounced because of the higher deflections achieved due to the "open" marriage wall. In addition to the temporary stiffening via the use of cables, it is recommended that double-wides install a temporary plywood wall and studs in place of the plastic tarp. It is possible that the temporary (reusable) plywood will and studs could generate sufficient stiffness to meet the minimum $\overline{EI}$ and $\overline{J}$ requirements. If not, then the cables could be added to achieve the requirements.

VIII. RECOMMENDATIONS

The following is the suggested wording for Subpart "J" of the Standard to achieve the $\overline{EI}$ and $\overline{J}$ for the transportation mode:

TEMPORARY STIFFENING

The rapid rate of degradation associated with the transportation phase for mobile homes is reduced by the application of temporary stiffeners to supplement the assembled structure. Temporary stiffening shall be applied to double-wides:

(i) Install a temporary stud and plywood wall along the marriage wall in place of the protective plastic sheet. Attach the wall securely to develop additional stiffness. (The increased stiffness can be measured by the torsion and deflection test described in Subpart E "Testing".)

(ii) In the event the temporary marriage wall does not produce the required $\overline{EI}$ and $\overline{J}$, cable stiffeners shall be added in both the diagonal and vertical planes to increase torsion and vertical stiffness, respectively.

AXLE/SPRING/SPRING HANGER/WHEEL SYSTEM

I. OBJECTIVES

Degradation and possible overstressing of undercarriage components during the previous mobile home research prompted SwRI to recommend to HUD that a study be conducted specifically addressing running gear behavior.

The resulting report herein is an evaluation of the undercarriage components, both individually and as a system. The objective of the report is to present the conditions under which the undercarriage performs, its resulting degradations, and any recommendations regarding improvement of running gear performance.

II. INTRODUCTION

The undercarriage system of a mobile home has become an area of increasing concern because of the frequent component failures occurring during routine transportation. Careful design and attachment of springs, axles, hangers, and wheel systems are especially important on two-axle systems since a failure of one could easily cause serious steering and handling problems. It follows that the design and dependability of a one-axle system is even more critical.

Southwest Research Institute has experienced problems with the mobile home running gear in testing mobile homes for transportation effects. For example, on one occasion during a 45-mph test run, two suspension spring hangers broke, one rotating forward and one backward. This allowed the axle to "twist" directing the mobile home out of its normal trailing position into an angular position across on-coming traffic lanes. The incident was sudden and without warning such that the driver had no time for evasive action. Moreover, mobile homes with their large vertical surface area fall easy prey to high-speed air currents. The inherent lateral instability of a unit resting on a narrow spring suspension system can be aggravated by natural high winds or high air pressure caused by a large vehicle passing in the opposite direction. However induced, the air pressure results in side force or over-turning moment that significantly increases the load on the suspension system.

In order to determine specific problem areas, SwRI, through the American Association of State Highway and Transportation Officials (AASHTO), asked all state highway departments to complete the questionnaire on the following page. From the summary spread sheet of the questionnaire followed by Table 2 which tabulates the ratio of percentages replying either yes or no to the questions, several comments can be made. Regrettably, half of the states that had a significant number of mobile home-related accidents did not categorize their causes. Of the states that did indicate causes, data revealed the incident involved failure of wheel, tire, axle, or bearings. In addition, but to a lesser degree, some states gave spring, shackle, or hanger failures as contributing factors. Speed is a significant contributor to degradation, and half the states permit 55-mph speeds for mobile homes. The need for good brakes is indicated by the number of panic stops involving mobile homes.

MOBILE HOME TRANSPORTATION PROBLEM AREAS
(Reference HUD Contract H-2411)

1. State of ____________________ Date: ____________________

2. Are Mobile Homes permitted to be transported across and through state: ____Yes ____No Max width____ft Max length____ft

3. Axle weight restrictions/requirements: ____________________lb/axle

4. Brake restrictions/requirements: ____________________

5. Maximum speed permitted:________mph: Daylight only ____Yes ____No

6. Weekend: ____Yes ____No Holidays: ____Yes ____No Inclement weather: ____Yes ____No

7. Mobile Homes permitted on Interstate Highways: ____Yes ____No

8. Overwide permits required: ____Yes ____No Escorts Required:____Yes ____No

9. Any major accidents reported involving mobile homes: ____Yes ____No

9.(a) Number accidents/incidents reported ____________________

10. Did accident(s) or incident(s) involve failure of wheel/tire/axle/bearings: ____Yes ____No

11. Did accident(s) or incident(s) involve failures of springs, shackels or hangers: ____Yes ____No

12. Did accident(s) or incident(s) involve damage to main box structure: ____Yes ____No

13. Did accident(s) or incident(s) involve sudden or panic stops: ____Yes ____No

14. Did any damage result from sudden stop to hitch, A-frame, or mobile home: ____Yes ____No

15. Are any accidents or incidents involving mobile homes required to be reported: ____Yes ____No

Mail to: Mr. C. R. Ursell, Dept. 03
Southwest Research Institute
P. O. Box 28510
San Antonio, Texas 78284
Phone: (512) 684-5111 Ext. 2426

TABLE 1. SUMMARY SPREAD SHEET

STATES

Question Number	ALASKA	ARIZONA	ARKANSAS	CALIFORNIA	COLORADO	CONN.	DELEWARE	FLORIDA	GEORGIA	HAWAII	IDAHO	ILLINOIS	INDIANA	IOWA	KANSAS
2	Yes	Yes/14/70	Yes/14/None	Yes/12/70	Yes/14/None	Yes/14/85	Yes/14/85	Yes/14/None	Yes/12/83	Yes/9/65	Yes/14/70	Yes/14/85	Yes/14/85	Yes/12/67	Yes/14/95
3	Yes-attach	Yes	Yes	6,000 lbs	Yes	Yes	Yes	No	Yes	Yes	--	Yes	Yes	Yes	Yes
4	Yes-attach	Yes	Yes	Yes (Min.2)	Yes	Yes	Yes	No	--	No	Yes	Yes	Yes	Yes	Yes
5	55/Yes	45/Yes	45/Yes	55/Yes	55/Yes	55/Yes	45/Yes	55/Yes	55/Yes	55/No	45-55/Yes	45/Yes	55/Yes	40/Yes	50/Yes
6	No/No/No	No/No/No	No/No/No	No/No/No	No/No/No	No/No/No	No/No/No	No/No/No	Yes/No/No	Yes/Yes/Yes	No/No/No	No/No/No	No/No/Yes	Yes/No/No	No/No/No
7	N/A	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes/12'	No	Yes
8	Yes/Yes	Yes/Yes	Yes/Yes	Yes	Yes/Yes	Yes/Yes	Yes/No	Yes/Yes	Yes/No	No/No	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes
9	--	Yes/170	--	Yes 77/156	--	--	No	Yes/55	Yes/72	--	Yes/8	No	No	Yes/1	Yes/114
10	--	Yes	--	Yes	--	--	No	Yes	--	--	--	--	None	No	--
11	--	Yes	--	Yes	--	--	No	No	--	--	--	--	--	Yes	--
12	--	Yes	--	Yes	--	--	No	Yes	--	--	--	--	--	No	--
13	--	Yes	--	Yes	--	--	No	Yes	--	--	--	--	--	Yes	--
14	--	Yes	--	No	--	--	No	Yes	--	--	--	--	--	Yes	--
15	--	Yes/+$300	Yes	Yes	--	No	Yes	Yes/All	Yes	--	Yes	Yes	Yes	Yes	Yes/+$200
Accident Data/Laws	Regs	Regs	No	--	No	No	No	No	Yes	No	Yes	Reg	No	Reg	No

Question Number	KENTUCKY	LOUISIANA	MAINE	MARYLAND	MICHIGAN	MINNESOTA	MISSISSIPPI	MISSOURI	MONTANA	NEBRASKA	NEVADA	NEW HAMP.	NEW JERSEY	NEW MEX.	NEW YORK
2	Yes/14/85	Yes/14	Yes/14/None	Yes	Yes/14/70	Yes/14/80	Yes/14/85	Yes/14/85	Yes/18/None	Yes/14/95	Yes/14/85	Yes/14'6/85	Yes/14/None	Yes/14/85	Yes/14
3	Yes	Yes	--	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
4	Yes	Yes	--	Yes	None	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
5	45/Yes	45/Yes	45/Yes	55/Yes	35-45/Yes	55/Yes	45/Yes	50/Yes	50/Yes	55/Yes	55/Yes	45-50/Yes	55/Yes	55/Yes	55/Yes
6	No/No/No	Yes/No/No	No/No/Yes	No/No/No	No/No/No	No/No/No	No/No/No	No/No/No	Yes/No	No/No/No	No/No/No	No/No/No	No/No/No	No/No/No	No/No
7	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
8	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes	Yes/No	Yes/Yes	Yes/Yes
9	No	--	No	--	Yes/137	Unknown	--	No/47	136	No	Yes/78	No/2	--	No/87	--
10	--	--	--	--	Yes	--	--	Yes	--	--	--	Yes	--	Yes	--
11	--	--	--	--	--	--	--	No	--	--	--	No	--	--	--
12	--	--	--	--	--	--	--	Yes	--	--	--	Yes	--	--	--
13	--	--	--	--	--	--	--	Yes	--	--	--	No	--	--	--
14	--	--	--	--	--	--	--	Yes	--	--	--	No	--	--	--
15	Yes	--	Yes/+$200	Yes/+$100	--	No	--	Yes/+$100	Yes	Yes	Yes	Yes/+$300	--	Yes/+$100	Yes
Accident Data/Laws	No	No		No	Yes	No	No	No	Regs	No	Regs	Regs	No	No	No

TABLE 1. SUMMARY SPREAD SHEET (Cont'd)

STATES

Question Number	NO. CAR.	NO. DAK.	OHIO	OKLAHOMA	OREGON	PENNA.	RHODE ISLAND	SO. CAR.	SO. DAK.	TENN.	TEXAS	UTAH	VERMONT	VIRGINIA	WASHINGTON D.C.
2	Yes/12/80	Yes/16/80	Yes/14/70	Yes/14/None	Yes/14/80	Yes/14/None	Yes/14/85	Yes/12/80	Yes/16/None	Yes/14/85	Yes/20/95	Yes/14/70	Yes/14/None	Yes/12	Yes/8/40
3	Yes	Yes	Yes	Yes	Yes	Yes	Yes	20.000 axle	Yes	No	Yes	Yes	Yes	Yes	Yes
4	No	Yes	Yes	Yes	Yes	Yes	Yes	Elec./Air	Yes	No	--	Yes	Yes	Yes	Yes
5	45/Yes	50/Yes	50/Yes	55/Yes	55/Yes	55/Yes	55/Yes	45/Yes	50/Yes	55/Yes	55/Yes	55/Yes	35-50/Yes	45/Yes	25/N/A
6	No/No/No	No/No/No	No/No/No	Yes/No/No	/No/	No/No/No	No/No/No	No/No/Yes	No/No/No	No/No/No	Yes/Yes/Yes	No/No/No	No/No/No	No/No/No	Yes
7	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
8	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes	Yes	Yes/Yes
9	Yes/8+	No/48	Unknown	No/2	--	Yes/79	No	No/21/.76	No	No	--	Yes	No	Yes/attach	--
10	Yes	--	--	No	--	--	--	Yes	No	--	--	Yes	--	--	--
11	No	--	--	No	--	--	--	No	No	--	--	Yes	--	--	--
12	Yes	--	--	No	--	--	--	No	No	--	--	Yes	--	--	--
13	Yes	--	--	No	--	--	--	No	No	--	--	Yes	--	--	--
14	No	--	--	No	--	--	--	No	No	--	--	No	--	--	--
15	Yes/+$200	Yes/+$200	Yes/+$150	Yes	Yes	Yes/+$200	--	Yes	Yes	Yes	--	Yes	Yes	Yes/attach	Yes/+$100
Accident Data/Laws	No	No	No	No	Regs	Regs	Reg	No	No	No	$1222.00	Regs	Regs	Regs	No

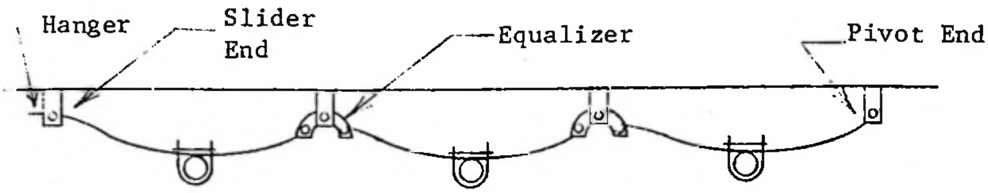
Question Number	WEST. VA.	WISCONSIN	WYOMING
2	Yes/14/85	Yes/8/60	Yes/None
3	Yes	Yes	Yes
4	Yes	Yes	Yes
5	45/Yes	45/Yes	45/Yes
6	No/No/No	No/No/No	Yes/No/No
7	Yes	Yes	Yes
8	Yes/Yes	Yes/Yes	Yes/Yes
9	No	Yes/1	No
10	--	--	No
11	--	--	No
12	--	--	No
13	--	--	No
14	--	--	No
15	Yes	Yes	Yes/+$250
Accident Data/Laws	No	Regs	No

