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

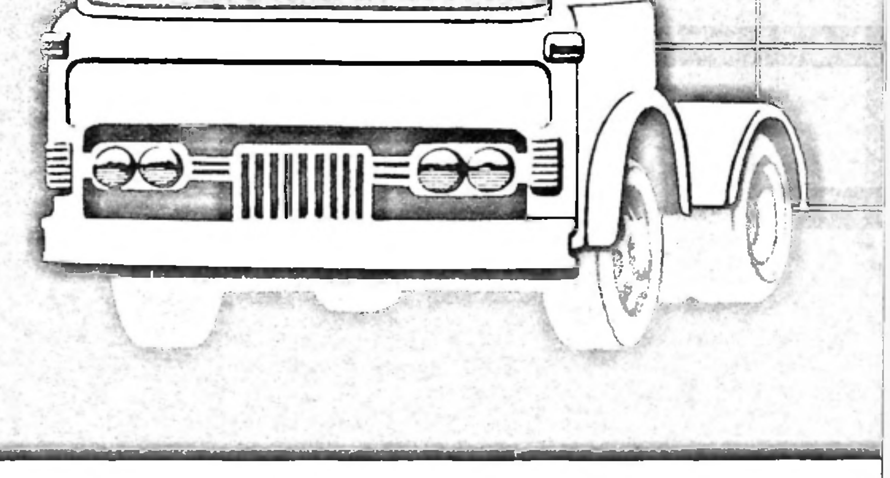
Mobile Home Research

Transportation and Site-Installation

Development of an Analytical Methodology and Transportation Field Test Method

Volume 6

Final Report



MOBILE HOME RESEARCH

TRANSPORTATION AND SITE-INSTALLATION

DEVELOPMENT OF AN ANALYTICAL METHODOLOGY AND TRANSPORTATION FIELD TEST METHOD

VOLUME 6
FINAL REPORT

By

Southwest Research Institute

Prepared for

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

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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
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; & Mods 2 & 3;
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.

ACKNOWLEDGMENT

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.

ANALYTICAL METHODOLOGY

SIMPLIFIED TORSION TEST

ANALYSIS METHODOLOGY

BY

C.R. URSELL, II

W.W. RAINE

I. SIMPLIFIED TORSION TEST ANALYSIS METHODOLOGY

A. Scope

Following the testing of six new and used mobile homes, Southwest Research Institute correlated both flexural and torsional stiffnesses of each unit with its road worthiness. Testing verified that a unit's stiffness decreases as the mileage increases. As a result of these studies, SwRI recommended that a particular minimum level of flexural and torsional stiffness be required of new mobile homes. Recommended minimum stiffness levels were chosen such that, with anticipated rates of degradation, a mobile home should endure a reasonable lifetime and at least 1700 or 1100 miles of transportation for single-wides and double-wides, respectively.

For calculating flexural stiffnesses, two equations were used (developed by Battelle Memorial Institute*): one for the simply supported front section of a unit and one for the cantilevered rear section. These equations were considered adequate since they are generalized and can be adjusted as statistical data becomes available. To calculate torsional stiffness, SwRI derived six equations: formulas for the front and rear sections of single-wides and for the wet and dry halves of double-wides. These formulas are essential for defining input requirements to the Remaining Useful Life (RUL) equations† developed in Task I. It is important to note that only these specific formulas result in applicable input for RUL determination.

However, since development of the six torsional stiffness equations, SwRI has determined these equations to be unnecessarily complicated for

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* Bearint, D.E. and Cress, H.A., "The Development of Performance Based Tests to Determine the Minimum Structural Integrity of Mobile Homes," Final Report, Battelle Memorial Institute, Columbus, Ohio, July 25, 1966.

† See Volume I.

simple verification of required stiffness values. Replacing the original formulas with a single general torsional stiffness formula enables a consistent method of comparison among all types of mobile homes and, thus, simplifies the qualification of new units for travel. Such a formula revison requires no test method alterations; the same data used previously with the six equations can be used with the single general formula.

II. SIMPLIFIED TORSION METHOD AND TEST CALCULATIONS

The object of the torsion test is to determine an apparent torsional stiffness of the front and rear sections of a mobile home by twisting each section, measuring applied torque and angular deflection, and applying an appropriate formula to the data. A consistent method of performing the twisting is required to enable correlation of resulting stiffness values.

SwRI examined several methods of twisting a mobile home and determined the following most suitable: support the home at two points front and rear, and immediately in front of the axles--a total of six supports; individually raise and lower each corner, measuring and recording the force required and the resulting angular deflection. Corners should be raised up to but not beyond the point at which the weight of the entire mobile home end is supported by the single support, that is, the point at which the load on the adjacent end jack is just relieved. The purpose of the test is to apply a purely torsional moment. It is recognized, however, that some bending does occur; but, as long as a corner is not raised past the point of supporting the entire end load, bending is minimized and torque maximized.

The general formula for apparent torsional stiffness $\overline{GJ}$ can be expressed

$$\overline{GJ} = Ty/\theta \qquad (1)$$

where,

T = the applied torque,
y = the length of the torsional member, and
θ = the angle of twist.

Torque T by this test method is the product of the applied force P and the distance h from its application point to the mobile home centerline.

Angular displacement can be measured by any one of a variety of means. Vertical displacement at the point of force application can be converted into angular deflection but the quantities may be too small to measure accurately. SwRI chose to suspend a plumb line pendulum from the ceiling at the endwall of the unit. Figure 1 illustrates this method. Angular displacement, θ, of the section is derived from horizontal deflection, W, of the pendulum by the formula

$$\theta = \tan^{-1}(W/\ell) \qquad (2)$$

where ℓ is the pendulum length. Actually, any reasonable measurement technique is permissible if it provides accurate data.

With these substitutions for torque and angle, the torsional formula becomes

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

Both front and rear stiffness are derived from this formula.

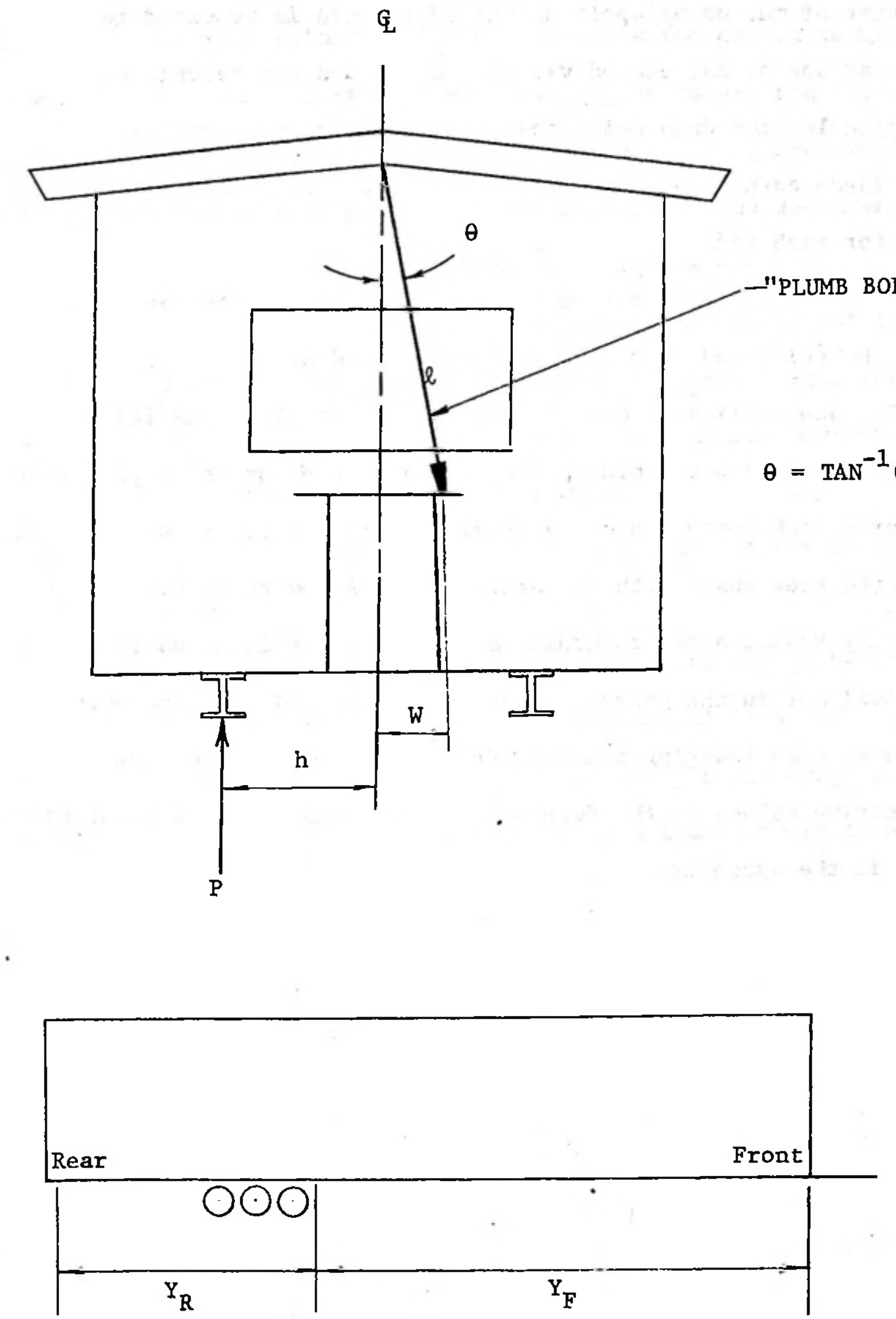


FIGURE 1. TORSION TEST DIAGRAM

III. DATA REDUCTION

A consistent method of applying the $\overline{GJ}$ formula is required to permit the comparison of calculated values. $\overline{GJ}$ values are calculated for each force/deflection data pair; these values of each corner are averaged, and these corner $\overline{GJ}$ values are in turn, averaged to yield an average value for each end.

