U.S. Department of Housing and Urban Development
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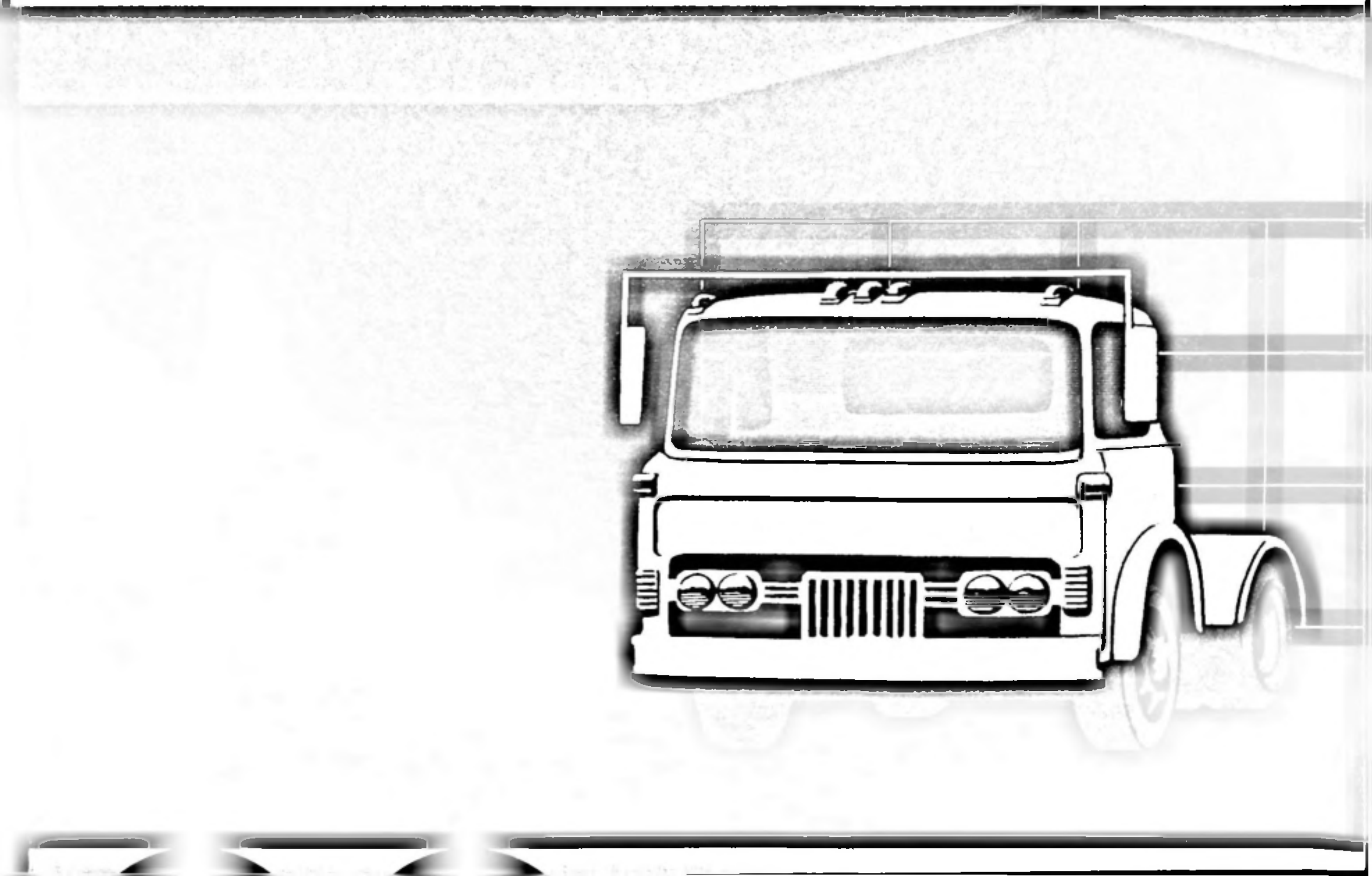
Mobile Home Research

Correlation of Test Data With Dynamic Predictive and Finite Element Analyses

Transportation and Site-Installation

Volume 4

Final Report



MOBILE HOME RESEARCH

TRANSPORTATION AND SITE-INSTALLATION

CORRELATION OF TEST DATA WITH DYNAMIC PREDICTIVE AND FINITE ELEMENT ANALYSES

VOLUME 4
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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The research and studies forming the basis for this report were conducted pursuant to a contract with the Department of Housing and Urban Development (HUD). The statements and conclusions contained herein are those of the contractor and do not necessarily reflect the views of the United States government in general or HUD in particular. Neither the United States nor HUD makes any warranty, expressed or implied, or assumes responsibility for the accuracy or completeness of the information herein.