TABLE 2. AASHTO SURVEY SUMMARY

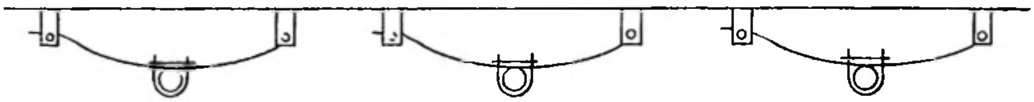
	Question	No. States Reporting	% Yes	% No
1.	State of ________			
2.	Are mobile homes permitted to be transported across and through state?	48	100	0
	Max. width and length? (12- to 14-ft wide; 65-ft min & 95-ft max length)			
3.	Axle weight restrictions?	47	94	6
4.	Brake restriction requirement?	46	93	7
5.	Max. speed permitted. (a)	48	48 @ 55 mph 8 @ 50 mph 15 @ 45 mph	
	(b)	48	98	2
6.	Weekend transport?	48	17	83
	Holiday transport?	48	4	96
	Inclement weather transport?	48	13	87
7.	Mobile homes permitted on interstate highways?	47	98	2
8.	Over-wide permits required?	48	98	2
	Escorts required?	48	92	8
9.	Any major accidents involving mobile homes?	35	57	43
	Number of accidents/incidents reported?	35 (1119 accidents total)		
10.	Did accidents or incidents involve failure of wheel/tire/axle or bearings?	18	56	44
11.	Did accidents or incidents involve failure of springs, shackles, or hangers?	13	31	69
12.	Did accidents or incidents involve damage to main box structure?	13	54	46
13.	Did accidents or incidents involve sudden or panic stops?	13	46	54
14.	Did any damage result from sudden stop to hitch, A-frame, or mobile home?	13	38	62
15.	Are any accidents or incidents involving mobile homes required to be reported?	46	39	61
16.	Does the state have specific accident regulations or laws regarding mobile homes on the highways?	46	39	61

III. MOBILE HOME TEST SPECIMENS

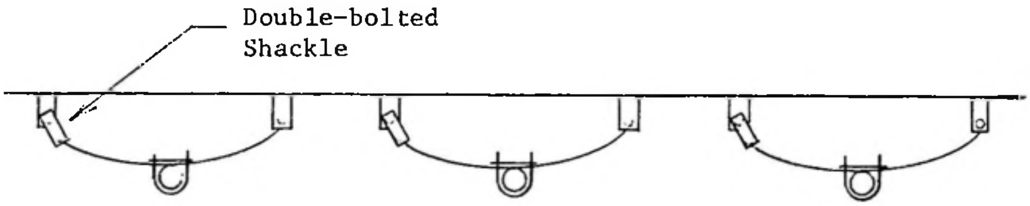
Among the test mobile homes selected for this study, the undercarriage design varied considerably. Most of the units had three axles supported by single-leaf slider type springs; others had only two axles, and some with multi-leaf springs. The design of the axle spring depended on the type of suspension system utilized. Close fore-and-aft spacing of axles was achieved with the dual use of spring hangers also being used by adjacent slider springs. This system sometimes incorporated equalizers, which are rocker arm connectors between axles/springs that pivot at the spring hanger or shackle and tie together the actions of adjacent springs. This rocker arm action equalizes the loads much more effectively. Other spring hangers applying the dual load concept supported a pivot bolt of one spring and the sliding end of the other. In this situation, each spring was pivot-bolted to its front hanger with the slider action in the rear hanger. The spring/axle configurations are illustrated in Figure 1. Figure 2 presents typical axle mounting instructions and hanger spacings. Table 3 lists the running gear configuration for test units.



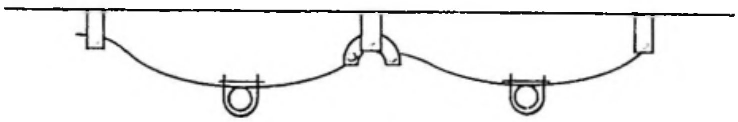
Mobile Homes T-1 and T-3



Mobile Home T-2



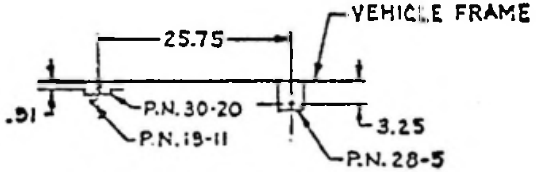
Mobile Home T-7



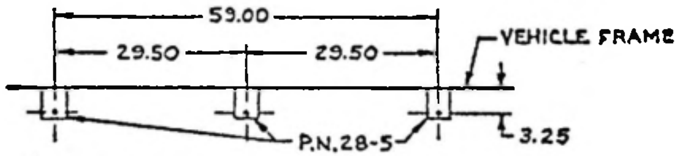
Mobile Home T-4

FIGURE 1. SPRING/AXLE CONFIGURATIONS

NOTE:
1. LR = RADIUS OF TIRE AT RATED LOAD.
2. SR = RADIUS OF TIRE AT NO LOAD.
3. ALL DIMENSIONS AT RATED LOAD.

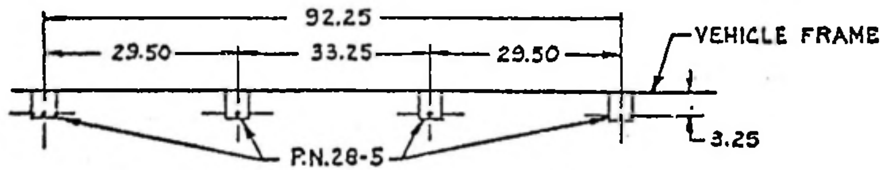


SINGLE HANGER SETTINGS

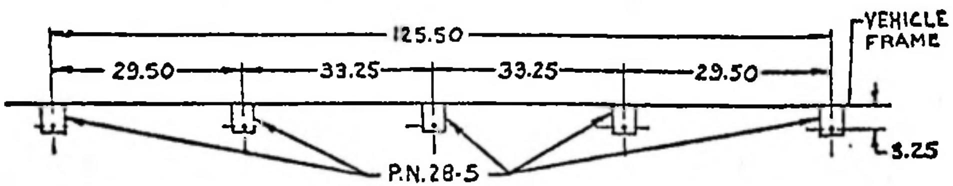


TANDEM HANGER SETTINGS

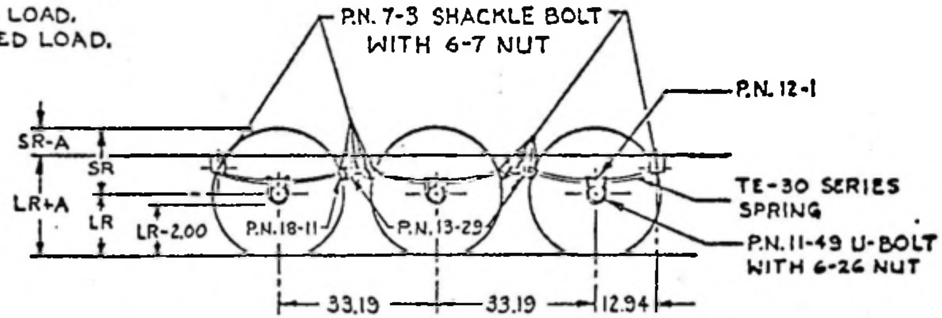
FRONT



TRIPLE HANGER SETTINGS



QUAD HANGER SETTINGS



OVERSLUNG SPRINGS ON 3.00 DIA. AXLE.
DIMENSIONS FOR TANDEM, TRIPLE, & QUAD.

SPRING	CAPACITY	STACK	A
TE-30	3000	.90	8.69

MOUNTING INSTRUCTIONS FOR NEW "TOWED AXLE" SUSPENSIONS

It is suggested the following procedure be used in mounting Dexter axles:

Step 1 - Mount equalizers in center hanger with "wish bone" to rear. Use 9/16 shackle bolt. Tighten lock-nut just enough to see end of bolt thru outside of nut. DO NOT SQUEEZE HANGER AGAINST SPRING.

Step 2 - Mount front spring eye of front axle in front hanger. Use 9/16 shackle bolt. Tighten lock nut just enough to see end of bolt thru outside of nut. DO NOT SQUEEZE HANGER AGAINST SPRING.

Step 3 - Mount front spring eye of second axle in "wish bone" end of equalizer. Use 9/16 shackle bolt. Tighten lock nut just enough to see end of bolt thru outside of nut. DO NOT SQUEEZE EQUALIZER AGAINST SPRING.

Step 4 - Mount shackle link - shackle bolt combination thru rear spring eye of front axle and thru front hole of equalizer at same time. (Shackle to be above equalizer.) Next mount loose shackle link on other end of two shackle bolts extending thru spring and equalizer. Tighten lock nuts just enough to see end of bolt thru outside of nut. DO NOT SQUEEZE LINES AGAINST SPRING OR EQUALIZER.

Step 5 - Mount shackle link - shackle bolt combination thru rear spring eye and rear hanger at same time. (Shackle to be above spring, below hanger.) Next mount loose shackle link on other end of two shackle bolts extending thru spring and rear hanger. Tighten lock nuts just enough to see end of bolt thru outside of nut. DO NOT SQUEEZE LINKS AGAINST SPRING OR HANGER.

These instructions are for mounting a tandem running gear. If triple running gear is to be mounted, follow above procedure thru steps 4. Then repeat steps 3 & 4 to mount middle axle. In case of quad running gear, again repeat steps 3 & 4.

FIGURE 2. TYPICAL AXLE MOUNTING INSTRUCTIONS AND HANGER SPACINGS

TABLE 3

RUNNING GEAR CONFIGURATION FOR
TEST UNITS*

T-1

Axles - 3 (2 with brakes)

Suspension System Single-leaf, Slider Springs with equalizers

Tires - 10 ply, 700 x 14.5, inflated to 70 psi

T-2 (A&B ea. Side)

Axles - 3 (2 with brakes)

Suspension System Single-leaf, Slider Springs with no equalizers

Tires - 8 ply, 700 x 14.5, inflated to 80 psi

T-3

Axles - 3

Suspension System Single-leaf Springs with equalizers

Tires - 6 ply, 700 x 14, inflated to 70 psi

T-4 (A&B ea. Side)

Axles - 2

Suspension System Single-leaf Springs and equalizers

Tires - 6 ply, 700 x 14, inflated to 70 psi

T-7

Axles - 3 (2 with Brakes)

Suspension System Single-leaf Springs with pivot bolts in front & double pivot-bolted shackels in rear

Tires - 6 ply, 700 x 14.5, inflated to 70 psi (lug nuts instead of bolts)

*Refer to Task III, Vol. I, Part I for test unit histories.

IV. TEST SET-UP AND PROCEDURE

The testing consisted of three types of work as follows:

(1) Dynamic data retrieval from the undercarriage components of interest - axles, springs, and hangers;

(2) Disassembly and measurement of undercarriage components;

(3) Filming of the system "on the road."

To complete the investigation, the data and film were both reviewed to determine the loads and stresses on the various components.

A. Dynamic Test

Instrumentation to retrieve data consisted of accelerometers, strain gages, and deflection transducers installed on axles, hangers, shackles and the mobile home floor over the axles. The transducer installation used on each test mobile home was in accordance with the approved instrumentation setup used in previous mobile home research (see Task III, Volume I, Part 1). The active transducers for each test unit appear in the tables of Section V of this study.

B. Disassembly and Inspection of Running Gear Components

In order to determine where and how much wear occurs in the running gear components, they were disassembled and inspected. The method of disassembly was as follows:

(1) Remove tire.

(2) Remove brake drum and bearings.

(3) With the help of a hydraulic jack, remove slides and pivot bolts of the spring hangers.

(4) Separate axle from springs by removing U-bolts and their backing plates.

(5) Separate shackles, if supplied from springs.

After disassembly, measurement of wear points and other dimensions of interest was conducted. Pictures were taken and the running gear was reassembled. This process was performed for all the wheel/axle assemblies of Test Units T-1, T-2A, T-2B, and T-7.

C. Filming

Two cameras were mounted on T-1. One was positioned in front of the right front wheel system facing rearward. The other camera filmed the same right front wheel system from the left side. Lights were used for proper exposure. A significant amount of footage was exposed as this test unit was towed over a variety of roads from high-speed highways to a grassy ditch.

V. INTRODUCTION OF DATA

A. Dynamic Test Data

The data presented in Table 4 are a sampling from the dynamic data retrieved during the transportation testing of the mobile home test units. Table 1 presents the maximum positive and negative signals experienced by the various transducers that were functional on each test unit.

B. Disassembly and Inspection of Running Gear Data

The appendix contains several typical data sheets from the inspections of undercarriage components. Inspected components include springs, wheel drums, spring hanger pivot, slider bolts and shackles from Test Units T-1, T-2A, T-2B, and T-7. An inspection sheet of each component from each test unit is presented. All other data sheets are on file at SwRI and are available for review.

The data sheets note points of wear and dimensions of interest. Mileage of each of the units at the date of inspection was as follows:

Unit	Mileage	Date of Inspection
T-1	2186	11/17/77
T-2A	1383	11/21/77
T-2B	1413	11/18/77
T-7	273	11/22/77

Throughout their disassembly, it was noted that little grease was used in packing the bearings and a great amount of slack was present within the bearing/drum/axle assembly. Significant points of wear due to the non-lubricating design included the slider end of springs and the bolts upon which they slide, spring to spring hanger pivot bolts, spring bolt holes, shackle bolt holes, and spring hanger bolt holes.