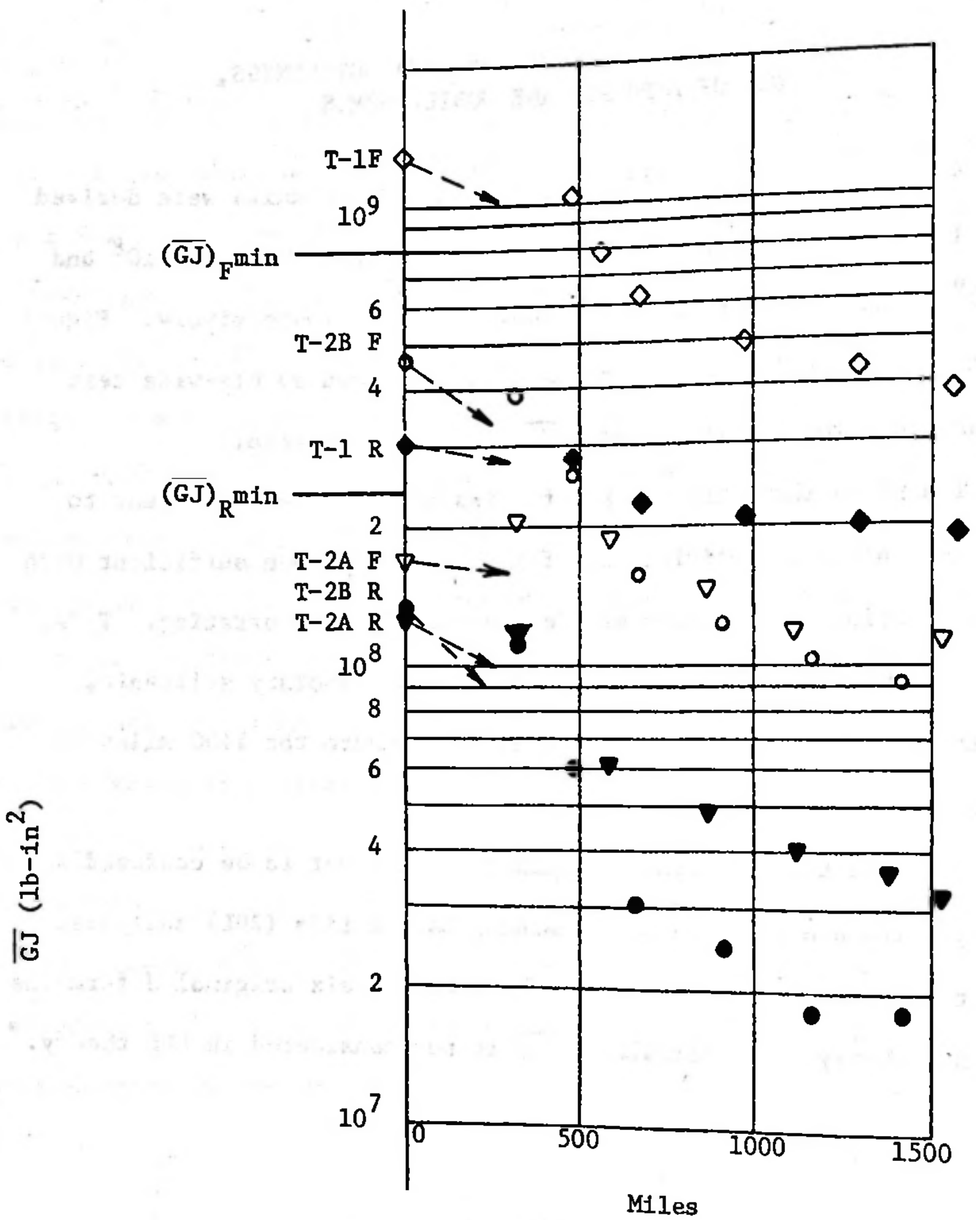
Confusion may arise in determining the force P and displacement h values from the collected data. Force P is defined as that force required to displace vertically one of the four corners from its level position at the force support point. That is, at any point of displacement, P is the measured jack force minus the level support force, or the force on the jack measured previously with the unit level. A new value for the level support force may result after returning a corner to the level position due to the mechanical set in the joints. Negative forces and displacements that are measured when lowering a corner from the level position are treated as positive values in the formula. Sample data sheets and calculations are presented in the Appendix.

IV. RECOMMENDED APPARENT TORSIONAL STIFFNESS, $\overline{GJ}$, OF ZERO MILEAGE MOBILE HOMES

Minimum torsional stiffness criteria for new units were derived by SwRI based upon Torsion Test data. These values are 8.0×10^8 and 2.4×10^8 lb-in.^{2} for the front and rear sections, respectively. Figure 2 presents the $\overline{GJ}$ stiffness histories of single- and double-wide test units and indicates the recommended $\overline{GJ}$ stiffness criteria.

The plots show that the stiffnesses of T-1 were sufficient to qualify the unit. The stiffnesses of T-2B may have been sufficient with only the addition of temporary stiffening during transportation. T-2A, however, would probably have required more than temporary stiffening particularly the front section, to adequately endure the 1100 miles of transportation.

As previously mentioned, values of $\overline{GJ}$ are not to be confused with $\overline{J}$ values, which are valid in the Remaining Useful Life (RUL) analysis. At this time, correlation exists only between the six original $\overline{J}$ formulas and the RUL theory. The formula for $\overline{GJ}$ is not considered in RUL theory.



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.

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

APPENDIX

SAMPLE DATA SHEET AND

CALCULATIONS

The following pages present a sample torsion test data sheet and the apparent torsional stiffness $\overline{GJ}$ for the front and rear sections of a mobile home. The general torsion formula used is

$$\overline{GJ} = Ty/\theta \qquad \text{(I-1)}$$

where,

T = the applied torque,
y = the length of the twisted member (distance from mobile home center supports to end supports), and
θ = the resulting angular deflection.

The values for T and θ can be calculated as follows:

$$T = Ph \qquad \text{(I-2)}$$

$$\theta = \tan^{-1}(W/\ell) \qquad \text{(I-3)}$$

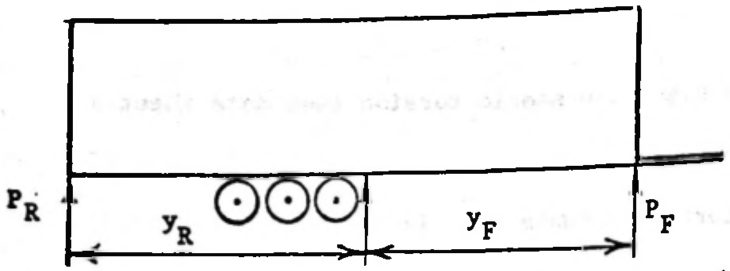
where,

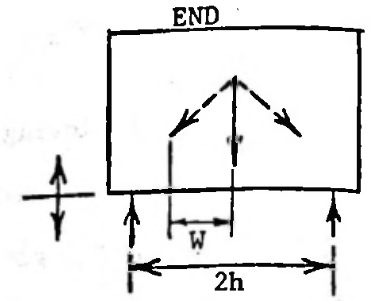
P = the applied vertical force that raises or lowers a corner from level,
h = the moment arm length (distance from mobile home centerline to applied force),
W = the horizontal displacement of the pendulum point, and
ℓ = the pendulum length.

Units are lb and in. to calculate $\overline{GJ}$ in $lb\text{-}in.^2$ The force P does not include the force required to support the unit in a level condition. P is either the force added to the level support force to raise a corner or the portion of the level support force that is relieved to lower the corner. Zero angular deflection (or pendulum displacement) and applied torque (or applied vertical force) correspond with the leveled state of the unit.

Apparent torsional stiffness values are calculated for each data pair T and θ (or P and W) and averaged to produce a $\overline{GJ}$ for each of the four corners. The values for the corners of each end are averaged to produce an apparent torsional stiffnesses for each end or section, front and rear.

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= 750	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

SAMPLE CALCULATIONS

FRONT END

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

h_F = 48 in.

ℓ_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})
Left Corner				
1000	2330	0	0	-
1250	2920	590	0.16	6.12 x 10^7
1500	3500	1170	0.28	6.93
1750	4080	1750	0.41	7.08
1800	4200	1870	0.44	7.05
1000	2330	0	0	-
750	1750	-580	-0.09	10.7
500	1150	-1180	-0.22	8.90
250	580	-1750	-0.34	8.54
0	0	-2330	-0.47	8.22

MEAN $(\overline{GJ})_F$ Left = 7.94 x 10^7 (lb - in.^{2})

Jack Pressure (psi)	$P_F + F$ (lb)	P_F (lb)	W_F (in.)	$\overline{GJ}$ (lb - in.^{2})
Right Corner				
750	1750	0	0	-
1000	2330	580	0.15	6.41 x 10^7
1250	2920	1170	0.22	8.82
1500	3500	1750	0.34	8.54
1750	4080	2330	0.53	7.29
750	1750	0	0	-
500	1170	-580	-0.13	7.40
250	580	-1170	-0.29	6.69
0	0	-1750	-0.39	7.44

MEAN $(\overline{GJ})_F$ Right = 7.51 x 10^7 (lb - in.^{2})

MEAN $(\overline{GJ})_F$ = 7.73 x 10^7 (lb - in.^{2})

REAR END

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

h_R = 48 in.

y_R = 324 in.

ℓ_R = 50 in.