FOREWORD

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

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

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

Moon Landrieu
Moon Landrieu
Secretary

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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;
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- 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.

CORRELATION OF PREDICTIVE ANALYSIS WITH TEST DATA

by

J. J. Labra, Ph.D.

ABSTRACT

In Task I, an analytical methodology was developed which could be used as a tool to evaluate the structural integrity of a mobile home and estimate its remaining useful life. However, the methodology was based on limited experimental data. In Task III, the analytical procedures outlined in Table I are modified based on actual in-transit testing of typical mobile homes. The newly defined formulae and methodology are herein validated through correlation of predictive response and degradation with actual findings from the in-transit tests of single- and double-wide mobile homes.

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I. OBJECTIVES

The objectives of Task I were to develop and apply an analytical methodology that would accurately measure the effects of highway transportation and site installation activities on the structural durability of typical mobile homes (T-1, T-2A and B). However, as noted in that report, the structural parameters and equations used in the predictive analysis were based on only limited available data. Because of this limitation, the developed methodology was designed to allow for any eventual changes warranted in the initial "assumed" mobile home structural properties and related predictive equations.

The main objective of this part of Task III (Volume II) was to perform the needed changes to the predictive analysis based on the actual full-scale testing performed by SwRI during this program. Once the warranted modifications were made, the Remaining Useful Life (RUL) of the units tested (T-1, T-2A and B) was evaluated using the modified predictive methodology and then compared with the actual conditions of each unit.

II. ORIGINAL ANALYSIS

In the Task I report, a predictive methodology based primarily on computer modeling was presented as a potential tool for designers, engineers, financial investigators, builders, etc., interested in estimating the Remaining Useful Life (RUL) of typical single- and/or double-wide mobile homes. This methodology was based, in part, on predictive equations that define probabilistic acceleration levels in a unit transported between site locations. Those original predictive equations were:

$$\sigma_R = 6.42 \times 10^4 \frac{V^{0.734} rc}{EI^{0.468} C_D^{0.363} \left[\text{Ln } 10^n - \frac{\text{Ln } 10^{n-1}}{n^2} \right]^{2.046}} \qquad (1)$$

$$\sigma_F = 7.13 \times 10^{-3} \frac{EI^{0.208} V^{0.530} rc}{C_D^{0.448} \left[\text{Ln } 10^n - \frac{\text{Ln } 10^{n-1}}{n^2} \right]^{1.610}} \qquad (2)$$

where,

σ_R - is the RMS* vertical acceleration (G units) of the mobile home rear corner,

σ_F - is the RMS vertical acceleration at an upper side wall location approximately midpoint between front axle and hitch,

V - is transport velocity (mph),

EI - is the effective vertical flexural stiffness (lb-in.^{2}),

J - is the effective torsional stiffness (in.^{4}),

C_D - is the structural damping of the unit ($0 < C_D < 1.0$),

and rc and n are found in Table 1.

---

* Root mean square value of acceleration, also referred to as standard deviation. In terms of probabilities and random processes, RMS correlates to a 68-percent confidence level that the actual acceleration levels will be equal to or less than this value.

TABLE 1.

COEFFICIENTS FOR PREDICTIVE EQUATIONS

Road Condition	$\overline{rc}$
Paved (smooth)*	1.0
Paved (waves)**	1.2
Paved (rough)**	1.5
Unpaved (waves)	2.5
Gravel	3.0
Unpaved (rough)	10.0
Effective Torsional Stiffness (J in.^{4})	**n**
10	1
10^2	2
10^3	3
10^4	4
10^m	m

*Typical of primary roadways.
**Representative of secondary roadways.