TABLE 4.

MAXIMUM POSITIVE AND NEGATIVE

SIGNALS FROM INSTRUMENTED UNDERCARRIAGE COMPONENTS

TEST UNIT	TRANS -DUCER	LOCATION	MAXIMUM +	MAXIMUM -	MEASURING UNITS
T-1	ACC	FLOOR OVER AXLE	1.34	1.77	G
	ACC	AXLE	2.71	6.67	G
	DEFL.	AXLE	.070	.075	inches
T-2A	ACC	CG	.76	1.89	G
	ACC	AXLE	2.85	3.1	G
	SG	FRONT-SPRING SHACKLE (WRECK)	463	1179	μ-in.
	DEFL.	AXLE	.114	.187	inches
	SG	FRONT AXLE HANGER	1011	1432	μ-in.
	SG	REAR AXLE HANGER	578	1422	μ-in.
T-2B	ACC	CG	2	.76	G
	ACC	AXLE	3	4.5	G
	DEFL.	AXLE	.13	.14	
	SG	FRONT SPRING SHACKLE	1302	279	μ-in.
T-3	ACC	AXLE	5.9	12	G
	DEFL.	AXLE	.25	.12	inches
T-4A	ACC	AXLE	3.05	3.75	G
	DEFL.	AXLE	.07	.07	inches
	SG	REAR HANGER	518	1129	μ-in.
T-4B	ACC	CG	2.1	2.5	G
	ACC	AXLE	3.6	2.5	G
	DEFL.	AXLE	.15	.23	inches
	SG	FRONT AXLE	1126	0	μ-in.
	SG	REAR AXLE	1118	0	μ-in.

A particular concern regarding bolt holes was that some of the wear occurred in the threads, the weakest part of a bolt. Wear was sometimes uneven along brake drums and shoe contact surfaces. Due to the "open back" design of some drums, dirt, grit, mud, and sand were often inside the assemblies.

In addition to critical wear, two instances of catastrophic failures occurred in the running gear during testing. One incident involved the failure of leaf springs on T-1, and the other, spring hangers of T-4A.

The leaf springs on the right first and second axles of T-1 broke through the broached hole after about 1800 miles of testing. At the time T-1 was loaded to simulate 4000 lb of furniture and personal belongings, so it weighed 20300 lb. The various routes over which T-1 had accumulated the 1800 miles were typical of those over which mobile homes are generally routed. Both fractures exhibited typical overload and fatigue type failures.

Mobile home T-4A suffered the failures of two spring hangers simultaneously after about 1025 miles of towing (436 miles under first owner plus about 600 miles of SwRI testing). The hangers separated from the chassis I-beams due to inadequate welding.

C. <u>Filming of Running Gear Under Towing Conditions</u>

A variety of conditions were recorded from the 16-mm movie films taken during normal towing speeds and slow scrubbing tests. Under high speeds, high-frequency vibrations were apparent. Scrubbing tests, slow speed sharp turns, force the tires and wheels on a side in opposite lateral directions by as much as 2 in. measured at the roadway interface. These films are available for review at SwRI.

VI. SUMMARY AND RECOMMENDATIONS

The running gears used on the majority of mobile homes are classed as "limited life" assemblies based on a design life of 2000 miles. There are no bushings or lubrication fittings installed on these assemblies in order to minimize costs. Also, there are no dust shields or backing plates on the brakes. Generally, the system will withstand the 2000 mile usage if:

- The system is operated predominately over paved roads with a minimum of dirt, grit, and mud;
- The system does not have excessive brake usage;
- The roads over which the system is used are not excessively rough and undulating;
- The system is not "laid up" for extended periods of time between usage;
- The system is not "overloaded" with weight inside the mobile home;
- The hitch/coupler assembly on the tow unit is not located excessively high or low, thereby overloading the front or rear axle;
- The tires on multiple axle installations are all the same size;
- All of the axle assemblies on each installation are of the same manufacturer;
- The operation of the mobile home, during the transportation mode, is within the running gear manufacturers prescribed limits.

Operation of a running gear within a range of 90-95 percent of the rated load does not contribute to its extended life. Moreover, transporting a mobile home with minimum quality tires in an unbalanced condition at high loads is most certainly a hazardous practice. On three or four axle mobile homes, a certain degree of safety is built-in with the number of assemblies. However, in some cases, one failure can lead to or cause another. The wear factor on the "limited life" running gear is significant, and frequent inspections on these marginal systems could possibly prevent some failures with emphasis on the moving or working parts that are not lubricated. The greatest wear items that are considered critical in order of importance are:

(1) Pivot bolts in the end of the shackles or springs,

(2) Pivot bolt holes in hangers,

(3) Equalizer pivot bolts and holes,

(4) Brake anvils,

(5) Slider spring contact area,

(6) Brake drums and linings (due to no dust cover).

Following the test program, some pivot bolts were found 50-percent worn on the bolt shank diameter at 1500 miles. This is considered dangerous and unsafe.

It is recommended that the pivot bolts and hanger holes as well as equalizer holes on limited life assemblies receive a detailed inspection at each 800-mile interval for safety.

If running gears are to be re-used, a thorough and complete overhaul needs to be performed on each assembly before returning to service. The prescribed inspection and overhaul should be as designated by the axle/brake manufacturer. Replacement parts on like axles should be of the same manufacturer's specifications. Mixing of different axles on a mobile home should be eliminated as well as mixing of single- and multi-leaf springs and mixing of tire sizes (such as 700 and 800's) which cause excessive loads to be introduced into the assemblies. In addition, axles for re-use should be identified, stamped, dated, and then logged to keep track of overhaul and usage details. Component parts should have the axle manufacturer's part number or stamp for ease of identification.

Since these axles are limited life assemblies, they must be inspected for acceptance before traveling any further. Moreover, if axles are not used for extended periods of time, they should be inspected for acceptance before re-use, especially if exposed to severe environmental conditions. Designers, carefully considering the side loads, torsion loads, and negative vertical loads on the hitch coupler and A-frame in designing running gears, can prolong the life of properly maintained undercarriage components as much as can be reasonably expected.

APPENDIX

SAMPLE RUNNING GEAR

(OR UNDERCARRIAGE COMPONENT)

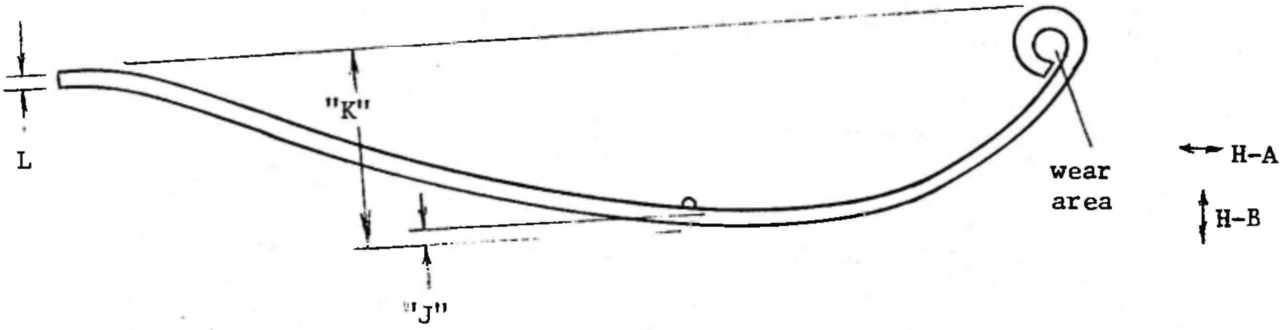
INSPECTION DATA SHEETS

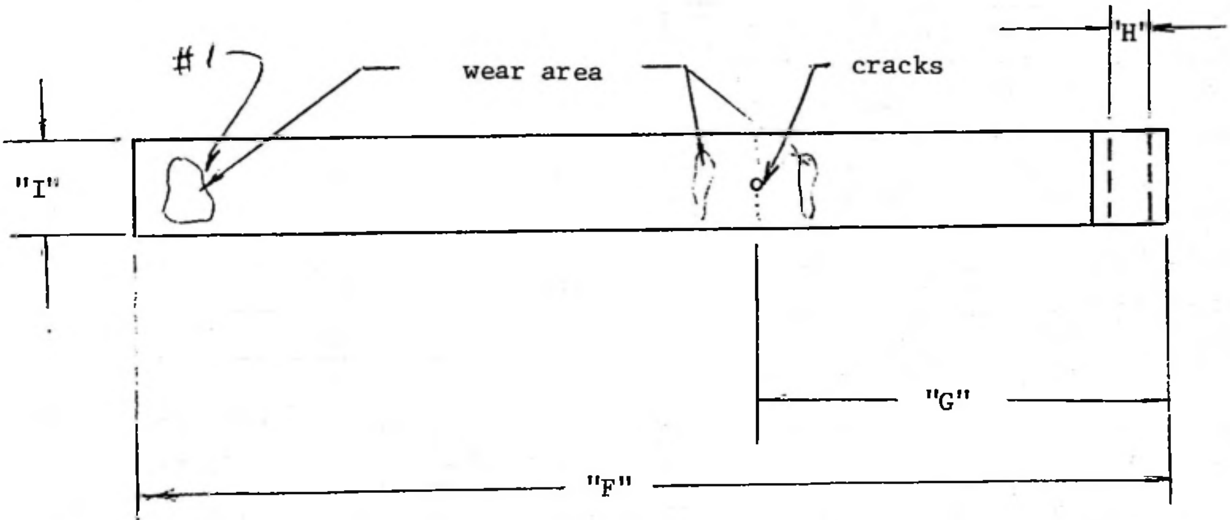
Inspector: Dennis D. Collins
Date: Nov, 14, 1977

RUNNING GEAR DATA SHEET (Cont'd)
SPRING DATA (SINGLE-LEAF)

Mobile Home No.: T-1

Spring Location: WBA-1L





Dim. "F" = 28 7/8
"G" = 13 3/4
"H" = A- 11/16 B- 3/4
"I" = 2
"J" = 7/8 or .796
"K" = 5 3/4
"L" = 3/8 or .384

Describe and locate on drawing any cracks or wear points: On area marked #1 the surface is worn evenly across the wid th of the spring. Surface is shiney. No noticeable wear on other critical areas.

APPROVED: ____________

DATE: ____________

RUNNING GEAR DATA SHEET
SPRING DATA

Mobile Home No.: T-2A

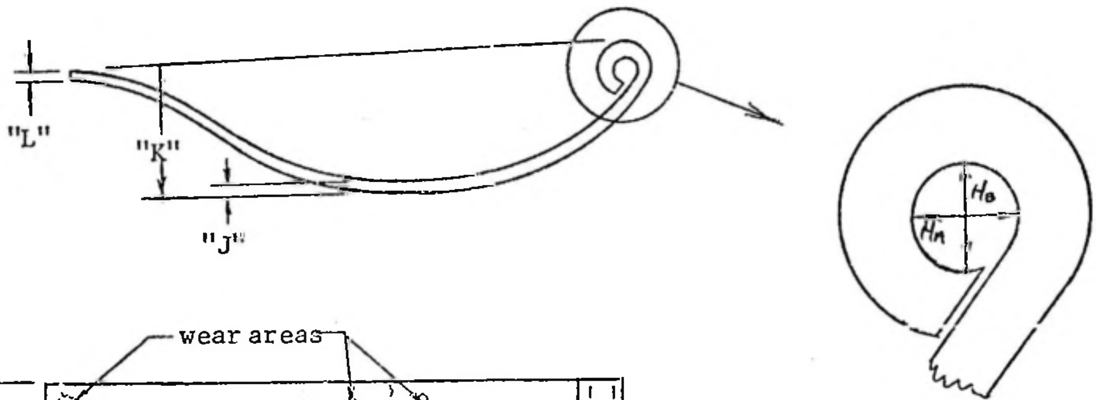
Length: 60' Width: 12' Weight: 12,200

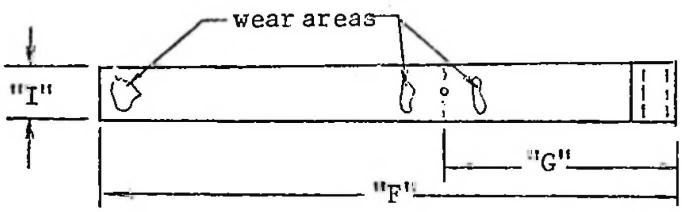
Manufacturer: ____________

Double-wide: ☑ Single-wide: ☐ Wet: ☑ Dry: ☐

Mileage: 1383

WBA-1L





Dimension "F" = 27 1/2 "I" = 1 3/4

Dimension "G" = 13 1/2 "J" = .845

Dimension "H_A" = 11/16 "K" = 5 5/16

Dimension "H_B" = 5/8 "L" = .333

Describe and locate on drawing, any cracks or wear points: The slider end of the spring is worn evenly across the surface. The area is about 1 1/4" wide. The area HB has a small wear area at each end of the hole on the bottom