Jack Pressure (psi)	$P_R + F$ (lb)	P_R (lb)	W_R (in.)	$(\overline{GJ})_R$ (lb - in.^{2})
Left Corner				
650	1520	0	0	-
900	2100	580	0.06	13.1×10^7
1150	2680	1160	0.13	12.1
1250	2920	1400	0.19	10.0
650	1520	0	0	-
400	930	-590	-0.09	8.90
150	350	-1170	-0.16	9.92
0	0	-1520	-0.22	9.38

MEAN $(\overline{GJ})_R$ Left = 10.6×10^7 (lb - in.^{2})

Jack Pressure (psi)	$P_R + F$ (lb)	P_R (lb)	W_R (in.)	$(\overline{GJ})_R$ (lb - in.^{2})
Right Corner				
700	1630	0	0	-
950	2220	590	0.19	4.21×10^7
1200	2800	1170	0.31	5.12
1300	3030	1400	0.37	5.14
700	1630	0	0	-
450	1050	-580	-0.13	6.06
200	470	-1160	-0.19	8.29
0	0	-1630	-0.31	7.14

MEAN $(\overline{GJ})_R$ Right = 5.99×10^7 (lb - in.^{2})

MEAN $(\overline{GJ})_R$ = 8.05×10^7 (lb - in.^{2})

TRANSPORTATION FIELD TEST METHOD–DEVELOPMENT

DEVELOPMENT OF A PROPOSED TEST PLAN TO CREATE A TRANSPORTATION FIELD TEST METHOD

by

C.R. Ursell, II
W. Raine

TABLE OF CONTENTS

I. INTRODUCTION

The objective of this task was to develop a simple, inexpensive method of determining whether or not a mobile home would meet the requirements of subpart "J" of the Federal Standard. A test of this type would be used by enforcement officials, compliance assurance agencies, manufacturers, and possibly financial organizations and consumers, all of whom are interested in the structural performance of new and used mobile homes under transportation conditions. Enforcement officials, compliance assurance agencies and purchasers testing mobile homes for their structural integrity are concerned with consumer protection. Manufacturers, on the other hand, have a greater variety of usage for such a method.

For a manufacturer, the job of designing mobile homes to minimize effects of complicated transportation loads would be simplified by designing to pass a structural integrity test that is a condensed version of actual transportation loadings. Performing the test on a finished product would essentially test the design calculations involved in forming a particular mobile home structure. Such a test would also help control the quality of the product by enabling comparison of workmanship on identical models. Similarly, units of the same model produced by different facilities of one manufacturer could be evaluated to compare the capabilities of the various facilities. In addition, a manufacturer can compare the performance of his units to those of his competitors.

Several methods of testing are examined in this document. Development of a performance standard based on these tests depends upon several steps (derived from the 1966 report by Battelle Memorial Institute for

Mobile Home Manufacturers Association and Trailer Coach Association).

- Guidelines--Test a completely assembled unit. Interactions of all structural components are to be considered because these are the conditions under which transportation effects are induced.

- Definition of test item--Test only the structural components of the unit, e.g., the box and chassis structure, which excludes the running gear, suspension system, A-frame, and hitch assembly.

- Definition of test environment--Test loads are to be the normal or typical loads imposed upon the unit during transportation.

- Criteria for acceptable performance--Design, materials, and workmanship must be of such quality that normal use does not produce an unacceptable amount of cumulative deterioration.

- Method of judging--A prime objective of Battelle's MHMA-TCA program on structural standards was "the development of a method for rating what has been termed the 'basic structural integrity' of a mobile home, a measure of how well the structure will stand up to various static and dynamic loads." That program developed what they called a "load-deflection" test that produces an "effective flexural rigidity." This volume examines that test and several others as adequate methods for determination of structural integrity.

Each test is reviewed with respect to several characteristics: advantages and disadvantages of cost and time; level of operator skill; sophistication of equipment; and degree of structural degradation that may be induced by the test method.

Including Battelle's test, the methods reviewed in this task are briefly described as follows:

- Natural frequency test - measuring the fundamental frequency of oscillation of the unit;

- Force-displacement test using pre-tensioned cables--recording force and displacement of the diagonal interior tension cables and external longitudinal lift cables with in-line devices;

- Strain gaging components - instrumenting wood, steel, and paneling, subjecting the home to dynamic loads and measuring the resulting stresses;

- Vibrating - simulating dynamic road conditions without transporting the unit;

- Weighing - determining axle and hitch weights;

- Dead load sag - measuring the deflections of the mobile home rear and hitch/axle midpoint that sag under the weight of the unit;

- Torsion test - twisting the mobile home and recording angular displacement and torque to determine torsional stiffness;

- Vertical bending or deflection test - bending the unit and recording vertical displacment in order to determine bending stiffness (Battelle's load-deflection test);

These potential methods were chosen after careful consideration of several analysis techniques. Since it was desired that the testing be performed on an entire assembled mobile home structure, testing of components implied by the Timber Analysis Handbook, mobile home calculation books, NBS Building Science Documents and Adhesives Manual were not considered. This literature generally refers to component or elements design, construction, and testing. Battelle's research program for MHMA-TCA was reviewed, as well as the analysis phases of the HUD contract under which this task is written. The analysis phases of this contract include the dynamic analysis of Task I, Volume II and Task III, Volume II, and the finite element model analysis of Task I, Volume III and Task III, Volume III. (See Figure 1.)

The next section of this volume examines the majority of the eight methods listed previously. Saved for further discussion in Section III of this document are the Torsion Test and the Vertical Bending Test. Emphasis is given these two tests because of their greater potential. In the final section of this document, a plan for development of formal versions of the acceptable tests is presented.

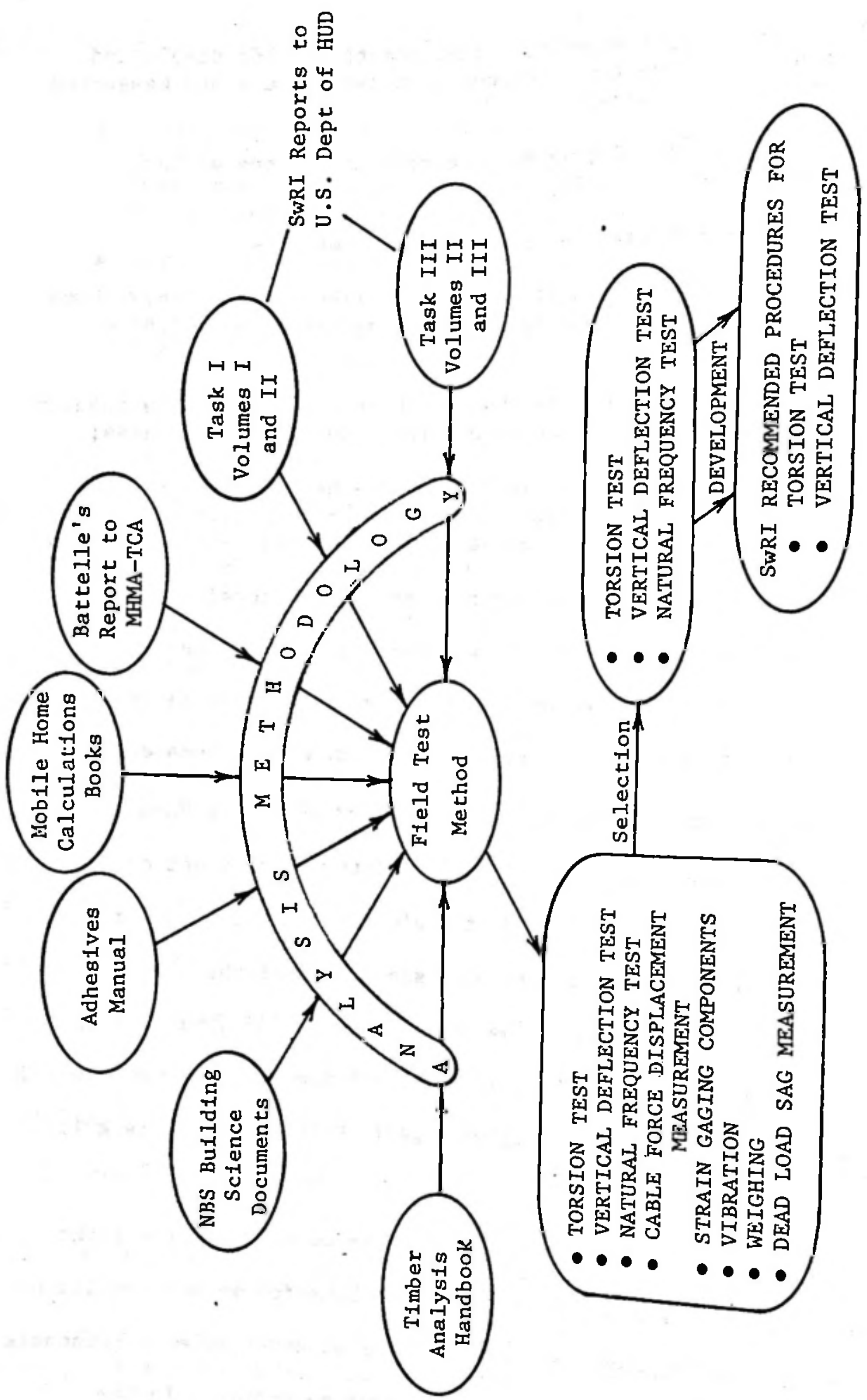


Figure 1. Flow Chart of Development of a Plan to Create a Field Test Method

II. SEVERAL POSSIBLE EVALUATION TECHNIQUES

A. Natural Frequency Test

Cumulative damage of a unit occurs primarily in the loosening of its many joints, which reduces overall stiffness. Since a change in stiffness is associated with a change in natural frequency, measurement of the latter value is an effective degradation quantifier.

A method of determining the natural frequency of a mobile home is to oscillate it as it sits on its running gear. This can be accomplished by dropping the tongue sharply or by several people simultaneously hopping in the rear of the unit. Oscillations of the structure are sensed by an accelerometer or a displacement transducer and recorded on magnetic tape or oscillograph. The natural frequency is computed from the measured period of oscillations. The apparatus for this test method includes an accelerometer, a tape recorder or oscilloscope, a power source, and some means of dropping the tongue.