Inspector: Dennis D. Collins Date: Nov. 21, 1977

APPROVED: ____________

DATE: ____________

RUNNING GEAR DATA SHEET
SPRING DATA

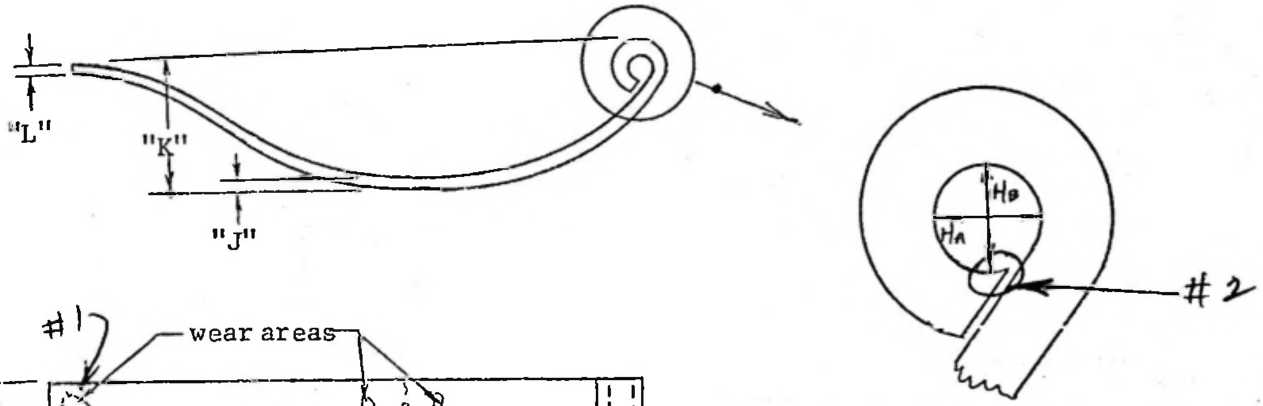
Mobile Home No.: T 2B

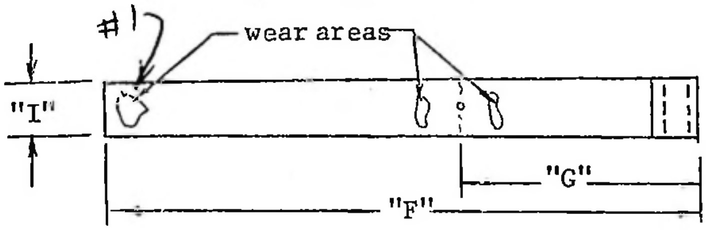
Length: 60' Width: 12' Weight: 16,000

Manufacturer: ____________

Double-wide: ☑ Single-wide: ☐ Wet: ☐ Dry: ☑

Mileage: 1,413 WBA-R1





Dimension "F" =	28"	"I" =	1 3/4
Dimension "G" =	14	"J" =	.861
Dimension "H_A" =	3/4	"K" =	4 13/16
Dimension "H_B" =	11/16	"L" =	.323

Describe and locate on drawing, any cracks or wear points: Point #1 has an even amount of wear across the width of the spring. #2 has a heavy concentration of wear at the bottom of the hole along the width of the spring

Inspector: Dennis D. Collins Date: Nov. 17, 1977

APPROVED: ____________

DATE: ____________

RUNNING GEAR DATA SHEET
SPRING DATA

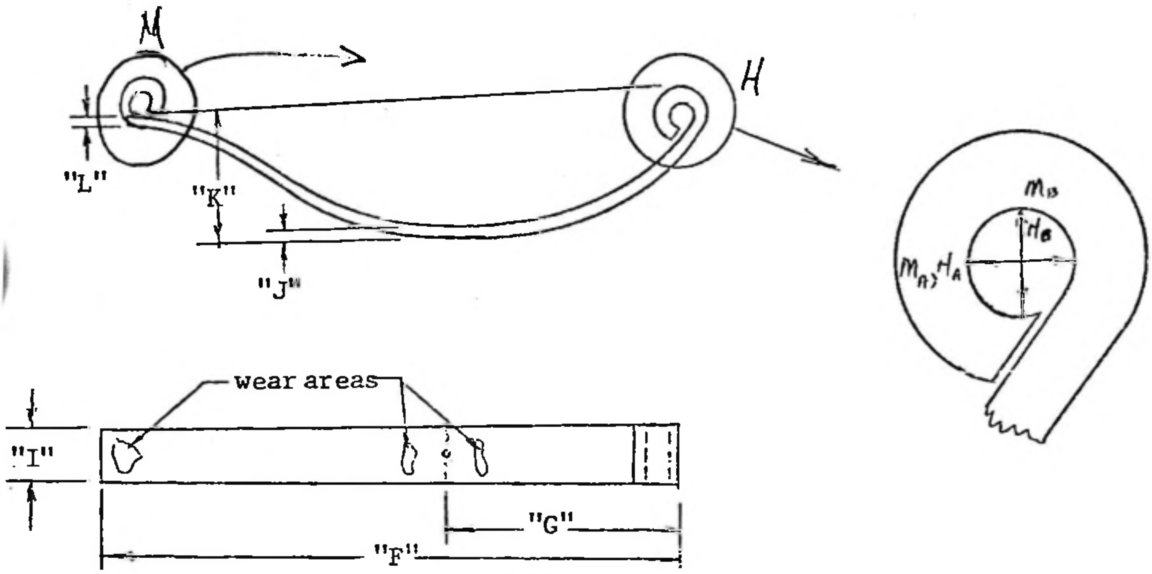
Mobile Home No.: T7

Length: 70' Width: 14' Weight: 18,800

Manufacturer: ____________

Double-wide: ☐ Single-wide: ☑ Wet: ☐ Dry: ☐

Mileage: 350 WBA-1L



Dimension "F" = 26 5/8 "I" = 1 3/4 M_A = "/16

Dimension "G" = 13 3/8 "J" = .855 M_B = "/16

Dimension "H_A" = "/16 "K" = 4 1/2

Dimension "H_B" = "/16 "L" = .339

Describe and locate on drawing, any cracks or wear points: T7 is equipped with pivot bolts on both ends of the springs. The only visible signs of wear are inside points H_A, H_B, M_A, M_B where the pivot bolt has worn into the inside surfaces.

Inspector: Dennis D. Collins Date: Nov. 28, 1977

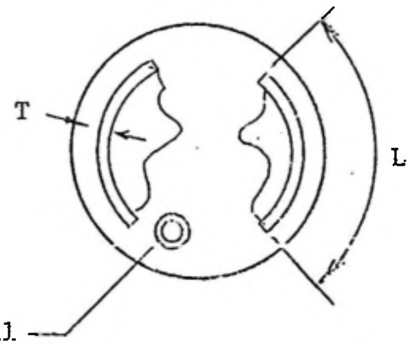
RUNNING GEAR DATA SHEET

Mobile Home No.: T-1

Date: Nov. 14, 1977

BRAKE DATA

WBA-1L



Secondary

L = 9 3/16

W = 2

T = 5/32

Primary

L = 11 5/8

W = 2

T = 5/32

Drum ID = 12

Drum Depth = 2 1/2

Coil Dia. = 2 3/8

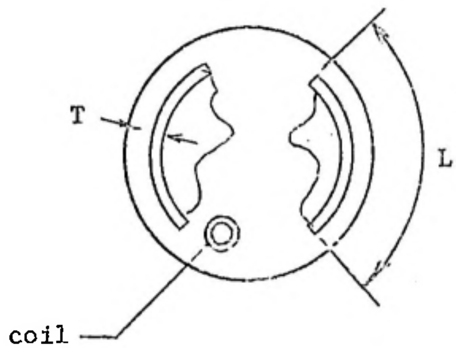
Comments: Inner surface of the drum is fairly smooth but the surface where the anvil rests is worn unevenly. Brakes are smooth but are worn more ~~by bo~~. on bottom edges.

Inspector: Dennis D. Collins

RUNNING GEAR DATA SHEET

Mobile Home No.: T-2A   Date: Nov. 22, 1977

BRAKE DATA W/BA-2L



Secondary

L = 9 1/8

W = 2

T = 3/16

Primary

L = 11 1/2

W = 2

T = 1/8

Drum ID = 12

Drum Depth = 2 3/8

Coil Dia. = 2 3/8

Comments: Drum is slightly grooved but the shoes dont look bad. They show slight wear on secondary shoe while the primary shows good wear.

Inspector: Dennis D. Collins

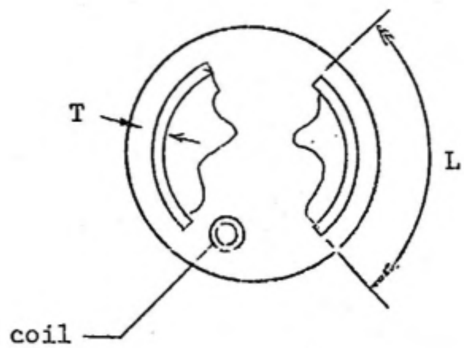
RUNNING GEAR DATA SHEET

Mobile Home No.: T-2B

Date: Nov. 18, 1977

BRAKE DATA

WBA-1R



Secondary

L = 9 1/4

W = 2

T = 1/8

Primary

L = 11 1/2

W = 2

T = 1/8

Drum ID = 12

Drum Depth = 2 3/8

Coil Dia. = 2 3/8

Comments: Inside of drum is worn smoothly. This drum has a 1/4 inner lip while all the others have nearly 3/8" inner lips. There is a lot of mud & sand & brake debris in the corners of the drums & caked on the brake shoes.

Inspector: Dennis D. Collins

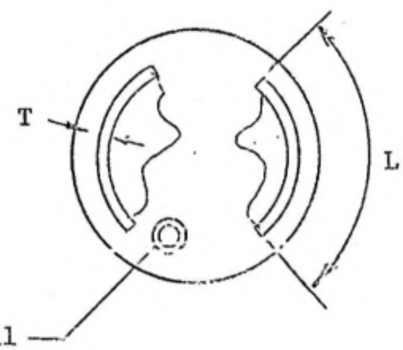
RUNNING GEAR DATA SHEET

Mobile Home No.: T-7

Date: Nov. 23, 1977

BRAKE DATA

WBA-1L



Secondary

L = 9

W = 2

T = 3/16

Primary

L = 9

W = 2

T = 5/32

Drum ID = 12

Drum Depth = 2 5/8

Coil Dia. = 2 5/16

Comments: Not much wear on drums or brakes Drums are smooth and so are the shoes

Inspector: Dennis D. Collins

Approved: ________________ Date: __________

PIVOT BOLT DATA SHEET

Mobile Home No.: T-1

Length: 61 Width: 14 Weight: __________

Manufacturer: ____________________ Model: __________

☐ double-wide ☐ wet ☐ dry ☑ single-wide

Mileage: __________

1. Pivot bolt location

   a. WBA 32L ☐ front ☐ rear ☑ slider bolt

2. Pivot bolt wear

   a. Bolt diameter "D" = 0.558

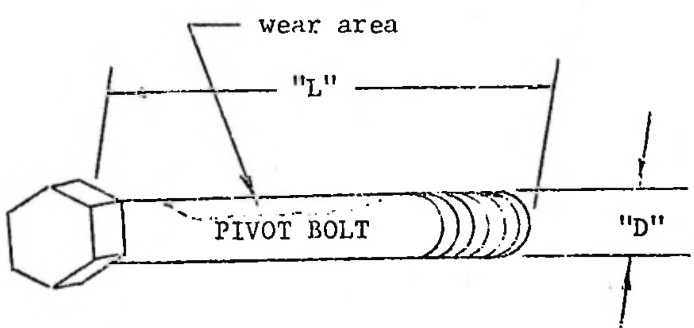
   b. Bolt length "L" = 3 1/4

   c. Bolt thickness at wear area = .504

   d. Length of wear area = .2

   e. Width of wear area = 3/8 - 1/8

Comments: ______________________________



Approved:________________ Date:____________

PIVOT BOLT DATA SHEET

Mobile Home No.: T-2A

Length: 60 Width: 12 Weight: 12,200

Manufacturer: ________________ Model: ____________

☑ double-wide ☑ wet ☐ dry ☐ single-wide

Mileage: 1353

1. Pivot bolt location

   a. WBA 12 ☑ front ☐ rear ☐ slider bolt

2. Pivot bolt wear

   a. Bolt diameter "D" = 0.559

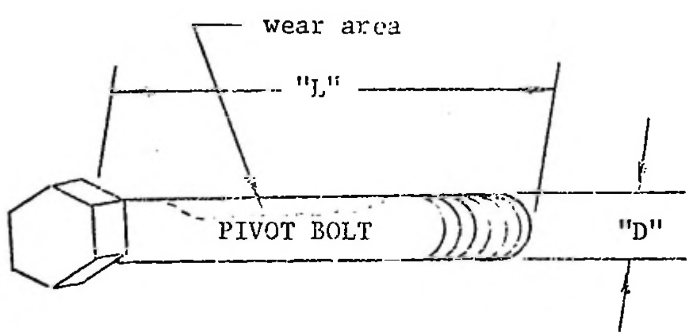
   b. Bolt length "L" = 3.25

   c. Bolt thickness at wear area = .555

   d. Length of wear area = 2.0

   e. Width of wear area = 0.312

Comments: This bolt has a heavy wear area 2" long - part of it is rusty.



Approved: _______________ Date: _______________

PIVOT BOLT DATA SHEET

Mobile Home No.: T 2B

Length: 60 Width: 12 Weight: 16,000

Manufacturer: _______________ Model: _______________

☑ double-wide ☐ wet ☑ dry ☐ single-wide

Mileage: 1413

1. Pivot bolt location

   a. WBA 16 ☑ front ☐ rear ☐ slider bolt

2. Pivot bolt wear

   a. Bolt diameter "D" = 0.557

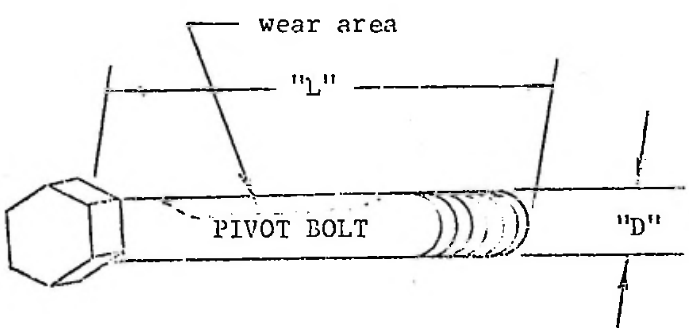
   b. Bolt length "L" = 3.20

   c. Bolt thickness at wear area = .555

   d. Length of wear area = 1.75

   e. Width of wear area = 0.180 - .310

Comments: These bolts are pivot bolts instead of slider bolts so their wear is not excessive.



Approved:__________ Date:__________

PIVOT BOLT DATA SHEET

Mobile Home No.: T-7

Length: 70 Width: 14 Weight: 18,800

Manufacturer: __________ Model: __________

☐ double-wide ☐ wet ☐ dry ☑ single-wide

Mileage: 350

1. Pivot bolt location

   a. WBA 1L-C ☐ front ☑ rear ☐ slider bolt

2. Pivot bolt wear

   a. Bolt diameter "D" = 0.496

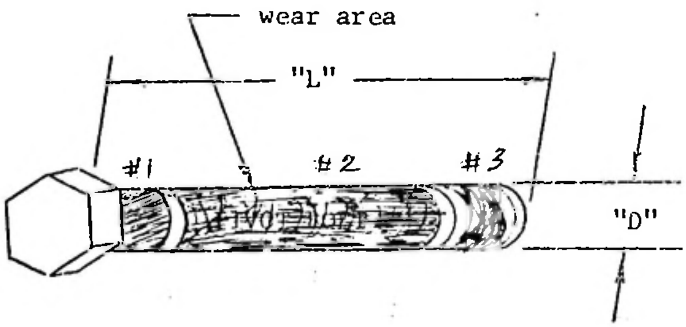
   b. Bolt length "L" = 2.938

   c. Bolt thickness at wear area = .494

   d. Length of wear area = (1) .125, (2) 1.658, (3) .250

   e. Width of wear area = circumference of bolt

Comments: Wear area of this bolt takes in the majority of the bolt. The wear measurement was taken on area #2.



APPROVED: ____________

DATE: ____________

SHACKLE DATA SHEET

Mobile Home No.: T-7

Length: 70 Width: 14 Weight: 18,800

Manufacturer: ____________ Model: ____________

Double-Wide ☐ Wet ☐ Dry ☐ Single-Wide ☑

Number of Axles: 3 Equalizers: ______ Separated Axles: ✓

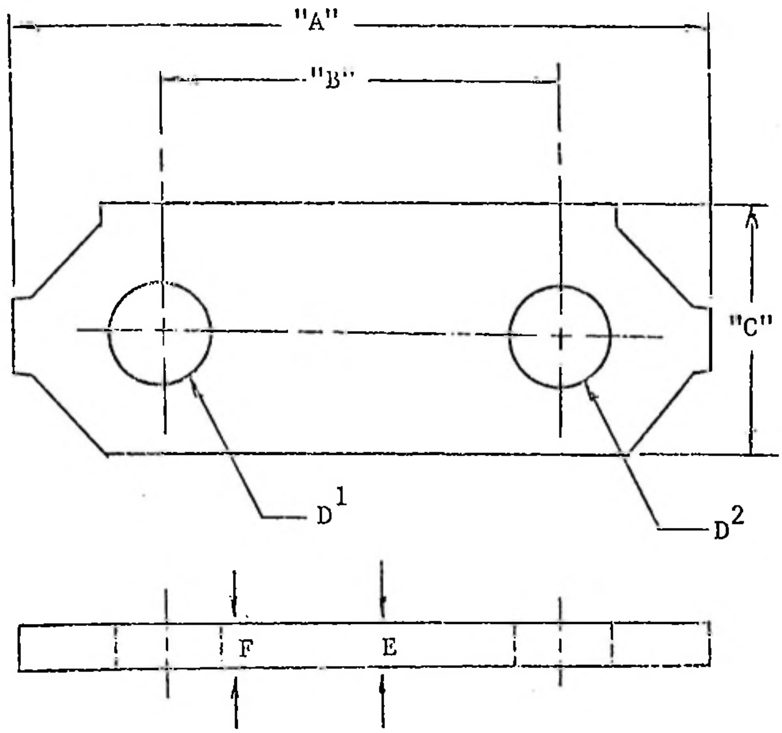
Axle Number: 2 Left Side: ✓ Right Side: ______

Mileage: ____________

1. Shackle Location

   A. WBA 2L * ☐ Front ☑ Rear

2. Shackle Wear



	(1)	(2)
A.	3.50	3.50
B.	2 06	2.06
C.	1.25	1.25
D_1.	.53	.56
D_2.	53	.56
E.	.26	.25
F.	.25	.25

* See Code Identification.

A-FRAMES & COUPLING MECHANISMS

I. OBJECTIVE

Through the course of previous mobile home research, SwRI noticed transportation-induced deterioration in test units' A-frames, and hence, recommended to HUD that further research be directed in areas regarding strength and design of A-frames and coupling mechanisms as well as the question of safety chains.

This report investigates the static and dynamic loading of A-frames and couplers, and also examines safety chains and caster wheels. The objective is to present the expected forces on these components and resulting strains through which recommendations for changes in design or use may be made.

II. INTRODUCTION

If failure of mobile home coupling mechanisms or A-frames occurs during transportation, it presents a serious safety hazard on the highway. Coupling failures usually result from fatigue and overload (although some are attributed to workmanship) while A-frames may buckle because of heavy braking or combined braking and turning loads. In a questionnaire answered by every state highway department, several states revealed data that indicated damage to mobile home hitch or A-frame resulting from sudden stops (Refer to Questionnaire and Summary Sheet in Modification Report on Axles/Springs/Spring Hangers/Wheel System.) Although response to this questionnaire is inconclusive because most states do not compile their data for mobile homes separately, the response does indicate that potential for damage and failures does exist.

Safety hazards are further compounded by the fact that most transport companies refuse to use safety chains while transporting mobile homes. Transport companies anticipate that, if a failure occurs, the coupler will dig into the pavement because of the heavy tongue weight resulting in high retarding forces. If the mobile home rolls over, a safety chain joining tractor to unit will probably pull the tractor over as well. However, in the event of ball hitch failure, there should be some means of steering the mobile home, such as caster wheels, if separation of tractor and unit occurs.

This report contains results of the A-frame and coupler load tests versus stresses and forces generated at the A-frame coupler via load readouts on the instrumented hitch. Clearly, the size of the I-beams used in fabrication of the A-frame has a significant effect on the resulting stresses generated in the assembly. The most common mode of failure for the A-frame is caused by a severe braking turn (controlled or uncontrolled).

III. TEST SPECIMEN

The mobile home designated T-1 under previous research for HUD was chosen for this study since it was already instrumented and its full life history was known.*

The towing or A-frame of T-1 is made up of a pair of junior I-beams welded to the mobile home chassis. This frame experienced all the static and dynamic towing loads of starting, stopping, turning, and operating in rough roads and dips. T-1 was towed by a 1968 tow tractor weighing 9000 lb, using an instrumented hitch coupler.

Figure 1 shows the basic configuration of the forward end of the chassis including longitudinal I-beams, cross-beam, and A-frame. The A-frames on the test mobile homes are listed with the size of I-beams used to fabricate the A-frame as well as the rating of the hitch coupler.

T-1	10"	20,000 lbs
T-2A/B	10"	20,000 lbs
T-3	10"	20,000 lbs
T-4A/B	10"	20,000 lbs

*Refer to Task III, Vol. I. Part I for T-1 history.

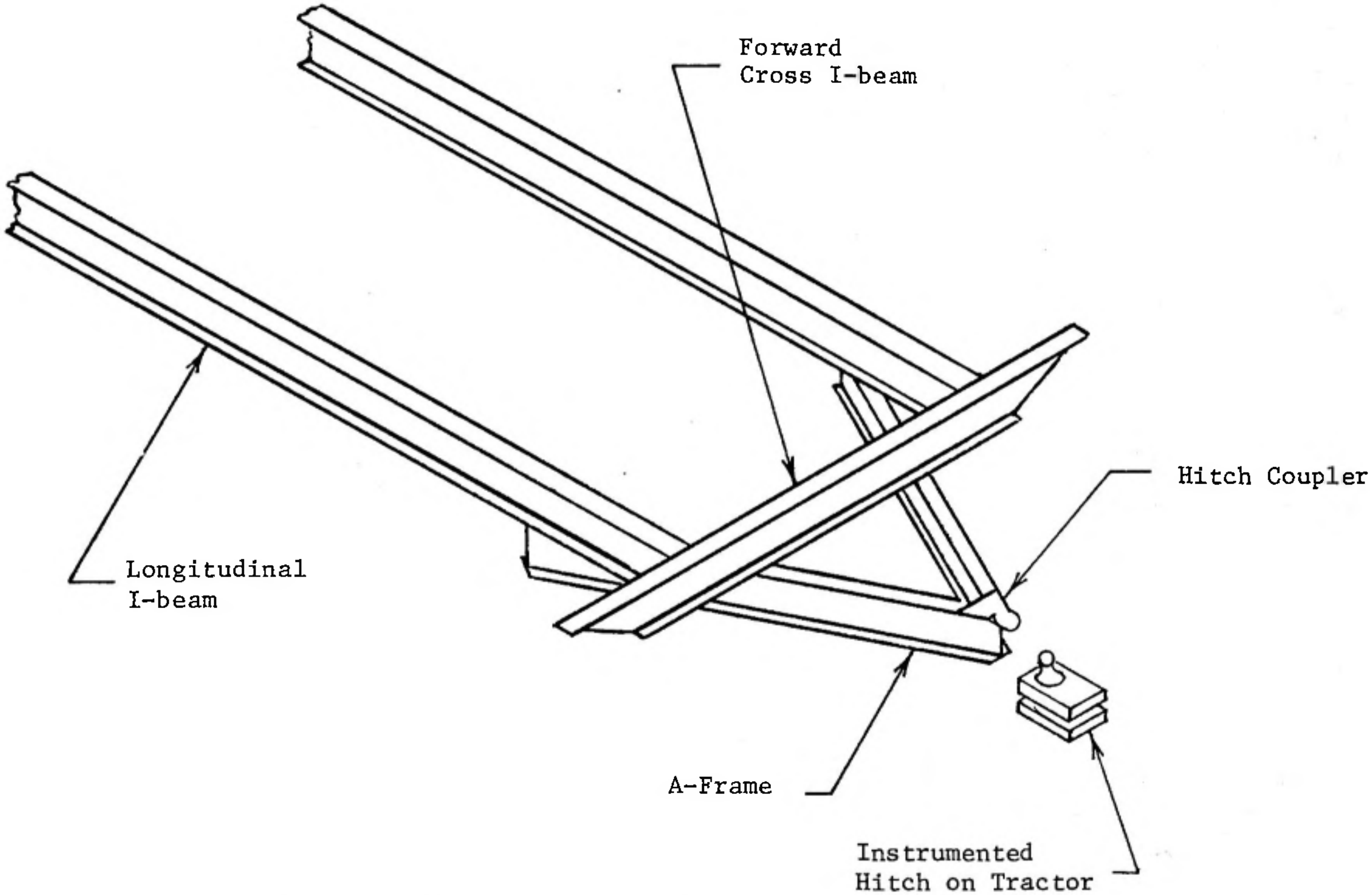


FIGURE 1. FORWARD END OF CHASSIS AND A-FRAME OF MOBILE HOME T-1

IV. TEST SET-UP AND PROCEDURE

The testing of this effort consisted of two types of work.

(1) Static load testing -- instrumentation and data retrieval of strain gage signals from critical points on A-frame of test unit as subjected to several static loading conditions.

(2) Dynamic load testing -- retrieval of dynamic data from critical points on the A-frame. Dynamic data include readouts from instrumented hitch or tow tractor.

A. Static Load Test

The static load test required a leveled mobile home; a means of restraining the mobile home chassis; a means of applying static loads to the hitch coupler and holding the loads in order to record signals from appropriately located strain gages. The Test Unit T-1 was restrained by fastening the longitudinal I-beams to buried steel members at points 4 ft to the rear of the forward cross I-beam. The set-up was such that movement of the home in every direction was restricted. Loads were applied to the hitch by a vehicle-mounted hydraulic winch. The input loads were applied on the mobile home hitch through a ball connection and elsewhere on the A-frame with a hook or harness.