B. Force-Displacement Test

Another means of quantifying the stiffness of the mobile home box structure is measuring the tensile force in pre-tensioned cables (internal diagonal and external longitudinal cables) that tie together the opposite wall/ceiling and wall/floor interfaces and lift the rear of the unit and the midpoint of the span between the axle and hitch. The collected data are then used to calculate effective torsional and bending stiffnesses, both of which relate to cumulative damage of the box structure.

C. Strain Gaging Components

Strain gages could be installed in a unit subjected to actual or simulated dynamic conditions in order to measure forces and stresses occurring in components of the mobile home. However, it is difficult to reproduce identical dynamic conditions for each test unit in order to compare the data.

D. Vibrating the Test Unit

Mechanical vibrators could be installed on a test unit to recreate dynamic conditions and subsequent displacements, strains, and accelerations recorded. However, once again, the problem of simulating actual conditions on each size and type of mobile home becomes a problem.

E. Weighing the Mobile Home and Measuring Dead Load Sag

These are two very simple and inexpensive measurements to perform on a mobile home. Although their results are limited and cannot be used to evaluate a unit's performance during transportation conditions, the tests are useful and worth discussing at this time.

In weighing a mobile home, only some means of vertical load or force measurement at the hitch, axles, and rear is required, such as a calibrated hydraulic load cell, or public scales. This weight test should be performed to check designer calculations and estimates of total weight and its distribution. If it is assumed that the difference in weight distributions of identical models is negligible, then an effective and quick means of comparison between them is by measurement of the dead load sag at the rear of the unit and at the midpoint of the span between the hitch and axles. As each unit of identical design rolls out of a manufacturer facility, these two deflections could be measured to roughly evaluate each unit's vertical bending stiffness. This test also provides a check on the chassis for precambering calculations. The equipment necessary for this test are three to five supports, depending on the method of support, a vertical displacement measuring device, a load measurement device, a transit-level and a rule or scale.

III. TORSION AND VERTICAL BENDING TESTS

Two tests that best fulfill the objective of this task and the constraints imposed by the Department of Housing and Urban Development are the Vertical Bending Test and the Torsion Test. The Vertical Bending Test is the same as that referred to in the Battelle literature as the "load-deflection test." These tests satisfy the performance standard development steps of Section I of this document: They subject the structural box of a mobile home (excluding running gear, suspension system, A-frame, and hitch assembly) to loads typical of those imposed on the unit during transportation in order to determine whether or not the manufactured product's cumulative degradation will be acceptable. Actually, the imposed loads of these tests are not dynamic in nature, as they should be to correlate with those of the transportation mode, but the imposed loads are considered to be their static equivalents.

A. Methodology

Generally, the tests are performed in the following manner. In the Vertical Deflection Test, a leveled mobile home is sequentially loaded with cumulative weights inside along the centerline at the midpoint of the span between the hitch and axles. The corresponding deflections at the various load increments are measured. The same procedure is performed at the unsupported rear end of the unit. The data pairs, load and deflection, are used to compute the apparent flexural rigidity or vertical bending stiffness.

The Torsion Test is conducted similarly except that instead of bending the mobile home, the torsion test primarily twists the structural box to relate angular displacement and torsional moment. Some bending occurs but is minimized by the procedure. A known vertical force is applied at each corner of the unit and the resultant angular displacement or that corner's deflection is measured. From these data pairs of force and deflection or rotation, the apparent torsional stiffness is calculated.

B. Advantages

From these two tests, significant information is obtained relatively quickly, easily, and inexpensively without requiring a great amount of instrumentation and sophisticated test equipment. The apparatus to perform the two tests (listed in detail later) consists of off-the-shelf and commonly used items. Only displacements and weights are measured and can be recorded by hand; consequently, little operator skill is needed. The two tests can be performed in a 3 to 6-hour period by as few as two technicians, although three would be more efficient. The calculations for stiffness can be computed in the field for immediate evaluation, and results are considered consistent and repeatable.

To enforcement officials, this means a plant inspector, compliance assurance agent, or designer with an assistant can test a unit straight off the fabrication line for its 'roadability' compared to others of similar construction. Knowing the stiffness of the mobile home through these tests as well as the road conditions and vehicle speed, one can calculate expected degradation incurred from a specific transport. (This is detailed in Task I, Volume II.)

C. Disadvantages

There are some drawbacks to these methods. Somewhat level ground is desirable for performance of these tests and may not always be available. Also, it may be difficult to gather as much as 1000 lb of portable weights required for the Vertical Deflection Test. (If water contained in barrels is used as weight, a water source would be required.) Moreover, there is

some degree of danger present in supporting a mobile home on as few as six supports, as required by the tests, especially if the wind is high or the supports unstable.

D. Equipment

The following equipment, in addition to a mobile home and an equipment transport vehicle, are required in one method of performing the Torsion and Vertical Bending Tests.

1. Torsion Test

(a) Six supports--piers with adjustable tops are preferred;

(b) Six hydraulic jacks, stands, or mechanical jacks;

(c) Level measurement device--transit level or spirit level depending upon desired accuracy;

(d) Vertical load and measurement device--calibrated hydraulic jack (or mechanical jack with load or force indicator);

(e) Angular displacement measurement device--pendulum, plumb bob inclinometer, or corner vertical displacement ruler;

2. Vertical Deflection Test

(a) Six supports--piers with adjustable tops are preferred;

(b) Six hydraulic jacks, stands, or mechanical jacks;

(c) Level measurement device--transit level or spirit level depending upon desired accuracy;

(d) Load media--water in barrels, handy weights (cinder blocks), or come-a-long between frame and ground with tension readout;

(e) Deflection measurement device--dial indicator, deflection potentiometer, or transit and rule.

E. Test Time And Costs

The time required to perform the two tests varies from 3 to 6 hours depending upon experience of the crew and convenience of the test site.

F. HUD Criteria

In requesting a physical test technique, the Department of HUD defined several criteria for the test.

Simplicity: The ability to require a minimum of sophisticated testing equipment and professional skill levels while conducting, recording and judging the test results;

Accuracy: The capability of the test method to consistently provide a "pass/fail" baseline that can be periodically verified by calculations;

Acceptability: The general endorsement of the test method by HUD, state enforcement officials, the mobile home industry and consumer groups;

Economy: Overall cost-effectivity to the industry, purchaser and regulator.

Under the field test method development, these criteria will be examined in detail. However, since it is known that the Torsion and Vertical Bending Tests fair well under these guidelines, preliminary statements can be made as follows:

With regard to simplicity, all of the required equipment is off-the-shelf, used, or surplus items. There is no need for development of sophisticated measuring devices or transducers. There is no need for extensive training to operate any of the equipment. The only measurements are forces (or pressures) and displacements, which can be read and recorded manually. Also, calculations can be performed at the test site for immediate evaluation using a hand calculator.

The accuracy of the data is known to depend on the accuracy of the recorded measurements, which, in turn, is dependent on the degree level of the mobile home. The actual sensitivity of the data to the level condition is difficult to determine without consistent, consecutive tests. This is not possible because each test has some effect on the stiffnesses, and a second test would measure a different stiffness. SwRI recommends that the

time it takes to minimize any out-of-level condition is essential for these two tests until a better understanding of the sensitivity of data to a unit's level condition can be achieved.

The third HUD criteria of acceptability is a matter yet to be determined. The plan to further develop these methods, which is presented later in this volume, includes means of determining the plan's acceptability. Initially, all parties involved must agree that torsional and bending stiffnesses are appropriate measures of structural integrity and cumulative deterioration. From the experience of SwRI, this appears to be a well received concept. Then, it must be agreed that a Remaining Useful Life (RUL) calculation can be based on these stiffnesses. The final task is to agree on base or reference stiffness values that are to be required of new mobile homes or that indicate zero RUL. This may be the most difficult.

The last HUD criteria to be met is economy with regard to industry, purchaser, and regulator. Industry would incur a possible expense to upgrade its product. In addition, a manufacturer would possibly incur a negligible expense to provide space and possibly water for tests at his factory door. The cost of the actual enforcement testing will fall to the regulator or enforcement official performing it, unless the official chooses to pass the expense on to the manufacturer and inevitably to the consumer.

One of the objectives of the development of a test plan is to determine the minimum number of tests needed to develop the data and still minimize the total testing cost. That is, if the total cost to test a single unit was $150 and only 1 out of 30 units was tested, the cost per unit would only be $5. This assumes that the cost to develop configurations for various models to pass the tests is not an additional expense, but a redirected development expense.

IV. DEVELOPMENT OF A FIELD TEST METHOD

The development of a field test method from this point forward will concentrate on the Torsion and Vertical Bending Tests because of all methods considered they offer the greatest promise. The other methods will be performed, if practical, to verify the characteristics defined previously. However, the primary purpose of this development will be to assess the feasibility of the Torsion and Vertical Bending Tests and devise practical methods for their implementation.

This effort will be accomplished through performance of several versions of each test and evaluation of their individual characteristics--advantages and disadvantages, necessary equipment, operator skill level, time and costs, simplicity, accuracy, acceptability and economy as applied to several models and types of mobile homes.

A. Variations of the Torsion and Vertical Bending Tests

General methodologies of these two tests were defined previously in this volume. Each can be performed in several different ways. Variations on each follow.

1. Torsion Test

The Torsion Test involves twisting the mobile home at each end of the unit by applying known vertical forces at one corner at a time and measuring the angular deflection. The test is usually performed by raising and/or lowering each of the four corners individually. Effective torsional stiffness values are computed for each load displacement data point and are averaged for each corner. The two corner averages of one end are also averaged to determine the effective torsional stiffness of that end of the structural box.

Variations on this method to consider individually or in conjunction with each other are as follows:

(a) Apply forces to raise and lower only one corner of each end, twisting the unit both directions.

(b) Twist in only one direction while working at each corner but in opposite directions at each corner of one end. That is, apply the force in only one direction, such as upward, at every corner.