The A-frame hitch coupler was loaded in five different directions. Applied loads were pulled to the left and right at both the top and bottom of the A-frame. The side loads at the top of the A-frame were introduced through a ball at the hitch. Four of the applied loads were side loads, left and right. The fifth applied load was introduced at the ball hitch in an upward direction. To reduce any mechanical "set" in successive pulls, the load tests were performed in the following order:

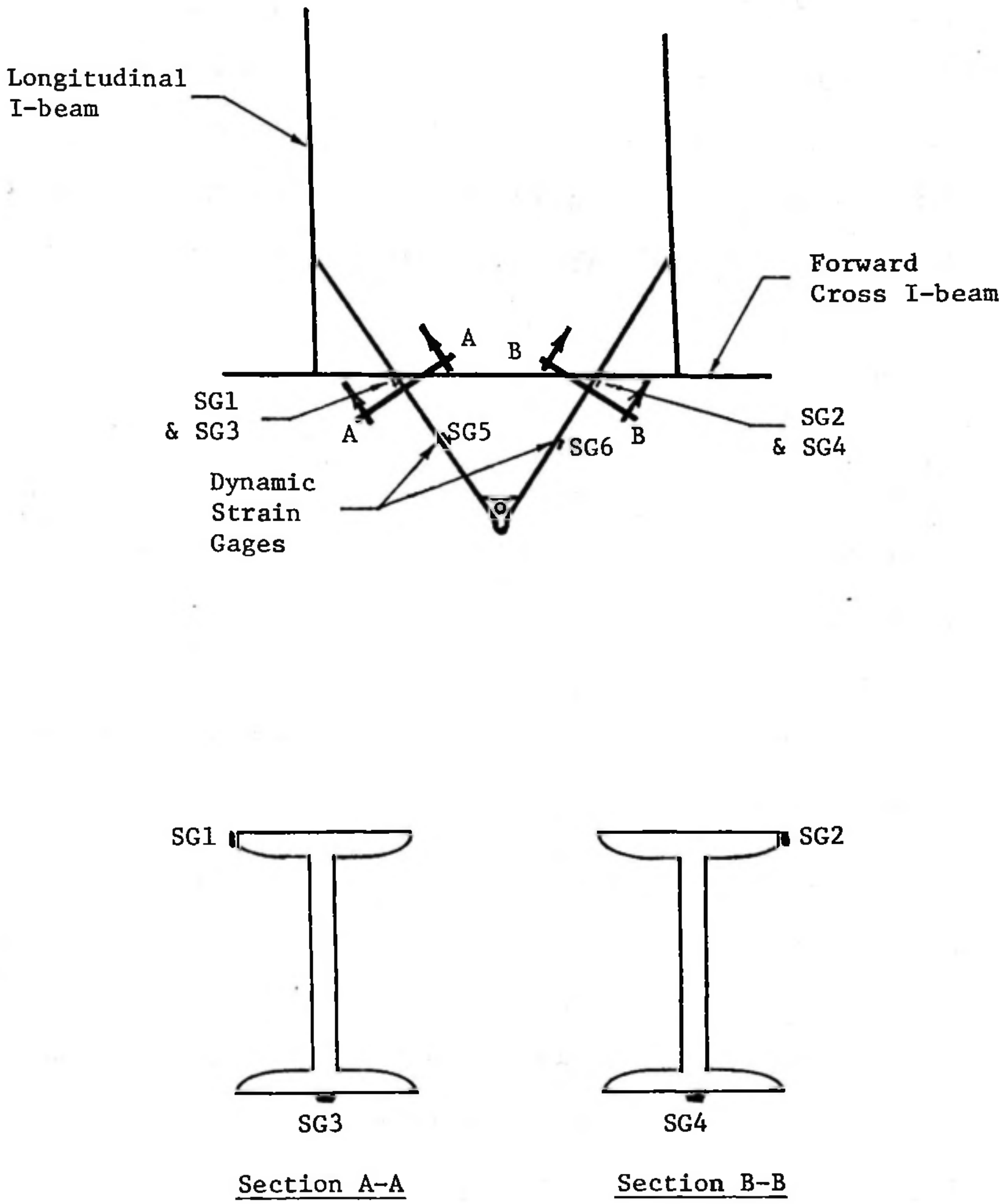
(1) Left side pull at top of A-frame through the ball/hitch;
(2) Right pull at top of A-frame through the ball/hitch;
(3) Left pull at bottom of A-frame;
(4) Right pull at bottom of A-frame;
(5) Vertical up pull at point of A-frame through ball/hitch.

Each loading was accomplished in 1000 lb increments to 5000 lb with load indicators revealing the strains made at each increment. The forces were measured by an in-line tension gage.

Four strain gages were installed on the A-frame as indicated in Figure 2. All were mounted to register strain along the length of the A-frame I-beams. In order to mount strain gages 1 and 2 on the outside of the flanges, the flange edges were ground flat with a minimum loss of material.

B. Dynamic Load Test

Data were also retrieved from A-frame strain gages during transportation testing of the mobile home. A strain gage was located on top of each of the two A-frame I-beams just in front of the intersection with the forward cross-beam. See Figure 2 for location of these left and right dynamic strain gages. Data were collected over a variety of pavement conditions and towing situations. The strain gage signals were conditioned, amplified, and recorded on magnetic tape. Later the tape was replayed into a Honeywell visicorder, or light beam oscillograph, to produce a trace from which actual strains were measured.



Note: Strain gages 1 through 4 were added only for static loading.

FIGURE 2 A-FRAME STRAIN GAGE LOCATIONS

V. INTRODUCTION OF DATA

A. Static Load Data

Figures 3 through 5 present plots of data collected from the statically loaded A-frame test. Each figure shows elongation of the strain gages versus load in 1000-lb increments to 5000 lb for a different loading situation. Because of the symmetry of the apparatus, figures of right pulls are omitted because they would merely be a duplication of the left pull figures with opposite signs.

B. Dynamic Load Data

Tables 1 and 2 list several maximum positive and negative strains resulting from dynamic load situations. Table 3 lists lateral accelerations. The road condition factor $\overline{RC}$ (see Task I) is included for reference.

C. Analysis

The above data results in the following A-frame and hitch coupler loads:

Correlation between the strains of SG-5 and SG-6 versus SG-1, 2, 3, and 4 is difficult to confirm because SG-5 and 6 are laid on the top centerline of the flange while SG-1 and 2 are laid on the edges of the flange. SG-3 and 4 are laid on the bottom centerline of the flange. Also, they are all outer fiber stresses, but in different planes or different locations with respect to bending strains. SG-1, 2, 3, and 4 can indicate vertical bending strains. SG-1 and 2 can indicate side bending. SG-5 and 6 can indicate vertical bending. The strains at SG-1, 2, 3, and 4 will be greater in vertical bending and torsion than those at SG-5 and 6.

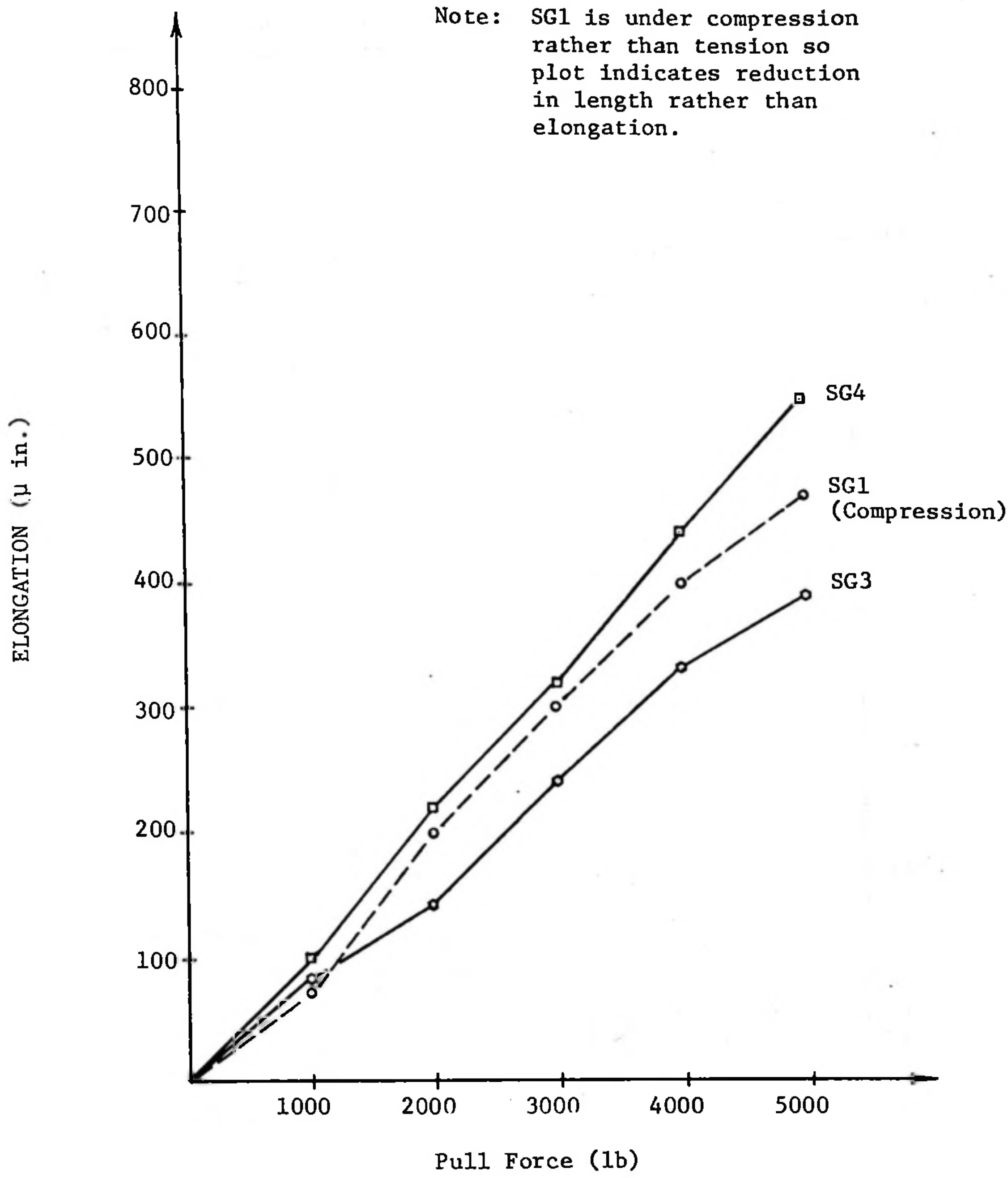


FIGURE 3. UPWARD PULL

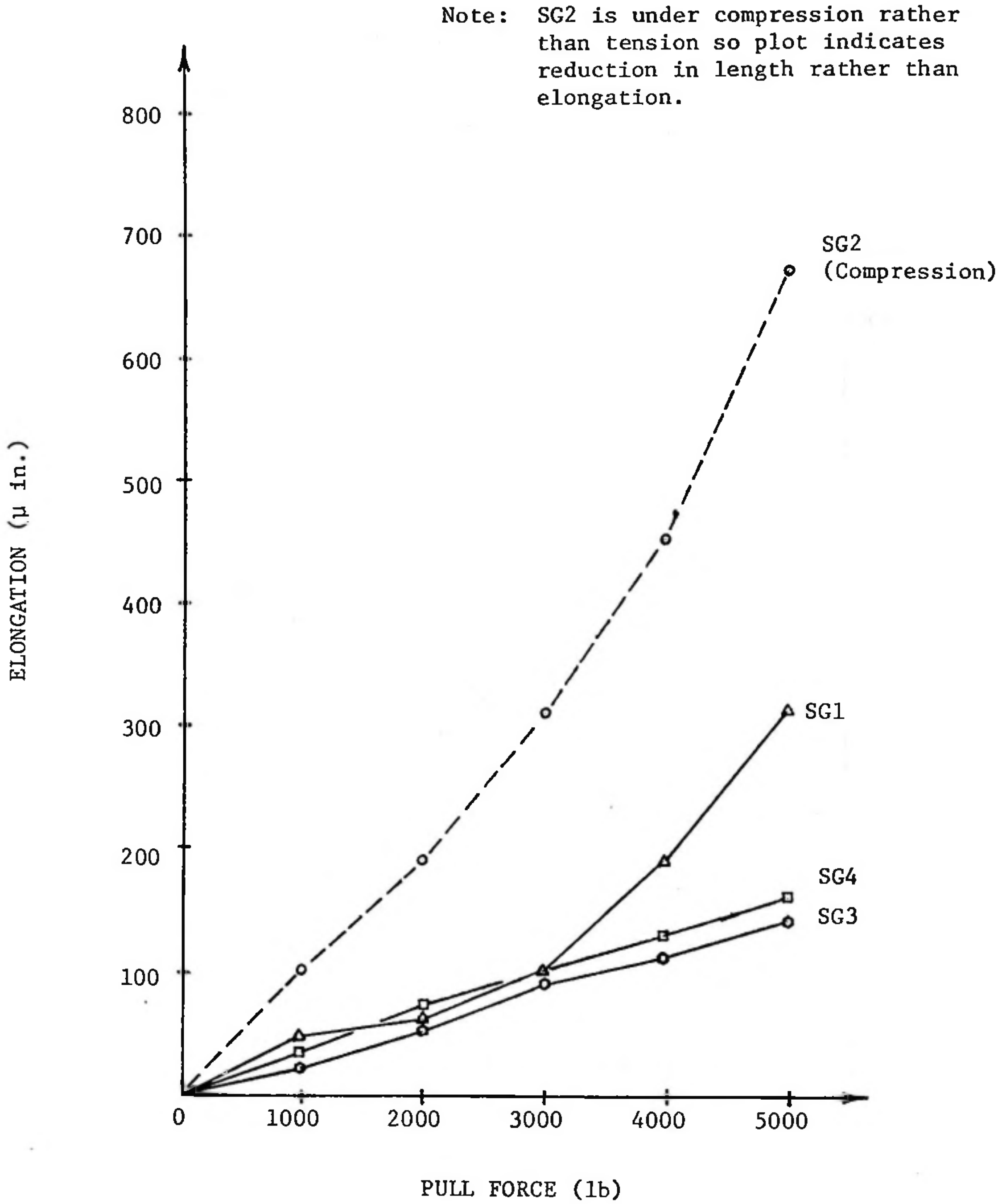


FIGURE 4. TOP LEFT PULL

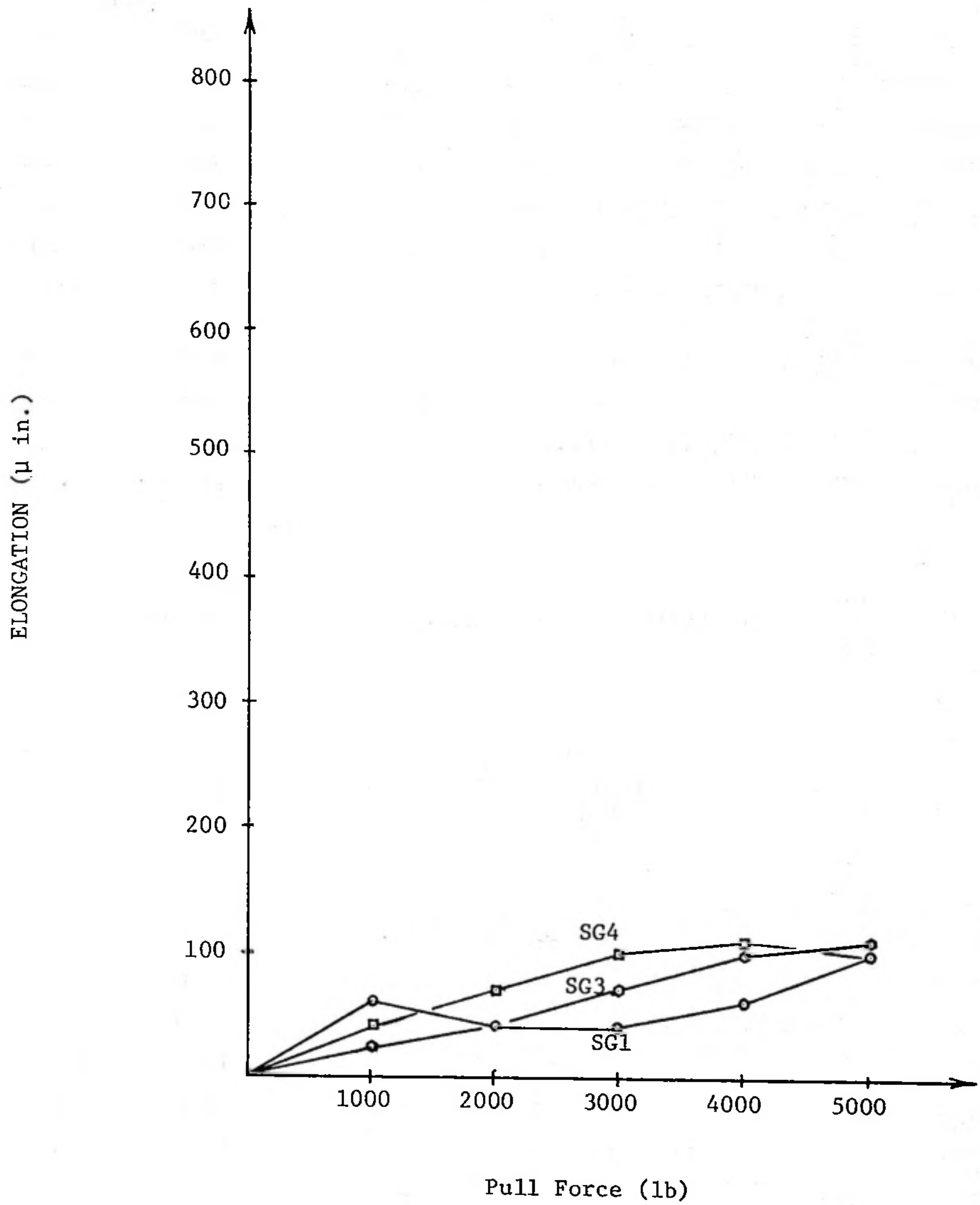


FIGURE 5. BOTTOM LEFT PULL

TABLE 1
DYNAMICALLY LOADED STRAIN GAGE DATA (μ in.)
(Vertical)

SG No.	S. G. LOCATION †	RC	Max. Pos.	Max. Neg.
SG-5	"A" & "I", Right A-frame	1.5	720	2480*
SG-5	"A" & "I", Right A-frame	1.3	720	1560*
SG-5	"A" & "I", Right A-frame	1.2	840	1480*
SG-5	"A" & "I", Right A-frame	1.1	1140	1010
SG-5	"A" & "I", Right A-frame	1.5	1140	1140
SG-5	"A" & "I", Right A-frame	1.2	1220	1050
SG-6	"A" & "I", Left A-frame	1.5	670	2530*
SG-6	"A" & "I", Left A-frame	1.5	670	2190*
SG-6	"A" & "I", Left A-frame	1.3	630	2320*
SG-6	"A" & "I", Left A-frame	1.2	715	2905*

*Minimum dwell time.
†"A" and "I" refers to the intersection of the A-frame and front cross I-beam.

TABLE 2
DYNAMICALLY LOADED STRAIN GAGE DATA (μ in.)
(Longitudinal)

SG No.	S. G. LOCATION	RC	Max. Pos.	Max. Neg.
SG-5	"A" & "I", Right A-frame	1.5	1070	1240
SG-5	"A" & "I", Right A-frame	1.3	1110	1790
SG-5	"A" & "I", Right A-frame	1.2	1140	1470
SG-5	"A" & "I", Right A-frame	1.1	950	1160
SG-5	"A" & "I", Right A-frame	1.5	1020	1640
SG-5	"A" & "I", Right A-frame	1.2	1480	1580
SG-6	"A" & "I", Left A-frame	1.5	1280	1330
SG-6	"A" & "I", Left A-frame	1.3	1290	1880
SG-6	"A" & "I", Left A-frame	1.2	1060	2070
SG-6	"A" & "I", Left A-frame	1.2	1400	1590

TABLE 3

DYNAMICALLY LOADED A-FRAME (ACCELEROMETER) g's

(Lateral)

ACCELEROMETER	RC	PEAK TO PEAK g's	ZERO TO PEAK g's
Front Lower Lateral	1.3	1.38	1.09
Front Lower Lateral	1.5	1.67	1.27
Front Lower Lateral	1.2	1.49	0.97
Front Lower Lateral	1.2	1.20	0.92

The strain gage data recorded indicate that the maximum peak to peak strains are from +1140 to -2905 μ in. One peak strain is noted as +2530 μ in. with a -630 μ in. peak. These strains can be converted to hitch loads as follows:

(2530 μ in.) ÷ 540 = 4.69 (5000) = 23,426 lbs max

(630 μ in.) ÷ 540 = 1.17 (5000) = 5,833 lbs min

These are dynamic loads and the degree of damage is directly proportional to the energy in the impact. The 2530 μ in. peak contained minimum area or energy (or a very short dwell period) while the 630 μ̃ in. peak contained a longer dwell period resulting in significant energy. As can be seen from the above, developing 2530 μ in. of strain in the steel I-beams can result in near failure if any asymmetrical loading or crippling damage is introduced. The vertical strains recorded in the 1000 μ in. and less contained the greater energy while the above 1000 μ in. contained practically no energy or dwell time. Accelerations are directly proportional to the strain plots with similar contours. Therefore, from the above data related to the hitch coupler and A-frame and the accelerations generated on the front wall of the mobile home immediately behind the A-frame,* the following accelerations are generated and recommended for the hitch coupler and A-frame:

Vertical g's	2.50
Longitudinal g's	1.80
Lateral g's	1.10

---

* See Task III, Volume I, Part II.

VI. SUMMARY

A. A-Frame

The A-frame forms the stabilizing connection between the mobile home and the tow tractor. Since the longitudinal acceleration of a significant degree can be generated by snapping the clutch or maximum braking, the stability of the A-frame is more important than the stresses generated in the I-beams. On many mobile homes, the I-beam of the A-frame is not stabilized by gussets or webs. Therefore, the welding of the top flange of the I-beam to the unit's longitudinal I-beams and cross beams permits significant freedom of the lower portion of the A-frame. This is especially true in asymmetrical loadings involving high side loads that result in torsion. The A-frames have been found structurally weak in torsion. Torsion can be introduced by a turning-braking mode. The apex of the A-frame should be tied together with a web gusset in addition to the hitch-coupler and screw jack. Welds should be the maximum size and integrity to ensure the greatest degree of safety.

B. Hitch Coupler

The hitch-coupler is a prefabricated component that meets the applicable SAE specifications. Most of the hitch-coupler assemblies carry a 20,000-lb load rating, and when properly installed, could carry a 6000- to 7000-lb tongue weight. According to the AASHTO survey, no coupler failures occurred. Failures have occurred in the coupler to A-frame welds, and latching mechanisms have been damaged and released the ball hitch, but no structural failures of the coupler have been reported. Therefore, integrity in the weld assemblies is important.

C. Safety Chains

The use of safety chains that connect the tractor to the mobile home is controversial because of the potential safety hazards involved in the event the mobile home rolls or comes loose. On the one hand, if that were to happen the tractor driver would want the ball hitch to break loose and leave the tractor free of entanglement with the unit; on the other hand, the heavy tractor could be a significant aid in controlling the mobile home. A caster wheel on the A-frame would prevent the "digging-in" of the A-frame in the case the coupling was lost. If safety chains were installed, the driver could jam the tractor against the mobile home and aid in steering as well as stopping. It is not in the interest of public highway safety to permit the mobile home to break free without any attempt to control its direction.

When the asymmetrical loads on the A-frame become significant, the stresses in the I-beam become very high, as noted by the plots of load versus stresses at designated locations. The stress increases more rapidly as higher loads are applied. This increase is attributed to the stress concentrations caused by the welds on top of the I-beams to the cross-beam during side loads. This torsional load usually contributes to the A-frame failure when it becomes large enough to cripple the flanges.

D. Acceleration Factors

The following design acceleration factors are recommended for the hitch coupler and A-frame for inclusion into Subpart J "Transportation" of the Federal Mobile Home Construction and Safety Standards.

Vertical	------------	2.50 x 1.45 = 3.6
Longitudinal	------------	1.80 x 1.45 = 2.6
Lateral	-----------------	1.10 x 1.45 = 1.6

The development of these acceleration factors is described in detail in Task III, Volume I, Part II.

RUNNING GEAR REUSABILITY

I. OBJECTIVES

Degradation and possible overstressing or high wear factors of undercarriage components during previous mobile home research prompted SwRI to recommend to HUD that a study be conducted specifically addressing running gear reusability. This was also prompted by the fact that some manufacturers and dealers have been buying-back running gear from new owners (through the dealer) and re-using it.

The resulting report herein is an evaluation of the undercarriage components,* both individually and as a system. The objective of this report is to present the conditions under which the running gear performs, its resulting degradations, and proposed overhaul and reuse of the system.

*The test units involved in this study are the same as is listed in the Modification Report regarding axles/springs/spring hangers/wheel system.

II. INTRODUCTION

The reuse of mobile home transportation components could provide a substantial savings to buyers of mobile homes. Many of the 300,000 homes sold annually are re-located only one or two times after the initial setup. This is particularly true of the multi-wide units - a continually growing market. The laying idle and subsequent deterioration of the running gear of these homes, which may have experienced less than 300 miles to the first setup site, is wasteful and unnecessary. Some owners remove the axle assemblies for reuse, but such practices are infrequent.

On the other hand, mobile home units, when sporadically relocated during their planned lifetime, may have defective equipment in the running gear components resulting from the long period of non-use. Since no procedures exist for certifying used running gear, hazards arise when units using the latter are towed at highway speeds on second class roads over which mobile homes are usually routed.

It is in the interest of all involved - mobile home manufacturers, dealers, consumers, and highway travelers - to overhaul and reuse running gear selectively. However, for such a plan to be effectively enacted, several procedures must be defined. Axle assemblies designed for reuse should be serialized, dated for reuse, and the manufacturer's name and load rating prominantly displayed. The manufacturer should devise an inspection/overhaul procedure applicable to that particular running gear, whereby components are replaced automatically or as determined by inspection or test. For example, brake linings may be an item replaced automatically when the wheel/brake drum are inspected for excessive wear, cracks, trueness, or rust in order to determine replacement requirements. It may be necessary to maintain records or logs on the mileage experience by the running gear.