(c) Apply (or release) vertical loads at a corner until one jack supports no weight at that end of the unit and the other jack supports the entire weight.

(d) Or apply (or release) vertical loads beyond the point at which only one jack supports the end. For example, this means that in an up loading condition of the front left corner, loads are applied past the point of no load on the front right corner. From this point, the front right corner must be anchored to hold its position and induce twist.

(e) Simultaneously raise one corner and lower the other corner at that end.

Another item to consider is the loading increment or how frequently deflection measurements are taken.

2. Vertical Bending Test

The Vertical Bending Test deflects the unit at the rear and midpoint of the span between the axles and hitch by adding vertical loads. Variations to consider separately or in conjunction with each other are as follows:

(a) Apply the loads downward by adding portable weight to the interior floor. Suitable weights to consider are bags of shot or sand, water barrels, or cinder blocks.

(b) Apply the loads downward from the chassis by attaching a tension cable to ground anchors.

(c) Apply the loads upward with jacks on the chassis.

(d) The loading increment and total load should be considered.

B. Evaluation Procedure

The testing variations just described will be implemented to determine their feasibility and effectiveness unless obvious reasons (such as damage to the test unit) prove the method to be impractical. Evaluations will be made of overall cost, which is affected by performance time, required equipment, operator skill level, and simplicity. Also assessed will be characteristics such as accuracy, acceptability, advantages and disadvantages.

The load increment or frequency of data collection and total load will be considered since they affect total test time and the number of calculations. Each data set yields a stiffness value that is averaged with similar values to produce the final factor; the greater the number of data sets, the higher the confidence level, but also the greater the number of calculations. The number of data sets is determined by both the load increment and the total load. Part of the evaluation will be to determine the number of points at which measurements should be taken. This will depend on the linearity of the stiffnesses of the test units; that is, whether a linear relationship exists between force and displacement.

Testing will be performed on single-wide units and each half, wet and dry, of double-wide units in order to determine the feasibility of all the methods performed for each type of mobile home unit.

TRANSPORTATION FIELD TEST METHOD— VALIDATION

IMPLEMENTATION OF A VALIDATION PROGRAM TO DEVELOP A TRANSPORTATION FIELD TEST METHOD

by
C.R. Ursell, II
W. Raine

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I. INTRODUCTION

The object of this task is to implement the proposed test plan presented in Task VI to create a transportation field test method. That task compiled and briefly evaluated several candidates for such a field test. Of those methods considered, the Torsion Test and Vertical Deflection Test appeared most promising. Consequently, Task VI listed several variations of these two test methods to examine for feasibility.

The tests are to be evaluated on several points. A primary consideration is cost, which is affected by performance time, required equipment, operator skill level, and simplicity. Also to be assessed will be accuracy, acceptability by all parties involved and other advantages and disadvantages. These points will also be evaluated from the view point of enforcement officials, compliance assurance agencies, manufacturers and purchasers. Differences in performance among single-wides and each half of double-wides, dry and wet, will be noted.

The candidate methodologies presented in Task VI were as follows:

1. Natural frequency test - measuring the fundamental frequency of vertical oscillations of the unit.

2. Force-displacement measurements along pre-tensioned cables - recording force and displacement along diagonal interior cables and external longitudinal cables.

3. Strain gaging components - instrumenting wood, steel and paneling; subjecting the home to dynamic loads, and measuring the resulting stresses.

4. Vibrating - simulating dynamic road conditions in the laboratory transporting the unit.

5. Weighing - determining axle and hitch weights.

6. Dead load sag - measurement of the deflections of the mobile home rear and hitch to axle midpoint which sags under the static weight of the unit.

7. Torsion Test - measuring the resistance to twisting the mobile home and recording angular displacement and torque to determine torsional stiffness.

8. Vertical bending or deflection test - measuring the resistance to vertical bending of the unit and recording vertical displacement to determine bending stiffness (Battelle's load-deflection test).

II. SUMMARIES OF THE EVALUATIONS OF THE METHODS EXCLUDING TORSION AND VERTICAL BENDING TESTS

Torsion and Vertical Bending Tests are discussed separately in greater detail as presented in Section III of this document. The evaluations of the other six methods are noted as follows:

A. Natural Frequency Test.

Cumulative damage of a unit occurs primarily in the loosening of its joints which in turn reduces the overall stiffness of the structural box. Since a change in stiffness is associated with a change in natural frequency, measurement of the latter value is an effective degradation quantifier.

A method of determining the natural frequency is to oscillate the unit in a vertical mode as it sits on the running gear. This can be accomplished by either dropping the A-frame or tongue sharply or by the simultaneous hopping in the rear of the home by two or three people. Vertical oscillations of the structure are sensed by an accelerometer or a displacement transducer and recorded on magnetic tape or oscillograph. The natural frequency is computed from the measured period of oscillations. The apparatus for this test method includes an accelerometer, a tape recorder or oscilloscope, a power source, and some means of dropping the tongue or inducing vertical oscillations in the unit.

Most of the advantages of this method are associated with its simplicity. It is easy to set-up and perform. It can be accomplished in a short period of time. The equipment is relatively inexpensive and easily transported. However, there is some sophistication involved and requires a level of skill which may be higher than desired. Also, the equipment (accelerometers and recorders) are not common to manufacturing sites so that the test would not be convenient to perform by manufacturers.

The inclusion of a power source in the apparatus is an additional factor of inconvenience. Another disadvantage is the possible degradation of the mobile home as a result of the test, however this is no more than that experienced in a few miles of road.

Because of the test's possible degrading nature and the non-standard configuration of the required equipment, the natural frequency test is not recommended as a universal method of evaluation. However, since the results are quickly obtained and economical in cost, this method cannot be completely disregarded by those interested in the extensive analysis of a unit.

B. Force - Displacement Measuring Along Internal Diagonal Cables and Longitudinal Cables.

Another means of quantifying the stiffness of the mobile home box structure is by measuring the tensile force in cables which act in torsion creating loads between opposite wall/ceiling and wall/floor interfaces and lifting up the rear of the unit and the midpoint of the span between axle and hitch. The collected data would be used to calculate effective torsional and bending stiffnesses, both of which are related to cumulative damage of the box structure.

In order to measure the force between opposite corners of the structural box, fittings would have to be installed for attachment of the cables. This is something manufacturers may object to because of cost and possible degradation from test induced stress concentrations. However, with fittings available the tests could possibly be conducted using only a single man. He would need only the cables, an in-line tension indicator and a means of measuring the shortening or loosening of the cables. Stretch must be taken into account, but is not a restrictive complication. The test could be quickly accomplished and easily repeated. Although this method is not discussed further in this document it should not be disregarded entirely. The only reason examination ends here for this method is the preference of other methods.

C. Strain Gaging Components.

In order to accurately measure the forces and stresses incurred in components of a mobile home, strain gages could be installed and the unit exposed to actual or simulated dynamic conditions. The difficulty of this method is reproducing identical dynamic conditions for each test unit in order to compare the data. Also there are inconveniences in installing the transducers which may require a set period of up to 24 hours. Also it may require that some gages be installed during fabrication or assembly of the unit to which a manufacturer may object. Since so much of the structure is wood and plywood, a strain gage for wood components would require special skills and equipment. The other items of equipment required for this effort may require a degree of skill higher than desired. Also, this equipment requires a power source and other components not alway available at many locations. For these reasons, this method has not been considered further.

D. Vibrating the Test Unit.

In order to recreate dynamic conditions consistently, mechanical vibrators could be installed on a test unit and subsequent displacements, strains and accelerations recorded. The major difficulty is that the spectrum of vibrations induced by road conditions are almost impossible to reproduce, so any attempt would be merely a poor approximation. However, if the method is applied, the equipment required would be complicated and must be installed using special skills for desirable results. Even if an appropriate measurement method were devised, technical development is required on the vibration generation for an acceptable random spectrum. Still, with both of these problems solved the cost of the apparatus and the time to set-up and perform the test are likely to be prohibitive. The additional cost of data reduction and analysis are prohibitive. This method is not considered further for these reasons. Also, in order to retrieve adequate data, extensive testing may be required and some damage to the unit may occur.

E. Weighing the Mobile Home and Measuring Dead Load Sag.

These are two very simple and inexpensive measurements to perform on a mobile home and worth discussing. However, their results are limited due to the static configuration and cannot be used to judge a unit with respect to transportation conditions.

The equipment for weighing a mobile home requires some means of force or weight measurement at the hitch, at the axles and at the rear wall. This item could be a calibrated hydraulic load cell, or public scales. This test should be performed to check designers' calculations of total weight and distribution but cannot be used to evaluate the accumulated transportation deterioration.

If it is assumed that the difference in weight distributions of identical models is negligible, then an effective and quick means of comparison between them is the measurement of their dead load sag at the rear wall of the unit and at the midpoint of the span between the hitch and axles. As each unit of identical design rolls out of a manufacturers facility, these two sags could be measured to evaluate roughly each unit's vertical bending stiffness. This vertical bending test would also provide a check on chassis precambering and associated calculations. The only equipment necessary for this test would be six supports and measurement devices, such as a transit/level and a rule. The major drawback of this technique is that it only allows comparison of like units since non-identical models would naturally deflect differently.

These two methods are mentioned here because they are so simple and can be performed quickly and economically but, because of their limited output, are not proposed as methods of evaluating a unit per Subpart "J" of the Federal Standards.

III. TORSION AND VERTICAL DEFLECTION TESTS

The two methods which best fulfill the criteria as specified by HUD are the Torsion Test and the Vertical Deflection Test. These two methods twist and bend a mobile home to determine its effective torsional and bending stiffnesses under static equivalents of the normal or typical load imposed upon the box structure during the transportation mode.

Both stiffness values are important in the evaluation of a mobile home. It is possible for a unit to be stiff in one mode and not the other, though this is not too common. Analysis by SwRI determined that during transport, the torsional mode is the greatest contributor to degradation. This degradation occurs primarily as loosening of joints, whereas stiff side walls which yield a high bending stiffness would not necessarily prevent torsional weakening. The opposite case is also possible where a torsionally strong unit may be weak in the bending mode. This situation could occur with tight joints developing high torsional stiffness but weak side walls allowing undesirable vertical sag. Weak side walls may be the product of inadequate side wall design, poor material choices, insufficient fastening methods or improper workmanship. Thus, not only is torsional stiffness a proper measure of roadability, but also bending stiffness must be considered.

METHODOLOGY

Generally, the tests are performed in the following fashion. Under the Vertical Deflection Test a leveled mobile home is loaded internally at several increments at the midpoint of the hitch/axle span. The corresponding deflections at each load are measured at the point of loading. The same procedure is performed at the unsupported rear end of the unit. The data pairs, load and deflection are used to compute the effective flexural rigidity or bending stiffness.

The Torsion Test is conducted similarly except that instead of bending the mobile home, this test twists the structural box to determine the relationship of angular deflection and torsional moment. The method is to apply a known vertical force at each corner of the unit and measure the angular displacement of that end of the unit or measure the corner's vertical displacement. From these data pairs of force and deflection, the torsional stiffness is calculated.

Several variations of the methodologies for these two tests were considered as described below:

A. TORSION TEST

1. Apply loads at only one corner of each end of the mobile home, twisting the unit in opposite directions.

2. Twist in only one direction at each corner but in opposite directions at each corner of one end. That is, apply the force in only one direction, say vertically or up at every corner.

3. Apply (or release) vertical loads at a corner until one jack supports no weight at that end of the unit and the other jack supports the total weight of the end section.

4. Or apply (or release) vertical loads beyond the point at which one jack at that end supports all the weight. This means, for example, that in an up-load condition on the front left corner, loads are applied past the point of no load on the front right corner. From this point the front right corner must be anchored to hold its position. In a down-load condition at the front left corner, its support load is released until zero load is on the jack and then load is added to further deflect the corner.

5. While raising (or lowering) one corner, lower (or raise) the other corner of that end of the unit.

B. VERTICAL BENDING TEST

1. Apply the loads downward by adding portable weight to the interior floor. Suitable weights to consider are bags of shot or sand, water barrels or cinder blocks.

2. Apply the loads downward from the chassis by attaching a tension cable to ground anchors.

3. Apply the loads upward with jacks on the chassis.

EVALUATION OF THE TORSION AND VERTICAL BENDING TEST VARIATIONS

The following conclusions are conservative by necessity. In general, they allow for no shortcuts. Rather than approve abbreviated methods, SwRI recommends the full tests. Since the scope of this task did not provide for a larger sampling size, future evaluations based on the testing of many units may reach slightly more lenient conclusions. Points which bear future examination are indicated in this section and in the recommendations.

The TORSION TEST involves twisting the mobile home at each end of the unit by applying known vertical forces at corners and measuring the angular deflection. The test is usually performed by raising and/or lowering each of the four corners individually. Effective torsional stiffness values are computed for each load displacement data point and the total measurements are then averaged for each corner. The two corner averages of one end are averaged to determine the effective torsional stiffness of that end or section of the mobile home.

The first variation of raising and lowering only one corner per end of the unit can produce inaccurate results. During the SwRI testing, sufficient variation existed between the stiffnesses measured at each corner of an end section to encourage the measurement at both corners. Particularly, non-symmetry is most evident in the evaluation of double-wide units. However, data from numerous torsion-tested units in the future may indicate that the variation between the sides will be considered insignificant, such that testing of only one side will be sufficient. Also conceivable, is that in order to determine the compliance of a unit, data will be taken only from the side which yields lower effective stiffness values.

A problem with "mechanical set" may arise from performance according to the second variation, only the raising (or lowering) of each corner. Although each end of the unit is twisted in both directions, it is twisted in only one direction from the force application at each corner. The twisting action develops a latent set such that determining the torsional stiffness from the other corner will indicate a different stiffness. Raising and lowering a corner twists the structural box in both directions and removes any set. This is not true of a new mobile home with tight joints. Also, the additional data points are necessary to properly calculate the stiffness as measured at one corner. Therefore, if a unit is to be tested at all four corners, it should be twisted in both directions at all four corners.

The next two variations approach the question of how much vertical force should be applied at each corner - whether the unit should be loaded past the point at which the mobile home end is supported at only one corner. Exceeding this point may tend to weaken the structure by a greater proportion than that incurred by singly supporting an end. Enough data can be collected without this additional degradation. Therefore, twisting should not exceed the point of singly supporting an end.

Another variation involves the simultaneous lifting and lowering of opposite corners at an end. The lifting or lowering of most corners during testing seldom exceeded 2 inches. The angular displacement of the end or corner about the longitudinal axis is more than 7 times that about the lateral axis. With such great differences, benefits of lowering and raising the corners at one end simultaneously are negligible.

The final point to consider in the methodology of the Torsion Test is the increment of loading or the frequency of data measurement in the raising and lowering of a corner. An economic trade-off exists between time of test performance and accuracy of final results, both of which depend upon the number of data measurements. Since emphasis was placed upon the accuracy and performance, time was not affected as much by the number of measurements, SwRI settled upon 500 lb as convenient load increment. With this value, 8 to 10 data points per corner were collected, giving a reasonably detailed profile of the stiffness function of corner loading without requiring too much performance time for the conduct of the test.

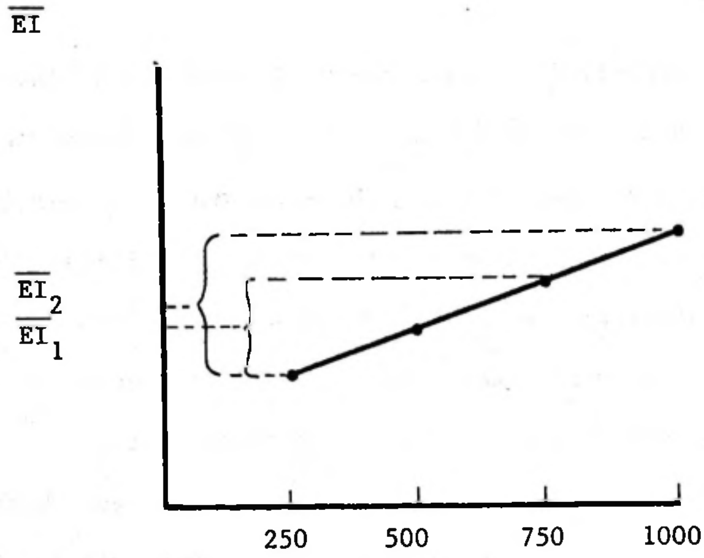
VERTICAL BENDING TEST variations differ basically in two ways--whether the applied loads should be upward or downward and how the loads should be applied. The question of load direction is still a point of debate. SwRI prefers downloading for several reasons, but realizes some disadvantages exist.

Measurement of force and displacement in either direction will give reasonable numbers with which to evaluate the vertical stiffness of a mobile home. Rather than load direction, consistency of method is considered the important factor. However, several problems are not present in downloading. Displacing the unit upward in the rear has the possibility of buckling the roof to some degree. There also may be a problem of permanent damage to the I-beams on which the concentrated up-loads are applied. A question of how to distribute the up-load between two supports arises since the static weight of the unit is seldom symmetrical. The most important factor which favors down-loading is the fact that in-transit loads are greater in the down direction in both magnitude and frequency. Unfortunately, the apparatus to create down-loads is bulkier and less convenient than a pair of load cell jacks to create up-loads.

Deciding upon down-loading, SwRI searched for a fast, convenient, economical method to perform the vertical bending test. One was not found, but an improvement to the Battelle technique was made. Rather than manually install and remove bags of lead shot, SwRI prefers to fill and drain calibrated water barrels. The convenience of this method depends upon the availability of water at a test site which eliminates carrying portable weights to the site and in and out of the test unit. Instead two 55 gallon drums and several lengths of water hose are used. Water pressure and siphoning accomplish the work in less time and with minimum investment in equipment.

Two drums can hold approximately 1000 lb of water which is considered as the maximum load to be applied to the interior for this test, including an operator and barrels, the total load would be about 1250 lb. The additional rear deflection measured from static sag due to this load seldom exceeds one inch. Calculations from and observations during dynamic testing indicated that this amount of vertical bending was common during the transportation mode and thus is not a significant contributor to the degradation of mobile homes. Taking measurements at 250 lb increments provides at least 4 data pairs from which to compute the effective bending stiffness. This is a sufficient number of values to average since typically the computed stiffness for an end section did not vary be more than 20%.

The spring rate, the ratio of force to deflection, is not constant since it increases with force. To derive a single stiffness value for each end section, an average value of incremental stiffness values is computed. A different average can be computed from the same data if fewer data points are considered. Observe the following graph. If the effective stiffness increases with force as shown, averaging only the stiffnesses calculated



$$\overline{EI}_1 = \left[(\overline{EI})_{250} + (\overline{EI})_{500} + \overline{EI}_{750}\right]/3$$

$$\overline{EI}_2 = \left[(\overline{EI})_{250} + (\overline{EI})_{500} + (\overline{EI})_{750} + (\overline{EI})_{100}\right]/4$$

from 750 lb and less will yield a different value than also averaging in the 1000 lb value. The point is that for test purposes, these two numbers should be standardized - the total force and the incremental force. SwRI recommends 1000 lb in addition to operator and barrel weight, or about 1250 lb, for a total Vertical Bending Test load. The incremental force at which measurements are taken is recommended at 250 lb.

ADVANTAGES

From these two tests, significant information is obtained relatively quickly, easily, and inexpensively without requiring a sophisticated system of test equipment. The apparatus to perform the two tests (listed in detail later) consists of off-the-shelf, used, and surplus items. Only displacements and weights as forces are measured and these can be recorded by hand. Consequently, only a minimum level of operator skill is needed. The two tests can be performed in a 3 to 6 hour period by as few as two technicians, although three is a more convenient number. The results are considered consistent or repeatable. Calculations for torsion and vertical stiffness ($\overline{EI}$ and $\overline{J}$) can be computed in the field for immediate evaluation.