With an overhaul procedure defined and specified by the manufacturer, any qualified mechanic could recondition the assembly and then, add his mark to the serial number and date to indicate by whom the unit was rebuilt. The liability and responsibility for the performance of the running gear would then fall on the last overhauler, as identified by the serial number and his stamp. If a failure occurs and it is proven that a running gear assembly was conditioned according to the manufacturer's procedure, then the procedure may be faulty or inadequate and need revision. Mobile home dealers and manufacturers are interested in the performance of the running gear they use and sell, and could prevent products of unqualified mechanics and shops from reaching the mobile home industry by means of the receiving inspection as well as the on-line inspection by various agencies.

This report is not designed to be a feasibility study of the reuse of running gear, but instead, an examination of wear and potential life of the various running gear components. A feasibility study would have to compare the costs of instigating an overhaul program and the typical overhaul versus the cost of discarding "limited-life" assemblies. The cost of a typical overhaul and how often overhaul is necessary are two quantities very difficult to determine considering the vast number of possible reuse assembly designs, components, costs, and mileage used. Consequently, rather than an industry-wide reuse program developed through federal action, some member of industry is likely to develop an overhaul procedure that other mobile home manufacturers will adopt.

III. EXISTING SPECIFICATIONS AND STANDARDS FOR RUNNING GEAR

Very few federal or professional association standards apply to the individual components and assemblies of mobile home running gear. Most design work and specification writing is by the manufacturer. Applicable standards which may be incorporated into the design of particular components are as follows:

- Leaf springs - ANSI/ASTM A147 - Heat Treated Steel Leaf Springs
  ASTM A689 - Carbon and Alloy Steel Bars for Springs
- Bolts and fasteners - several ANSI/ASTM standards relating to materials and thread designs (ASTM A153, A307, A320, A563)

In addition to these, HUD Mobile Home Construction and Safety Standards impose general regulations on running gear in Subpart J "Transportation". Generally, the regulations require only that design and workmanship be such that failures are infrequent. The only stringent performance criteria is that the brakes be of such quality that stopping at 20 mph be accomplished in less than 40 feet. This criteria is also a DOT regulation [Paragraph 393.53(d)] of Subchapter B, Motor Carrier Safety Regulations for the Federal Highway Administration).

No SAE standards apply particularly to mobile homes or their running gear. Existing trailer specifications concern either large tractor-trailers or small trailers of a gross vehicle weight less than 10,000 lb.

Mobile home manufacturers generally buy off-the-shelf running gear from manufacturers who have developed their own merchandise to meet the needs of the mobile home industry with cost per assembly being a controlling factor at this time.

IV. INSPECTION PROCEDURE

This effort involved the removal of the running gear from the mobile homes, their disassembly, and rigorous inspection of their components. The method of disassembly was as follows:

(1) Remove tire.

(2) Remove brake drum and bearings.

(3) With the help of a hydraulic jack, remove slide and pivot bolts of the spring hangers and equalizers, if provided, of separate spring/axle assembly from mobile home.

(4) Separate axle from springs by removing U-bolts and their backing plates.

(5) Separate shackles, if supplied, from springs.

After disassembly, wear points and other dimensions of interest were cleaned, inspected, measured, and recorded. Visual inspections were made and photographs were taken and the running gear was reassembled. This process was performed for the wheel/axle springs and shackles assemblies of Test Units T-1, T-2A, T-2B, and T-7.

The following inspection matrix (Figure 3) summarizes how the running gear assemblies and components were inspected. Whether an item is an assembly, or a component is indicated. If an item may be subject to wear, abuse, dimensional changes, misalignment, or instability, it is so marked as indicated on Figure 3.

	INSPECTION MATRIX	Assembly	Component	Wear	Abuse	Misalignment	Dimensional Change	Instability
1.	Wheel	–	X	–	X	–	X	–
2.	Tire	–	X	X	X	X	–	–
3.	Bearings	X	–	X	X	–	–	–
4.	Brake Assy.	X	–	X	X	–	–	X
5.	Brake	X	–	X	X	X	X	X
6.	Axle root/stub	X	–	X	–	X	X	–
7.	Axle overall	X	–	–	X	X	X	–
8.	U- bolts	–	X	X	X	X	–	–
9.	Springs	–	X	X	X	X	X	X
10.	Spring centering hole	–	X	X	X	–	–	–
11.	Equalizers	–	X	X	X	X	–	X
12.	Shackles	–	X	X	X	X	X	X
13.	Slider Brackets	–	X	X	X	X	–	X
14.	Brake wiring	X	–	–	X	–	–	–
15.	A-Frame	X	–	–	X	X	X	X
16.	A-Frame Bolts	–	X	X	X	X	–	–
17.	Coupler-Hitch Assy.	X	–	X	X	–	X	X
18.	Coupler-Hitch Latch	X	–	X	X	X	X	–
19.	Coupler-Hitch Ball Socket	X	–	X	X	X	X	X
20.	Coupler Hitch Jack	X	–	X	X	X	X	X

X=Area of probable concern

Comments on inspections on following page.

FIGURE 3. INSPECTION MATRIX

Comments on Inspections:

1. Wheels generally held up satisfactorily. Most damage occurred when tire blowouts caused wheel to "jump-off" or run flat. Tightening of lugs is critical.

2. Significant wear due to misalignment and scrubbing in turns. Blowouts occurred every 257 miles. Tires were not overloaded.

3. No bearing failures or seizures occurred. However, all wheel bearings were packed by SwRI crews at start of program.

4. Electric brake assemblies had minimal effect on stopping of combined units. Shoes, drums, and anvils wore significantly on those mobile homes that had copper wire in brake system.

5. Brakes wore intermittently around the periphery. Due to inability to lock-up, brakes wore more severely due to no backing plate, permitting mud, dust, and grit to enter system and act as an abrasive.

6. No failures or wear were experienced by the axle stub.

7. The overall axle experienced no failures, but it appears that there is no formula pertaining to the amount of camber that is put into the axle. Some had a large degree, while others had none. Also, many of the axle tubes are spliced with butt welds.

8. The U-bolts holding the springs to the axle quite often loosen up due to the flexing of the spring. These have to be checked prior to each run.

9. Since the spring is the only attachment between the axle and the chassis, a failure can be dangerous. A single-leaf spring offers minimum safety, especially if it fails. Multi-leaf springs offer a greater degree of safety. Also, one spring failure can cause a second if the first goes aft into the second wheel/axle.

10. Spring centering hole or broached recess is a critical point since it occurs at point of maximum stress and deflection. The recess acts as a significant stress riser. Numerous failures have occurred on the single-leaf springs of this type. Multi-leaf springs offer greater safety in a failure of this type.

11. Equalizers accomplish the job of distributing the loads more evenly between the axles. However, they are a point of high wear and most have no lubrication points.

12. Shackles are high wear items and the economy type brakes have no lubrication points, resulting in significant wear on bolts, shackles, and hangers. There are no bearings in the hangers or shackles; only dry steel against steel.

13. Slider brackets support the free end of the slider type spring and dirt/grit adds to the rapid wear process. Tire blowouts, spring failures, and wheel failures cause damage or abuse to hangers and brackets. Bolts wear severely under no-lubricant conditions.

14. Brake wiring is subject to damage in the exposed areas due to rocks, wheel/tire failures, and other road debris. Water is damaging to the electric brake system.

15. A-frames on the test mobile homes performed satisfactorily without a failure of any type. However, the test program did not produce the severity of use found in the normal day-to-day operation.

16. The A-frame bolts experienced no failures and showed no wear, only typical aging evident throughout the components of the frame.

17. Generally, the coupler-hitch assemblies withstood the test program with the exception of that of T-2A which did not survive the mobile home rollover.

18. No coupler-hitch latch failed during the test period.

19. Wear was evident in all the coupler-hitch ball sockets, but not enough to warrant any concern. This may not have been the case if the sockets had been subjected to excessive abuse.

20. No coupler-hitch jack performed properly upon initial receipt of the test units.

VI. INSPECTION RESULTS AND GENERAL OBSERVATIONS

The Appendix contains several typical inspection sheets from the undercarriage component inspections. Included are examples from each of the mobile homes applicable to springs, wheel drums, shackle bolts (spring hanger pivot bolts and slider bolts) and shackles.

The data sheets note points of wear and dimensions of interest. Mileage of each of the units at the date of inspection was as follows:

Unit	Mileage	Date of Inspection
T-1	2186	11/17/77
T-2A	1383	11/21/77
T-2B	1413	11/18/77
T-7	273	11/22/77

The term "limited-life" assemblies is used with these running gear systems for good reason. Throughout their disassemblies, it was noted that little if any grease was used in packing the bearings and a great amount of slack was present within the bearing/drum/axle assembly. Significant points of wear due to nonlubricated assemblies included the slider end of springs and the support bolts upon which they slide, spring to spring hanger pivot bolts, spring bolt holes, shackle bolt holes and spring hanger bolt holes. A particularly critical item regarding bolts concerned the wear that occurred in the threads, the weakest part of a bolt. Wear was sometimes uneven along brake drums and shoes contact surfaces. In fact, due to the "open back" design of some drums, mud and sand were often present inside the assemblies.

In addition to critical wear, two instances of catastrophic failures occurred in the running gear during testing. One incident involved the failure of leaf springs on T-1, and the other, spring hangers of T-4A.

The leaf springs on the right first and second axles of T-1 broke through the broached hole after about 1800 miles of testing. At the time T-1 was loaded to simulate 4000 lb of furniture and personal belongings so it weighed 20300 lb. During this and previous test trips its nominal velocity was 45 mph. The various routes over which T-1 had accumulated the 1800 miles were typical of those over which mobile homes are generally routed. Both fractures exhibited typical overload and fatigue type failures.

Mobile home T-4A suffered the failures of two spring hangers simultaneously after about 1025 miles of towing (436 miles under first owner plus about 600 miles of SwRI testing). The hangers separated from the chassis I-beams due to inadequate welding. Though this incident does not relate directly to the reuse of running gear it serves as an important reminder. If running gear overhaul and mobile home design provides for increased mileage accumulation, the junction points of chassis and running gear, which are more difficult to maintain, should be designed and installed for extended life initially. That is, overhaul of running gear should not have to extend to attach points of the system on the chassis.

VII. REUSE STANDARD

Although the economic feasibility of reusing running gear is to be determined by the industry, the regulation of such a program is the responsibility of HUD. When considering the necessity to dictate design, rated life, or overhaul schedule and technique, HUD can also dictate the logistics of the running gear reuse/overhaul program. This section discusses the procedures required to maintain a reuseable product of high quality and performance. Recommended language for inclusion to Subpart J "Transportation" of the Mobile Home Construction and Safety Standards to accomplish this end is presented here as it appears in Task IV, Volume I.

The primary concern of a mobile home running gear reuse standard is the identification of the components, the manufacturer and his agents who perform authorized overhauls. In addition, it is required to distinguish "limited life" running gear assemblies that are intended for overhaul or extensive reuse, from reuseable un-limited life assemblies that require minimum overhaul. This could be in the form of a coded serial number that may contain, for example, the letters "LL" denoting limited life or "UL" for unlimited life.

In addition, the serial number or code identifies the manufacturer, the date of manufacture, sequence number, and possibly a model number. An example of this is as follows:

PD - 8/78 - 2019 - 6KLL - 20B

20B — 20% Effective Brakes and Braked (or UB=Unbraked)

6KLL — Model 6K, Limited Life (or UL=Unlimited Life

2019 — Serial Number or Sequence Number

8/78 — Date of Manufacturer

PD — Phillips/Dexter

All this information would be required by a qualified mechanic or shop to perform an overhaul and maintain adequate records. The manufacturer should augment the serial number to include any other pertinent date. The serial number or some labeling means should indicate the rated capacity of the unit, brake efficiency, and any other descriptive data. This identification should appear on all major components to ensure that unauthorized replaced parts under unauthorized service are easily identified.

Upon completion of overhaul, an authorized mechanic will add his identification mark and date to the serial numbers of those parts reused. Replaced parts will bear his mark and date of overhaul. Records may be required which detail the procedure of inspection and replacement. This may be a simple check list provided by the original running gear manufacturer.

Development of the overhaul procedure is the combined responsibility of the overhaul or reuse agency and the running gear manufacturer. The procedure may entail mandatory replacement of some parts and arbitrary replacement of others depending upon condition at inspection. It may be that a running gear manufacturer will be selective in deciding to whom the procedure is made available (certified overhaul agencies) in order to protect the good name of the manufacturer. However, the performance of a unit after overhaul should be the responsibility of the approved overhaul mechanic or agency to the extent that the work follow the overhaul procedure. Thus, it is in the interest of the overhauler to properly process a unit according to the running gear manufacturer's recommended procedure, and it is in the interest of the manufacturer to provide a proper overhaul procedure and certified parts.

The system of augmenting serial numbers or additional identifying marks at the time of overhaul provides a maintenance history of each unit as well as identifying the unit as a "rebuilt" assembly. Mobile home dealers and manufacturers would be interested in this knowledge to be able to ensure a safe transport of their product and that the assemblies are worth buying back.

•U.S. GOVERNMENT PRINTING OFFICE : 1980 O-625-551/1957

U.S. Department of Housing and Urban Development

451 Seventh Street, S.W.
Washington, D.C. 20410

Official Business
Penalty for Private Use, $300

Postage and Fees Paid
U.S. Department of Housing
and Urban Development
HUD-401

U.S. MAIL

FIRST CLASS MAIL

Director
Energy, Building Technology &
Standards Research Division
Rm. 8158
HUD Central 020-2

May 1980
HUD-PDR-545-2