What all this means to enforcement officials is that a plant inspector, compliance assurance agent, or designer with an assistant can test a unit fresh off the fabrication line and determine if the mobile home meets the Federal Standard. The evaluation indicates the roadability of the unit in relation to others of similar construction. As detailed in Task I, Volume II, together with a knowledge of road conditions and vehicle speed, the results of these tests can indicate expected degradation incurred from a specific haul.

DISADVANTAGES

There are some drawbacks to these methods. Some inconveniences may be present in the performance of the tests since fairly level ground is desirable and may not always be available. Also, as much as 1000 lb of portable weights may be difficult to gather for the Vertical Deflection Test. (If water in barrels is used as weight a water source would be required.) There is some degree of danger present in supporting a mobile home on as few as six supports as required by the tests, especially during high winds.

EQUIPMENT

In addition to a mobile home and an equipment transport vehicle, the following equipment would be required for one method of performing tests:

A. Torsion Test

1. 6 supports - hydraulic jacks, stands, or mechanical jacks;
2. Level measurement device - transit/level or spirit level depending upon desired accuracy;
3. Vertical force device - calibrated hydraulic jack (or mechanical with load force indicator);
4. Angular displacement measurement device - pendulum or inclinometer, and a corner vertical displacement device ruler;
5. Alternate for measuring continuous loads and angular displacements - electronic load transducer and inclinometer with magnetic tape or strip chart recording.

B. Vertical Deflection Test

1. 6 supports - hydraulic jacks, stands, or mechanical jacks;
2. Level measurement device - transit/level or spirit level depending upon desired accuracy;
3. Downward load - water in barrels, handy weights (cinder blocks), or come-a-long between frame and ground anchor with load readout;
4. Deflection measurement device - dial indicator, deflection potentiometer, or transit and rule;
5. Alternate for measuring continuous loads and vertical displacements - electronic load cell under water barrels and deflection potentiometer with recording on magnetic tape or strip chart recorder.

Except for the electronic alternatives and the transit/level devices, none of the equipment requires any special level of expertise. The tests can be conducted by a plant inspector, or a junior engineer, with one or two mechanics or by two or three mechanics.

TEST TIME AND COSTS

The time required to perform the two tests varies from 3 to 6 hours depending upon experience of the crew and convenience of the test site. As many as 2 of these hours may be consumed merely by communicating and arranging setup and equipment before testing even begins. Actual testing time does not normally exceed 4 hours; - 1 hour for positioning and leveling the mobile home, 1 hour for the Torsion Test, and 2 hours for the Vertical Bending Test. This last test has the greatest potential for reducing elapse time with the volume of water flow into and out of the barrels as the limiting factor. The labor cost for the two tests using 3 men for 4 hours, or 12 man-hours, at $15/man-hour equals about $200, excluding travel expenses of lodging, transportation, and meals.

There is no supply cost for each test and only a one time equipment expense. The minimum required off-the-shelf and surplus items and their approximate costs are as follows:

2 barrels	$10 (surplus)
transit level	$300 - 1000
hose - 200'	30
8 jackstands (5 ton) or jacks	40 - 400
1 load cell jack	50
pendulum (plumb bob)	5
ruler	5
blocks - shoving	10 (surplus railroad ties)
dial indicator & stand	45
TOTAL	$495 - 1555

In addition a dolly may be desired for handling equipment.

HUD Criteria

In requesting a physical test technique, the Department of HUD defined several criteria for the test.

SIMPLICITY:	The ability to require a minimum of sophisticated testing equipment and professional skill levels while conducting, recording and judging the test results;
ACCURACY:	The capability of the test method to consistently provide a "pass/fail" baseline that can be periodically verified by calculations;
ACCEPTABILITY:	The general endorsement of the test method by HUD, state enforcement officials, the mobile home industry and consumer groups;
ECONOMY:	Overall cost-effectivity to the industry, purchaser and regulator.

The Torsion and Vertical Bending Tests meet these guidelines.

With regard to simplicity, all of the equipment are off-the-shelf, used, or surplus items. There is no need for development of sophisticated measuring devices or transducers. There is no need for extensive training to operate any of the equipment, except possibly the transit/level. The only measurements are forces (or pressures) and displacements which can be read and recorded manually. Rough calculations can even be performed at the test site using a hand calculator for immediate evaluation.

The accuracy of the data is known to depend upon the precision of the levelness of the mobile home. The actual sensitivity of the data to the level condition is difficult to determine since its determination would require numerous consistent, consecutive tests under different out-of-level conditions. This is not possible since each test has some effect on the stiffnesses and the second test would measure a different stiffness. Without a firm grasp on the sensitivity of data to a unit's condition of level, SwRI recommends that the time to minimize any out-of-level condition is worthwhile for these two tests.

Since all measured quantities of the two methods are accurate to at least 2 significant digits, the computed stiffnesses $\overline{GJ}$, $\overline{J}$, and $\overline{EI}$ are equally as accurate. Torsion test data are reduced by either a $\overline{GJ}$ formula or $\overline{J}$ formulas presented below, depending upon the use. Calculation of the torsional stiffness of a new unit to determine if it qualifies under minimum stiffness criteria,* the $\overline{GJ}$ formula is used. However, the $\overline{J}$ formulas are used in RUL† analysis. The $\overline{EI}$ formulas produce stiffness values used in both new unit stiffness criteria and RUL analysis. The formulas are as follows:

<u>Torsion Test</u>

$\overline{GJ}$ formula (new unit minimum stiffness criteria), front or rear section

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

$\overline{J}$ formulas (RUL analysis)

Single-wides

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

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

Wet double-wide half

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

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

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

<u>Vertical Deflection Test</u>

Front: $(\overline{EI})_F = 36y_F^3(P_F/d_F);$

Rear: $(\overline{EI})_R = 570y_R^3(1 + y_F/y_R)(P_R/d_R);$

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* See Volume 5.
† See Volume 4.

where:

subscripts F and R denote front and rear;

P is the known applied load (lb);

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

y is the length of the twisted section (in. for Torsion test, ft for Vertical Deflection);

W is the measured lateral displacement of the pendulum (in.);

ℓ is the pendulum length (in.); and

d is the vertical deflection at the point of vertical loading (in.).

In performing these tests, operators should be aware that disturbances can affect the results. The wind can be an uncontrollable disturbance which may cause the vertical deflections to oscillate by as much as .01 inch. Fortunately, this amount is not enough to compromise results. While conducting the tests, operators should control all conditions changing only those of interest. That is, during the Vertical Bending Test only calibrated weights should be added to the unit. Similarly, during the Torsion Test internal weight distribution should not change.

The third HUD criteria of <u>acceptability</u> is a matter yet to be determined. The plan to further develop these methods, which is presented later in this volume, includes means of determining the plan's acceptability. Initially, all parties involved must agree that torsional and bending stiffnesses are appropriate measures of integrity and cumulative deterioration. From the experience of SwRI this appears to be a well received concept. The next point to be accepted is that a Remaining Useful Life (RUL) can be based on these stiffnesses. The final task is to agree on base or reference stiffness values which are to be required of a new mobile home or which indicate zero RUL. This may be the most difficult.

The last HUD criteria to be met is economy with regard to industry, purchaser, and regulator. The only cost to industry is the possible cost to upgrade their product. There are no directly related test costs borne by the manufacturer and subsequently passed on to the consumer. (A manufacturer would have to provide space and possibly water for tests at his factory door but both are negligible expenses.) Since the manufacturer is not necessarily burdened by the cost of testing, neither is the purchaser.

The enforcement official performs the tests at no cost to the manufacturer. As detailed earlier, the test cost is not significant. However, this expense may be passed on to the manufacturer depending upon the results of the test. One of the objectives of the development of a test plan is to determine the minimum or optimum number of tests required in order to minimize the total testing cost. That is, if the total cost to test a single unit was $400 and only 1 out of 5 units was tested, the cost per unit would only be $80. This may be a small price to pay for increased roadability and useful life. This assumes that the cost to develop basic models to pass the tests is not an additional expense, but a redirected development expense.

IV. RECOMMENDATIONS

From extensive consideration, testing and evaluation the recommended field test procedure consists of the Torsion Test and Vertical Bending Test demonstrated by SwRI personnel at the official HUD conference April 19-20, 1978, and are presented in Appendix A. Attendees of that conference and a similar one January 25, 1978, are listed in Appendix B.

These versions of the test are as extensive (and expensive) as they ever need be. Future evaluation of the procedures after their application to many units may devise acceptable modifications (or shortcuts). However, based on the implementation of the validation program of this task, no shortcuts should be taken until an acceptable quantity of units have been tested uniformly. A procedure for evaluating such modifications is detailed later in this section.

The field testing of numerous units "out the factory door" can answer several other questions.

- Should every unit of a particular model or design be tested for compliance?
- If not, how frequently should units of a particular model be tested for compliance? Will this vary by facility or manufacturer?
- Or, rather than testing by models, should the compliance testing be to qualify a manufacturer's various sizes and weights?
- If so, how frequently should units of a particular size and weight be tested for compliance?
- How do these questions apply to each mobile home type, that is, single-wide, dry side and wet side of double-wides?
- How does degradation rate vary with construction methods, components, materials, and quality of workmanship?
- If the effective bending stiffness $\overline{EI}$ of a unit is sufficient to qualify, will the effective torsional stiffness $\overline{J}$ qualify, and vice-versa?

These questions cannot be answered until many units are tested. SwRI recommends testing every unit possible and that the recommended procedure be adhered to rigidly and that the data be recorded and reduced carefully. In order to determine the degradation rate of various construction techniques, subsequent testing should be performed on several factory tested units, following delivery to dealers' lots at a distance of 150 to 400 miles from the factory.

Evaluation of Modifications to the Field Test Procedure

As stated previously, the SwRI recommended procedures are conservative by necessity, and allow for no shortcuts. As a larger sampling size is completed, modifications to the procedures may appear permissible. Modifications to consider for the Torsion Test are as follows:

1. Work with only the corner of an end that will apparently produce the lower effective torsional stiffness value;
2. Only raise (or lower) each corner used;
3. Vary the load increment and total load.

To approve such modifications analysis of a significant volume of the load/deflection data is required. Apparent torsional stiffnesses would be calculated for each data point and averaged for each corner and end.

Comparison of these values for each data point, each corner, and each end would determine the loss of accuracy by modifying the fully test.

The first modification to consider is working with only one corner per end, presumably the one corner which will produce a lower stiffness value. If the examination of several torsional stiffness calculations indicates an allowable difference between $\overline{GJ}$ for each corner and $\overline{GJ}$ for that end, then abbreviating the Torsion Test can be justified.

The second modification can be examined similarly. To investigate only raising (lowering) each corner, rather than both raising and lowering, only the appropriate $\overline{GJ}$'s for a corner should be averaged to develop a $\overline{GJ}$ for a corner. Evaluation of this test modification will be based upon the comparison of this data from selective corner $\overline{GJ}$ and the normal corner $\overline{GJ}$.

Along these lines, the third modification to the Torsion Test, varying the incremental and total loads, is to be investigated by selecting every other data point from which to compute a corner's $\overline{GJ}$ that will produce a value, also to be compared to the normal corner $\overline{GJ}$.

The analysis of the feasibility of these test modifications would be extensive, and probably relatively expensive, but definitely worth the expense. The analysis cost is slight compared to the possible savings in test time. Ideally, the entire evaluation of a unit may consist of only leveling and data measurement at 4 or 5 load increments and at only one corner per end. This is about one-fourth of the presently recommended Torsion Test procedure.

The most efficient and extensive analysis of the data is by computer. With inputs of each data point test, outputs could detail the statistical comparisons of each abbreviated $\overline{GJ}$ vs the normally computed $\overline{GJ}$.

Recommended $\overline{EI}$ and $\overline{GJ}$ Values For New Mobile Homes

The torsion and vertical bending stiffness of the mobile home structural box has been proven to be an excellent indicator of degradation, especially for the transportation modes. During the transportation test program several models of mobile homes were tested over the roads with $\overline{EI}$ and $\overline{GJ}$ values measured after each trip plus the varying rate of degradation versus each mile traveled.

It is recognized that a mobile home can be fabricated and assembled with an acceptable $\overline{EI}$ out of the factory door and yet degrade rather rapidly, espcially during the transportation mode. However, it is very unlikely that a mobile home with an acceptable $\overline{EI}$ and $\overline{GJ}$ would degrade very rapidly. But to prevent this from occurring, a minimum $\overline{EI}$ and $\overline{GJ}$ have been developed as a result of all the testing, both predictive and actual, to provide a stiffness factor in both torsion and vertical bending.

Table 1 provides the recommended minimum $\overline{EI}$ and $\overline{GJ}$ for the front and rear sections of the mobile home. These factors contain sufficient margins for the average production mobile home and are applicable to both single-wide and double-wide models.

TABLE 1

REQUIRED MINIMUM STRUCTURAL STIFFNESS PROPERTIES
FOR MOBILE HOMES

PROPERTY	FRONT SECTION	REAR SECTION
$\overline{EI}$ ($lb - in.^2$) - Vertical Bending	2.4×10^{10}	3.6×10^{10}
$\overline{GJ}$ ($lb - in.^2$) - Torsion	8.0×10^{8}	2.4×10^{8}

APPENDIX A

SwRI RECOMMENDED
TEST PROCEDURE FOR
MOBILE HOME TORSION TEST
AND VERTICAL BENDING TEST

SOUTHWEST RESEARCH INSTITUTE RECOMMENDED TEST PROCEDURE FOR

MOBILE HOME TORSION TEST

SCOPE

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

APPARATUS

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

(a) 6 hydraulic jacks;

(b) 2 "load cell" jacks - calibrated to read as a minimum 0-5000 lbs in 50-lb increments;

(c) 48" to 52" plumb line pendulum bob;

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

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

(f) Spirit and optical level.

PROCEDURE

3. CAUTION! ACCURACY IS REQUIRED TO OBTAIN USABLE DATA. This method of the test involves jacking up to level position and above plus permitting the weight to sag on each corner of a leveled mobile home in prescribed weight increments. At each prescribed load, the corner deflection and the horizontal displacement or rotation of an end wall mounted pendulum (plumb bob) are recorded. The test procedure steps and suggested data recording sheet are as follows:

(a) Position 6 jacks, or support piers, beneath mobile home, 3 under each of the 2 longitudinal I-beams, 2 forward, 2 aft and 2 immediately in front of the forward axle or hangers.

(b) Jack up the home until load is off the wheels and home is roughly leveled using spirit level or engineer's level.

(c) Using engineer's level, level bottom of I-beams front-to-rear and side-to-side-to-level home with ±.01" accuracy.

(d) Hang 50" 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 to be on floor.)

(f) Place the two load cell jacks under the front cross beam or I-beam, 48" off center. Retain level position.

(f) Using load cell jack, jack up 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 position as "zero pendulum displacement" and record weight on jack or jack pressure indicated as "PSI." Calibration can furnish weight conversion from jack pressure.

(i) Jack up using 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 inside mobile home. Use a fine line pencil for marking.

(k) Continue jacking until mobile home is lifted clear of the other supporting jack at that end. Record data at that "clear" load. Jacking up beyond this point bends rather than twists mobile home.

(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 or the load may vary.

(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. Record data at that "clear" load.

(o) Repeat steps (e) - (n) for the other side of the front end of the mobile home.

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

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" - 52"), date, project no. and mobile home identification plus calibrations.

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

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 6 jacks or piers beneath the mobile home; 3 under each of the 2 longitudinal I-beams; 2 forward, 2 aft, and 2 immediately in front of the forward axle or hangers.

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

(c) Using transit, level bottom of I-beams front-to-rear and side-to-side ±.01" 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 touching. (Paper to be on floor.)

(e) Place the two load cell jacks under the front cross-beam or I-beam, 48" off center.

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

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

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

(i) 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.

(j) Raise the jack until its load equals the original level condition load (step (g) ȯn preceding page). 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 at the same load.

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

(l) Repeat items (e) - (m) for the other side of the front end of mobile home.

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

<u>ALTERNATE PROCEDURE NOTES</u>

6. See Note 4.

SOUTHWEST RESEARCH INSTITUTE RECOMMENDED TEST PROCEDURE FOR

MOBILE HOME VERTICAL BENDING TEST

SCOPE

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

APPARATUS

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

(a) 6 hydraulic jacks;

(b) 2 load cell indicators;

(c) 1 dial indicator, at least 1" maximum deflection reading in .01" increments;

(d) 1000 lb of portable weights to be installed in mobile home, such as 2 each calibrated 55 gallon drums to be filled with water;

(e) Data sheet and pencil, or equivalents;

(f) Spirit and optical level.

PROCEDURE

3. CAUTION! ACCURACY IS REQUIRED TO OBTAIN USABLE DATA. This test method involves leveling the home on 6 points, removing designated supports to measure dead weight sag followed by 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 (6) jacks, or support piers, beneath mobile home; 3 under each of the 2 longitudinal I-beams, 2 jacks forward, 2 aft, and 2 immediately in front of the forward axle or hangers.

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

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

(d) Install the dial indicator along the mobile home centerline, under a cross member located approximately halfway between the front cross-beam and the two support jacks located in front of the forward axle.

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

(f) Remove the two pre-loaded support jacks and measure the dead weight sag at this point using the dial indicator. Record this measurement in .001" units.

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

(h) Let the final total weight set for 30 minutes. Measure and record any added deflection due to "creep" in .001" units.

(i) Remove all added weight. Measure and record new no-load (dead weight) deflection in .001" units. 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 cross-member.

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

(l) As in item (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, also considering weight of technician inside mobile home.

(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 (dead weight) deflection. Mechanical set is normal.

(o) Calculate apparent $(\overline{EI})$'s front and rear. (See Calculations in data table.

NOTES:

4. (a) Record all information required on the data sheet, 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 gallon drums at the proper location in the mobile home. Adding water to the calibrated empty drums accomplishes the incremental loading.

Appendix B

HUD Official Conference Attendees

NAME	REPRESENTING
Rick Mendlen	HUD
Ed Davis	SDHPT, Texas
Donald R. Anderson	D.O.T Washington
Chuck Caambliss	Skyline
Michael Alexander	Texas Department of Labor & Strds.
Leon Feazell	Office of Motor Carrier Safety U.S. DOT
Ross A. Little	California Highway Patrol, Sacramento
J. Stevens	Boeing
Aron Kliewer	Fleetwoon Enterprises
Vince Wanzek	Fleetwoon Enterproses
Ray Tucker	Gueroon
Henry Omson	MHI
Ron Vollman	RADCO
John Mason	HUD
C. Muessig	Champion Mobile Homes
John L. Miller	Morgan Drive Away, Inc. Elkhart, Indiana
Ed Cervenka	Texas Dept. of Labor, Houston
Ninka Alexander	Texas Dept. of Labor and Strds.
Bangalore Sureshwara	Underwriters Laboratories
Jim McCollom	HUD
Ronald Ogawa	RADCO
Jim Amrine	Guerdon, Ind.
Hyder Jinnah	HUD, Washington, D.C.
John Steuens	Boeing
Edward Salsbury	Fleetwood Enterprises, Inc.
William Boules	HUD
Chuch Williams	State of California
Darle Hoover	Liberty Homes, Incorporated
C.R. Ursell	SwRI
W.W. Raine	SwRI

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