As discussed in the Task I report, because of the simplifying aspects of the computer analysis, the structural parameters (e.g., EI and J) in Equations 1 and 2 were only good approximations of actual unit stiffness properties. Completion of the testing phase of the present contract has enabled the Institute to obtain sufficient data to refine the predictive analysis methodology. In the following sections, the changes necessary to refine the predictive methodology as well as structural properties of typical single- and double-wide units are described.

III. STRUCTURAL PROPERTIES

In Task III, the effective flexural and torsional stiffness properties were measured for the single-wide (T-1) and double-wide (T-2A, T-2B) mobile homes based on the flexural and torsional rigidity test procedures defined in Task VI. These measurements were made prior to and after each road test. The data were then extrapolated to estimate these structural properties for new units with zero miles (new at factory). The extrapolated "new" values and the assumed values used in the Task I report are given below.

A. T-1 (Single-Wide)

$EI_R = 357 \times 10^8$ lb-in^2 (1000×10^8 lb-in^2)*

$EI_F = 243 \times 10^8$ lb-in^2 (250×10^8 lb-in^2)

$J_R = 4.92 \times 10^6$ in^4 (3500 in^4)

$J_F = 2.81 \times 10^7$ in^4 (875 in^4)

$C_{DF} = C_{DR} = .12$† (.20)

B. T-2A (Wet Side, Double-Wide)

$EI_R = 249 \times 10^8$ lb-in^2 (720×10^8 lb-in^2)

$EI_F = 171 \times 10^8$ lb-in^2 (170×10^8 lb-in^2)

$J_R = 4.04 \times 10^5$ in^4 (2500 in^4)

$J_F = 1.56 \times 10^5$ in^4 (600 in^4)

$C_{DF} = C_{DR} = .12$ (.20)

C. T-2B (Dry Side, Double-Wide)

$EI_R = 258 \times 10^8$ lb-in^2 (730×10^8 lb-in^2)

$EI_F = 192 \times 10^8$ lb-in^2 (170×10^8 lb-in^2)

$J_R = 3.02 \times 10^6$ in^4 (2600 in^4)

$J_F = 1.40 \times 10^6$ in^4 (600 in^4)

$C_{DF} = C_{DR} = .12$ (.20)

*Original values used in Task I Report in parenthesis.
†Based on National Bureau of Standards (NBS) data.

IV. EFFECT OF TRANSPORT DISTANCE ON STRUCTURAL PROPERTIES

In the original predictive equations (Equations 1 and 2) the flexural and torsional properties were assumed constant for each test trip. At that time the lack of experimental data prevented Institute researchers from postulating the dependency of these parameters on distance traveled for each particular unit. With the newly defined properties and the experimental data collected, regression formulae now have been derived for the T-1 and T-2 units that correlate transport distance $\underline{d}$ (in miles) with reduction in flexural and torsional stiffnesses. The following equations reflect the latter correlations as well as the error range* (in percent) when the actual field data were compared with the analytically evaluated expressions based on the regression analysis:

A. T-1 Unit

$$\frac{J_R}{(J_R)_{New}} = \frac{1}{1.046 + (3.610 \times 10^{-4})d} \qquad (1.3 \text{ to } 5.4\%) \qquad (3)$$

$$\frac{J_F}{(J_F)_{New}} = \frac{1}{1.093 + (1.322 \times 10^{-3})d} \qquad (1.1 \text{ to } 12.5\%) \qquad (4)$$

$$\frac{EI_R}{(EI_R)_{New}} = 1.0 - (2.798 \times 10^{-4})d \qquad (5)$$

$$\frac{EI_F}{(EI_F)_{New}} = 1.0 - (1.516 \times 10^{-4})d \qquad (6)$$

B. T-2A Unit

$$\frac{J_R}{(J_R)_{New}} = 5.86d^{-.448} \qquad (0.7 \text{ to } 7.5\%) \qquad (7)$$

*Error range for flexural stiffness was not made because of insufficient data points.

$$\frac{J_F}{(J_F)_{New}} + \frac{1}{.915 + .002d} \qquad (1.1 \text{ to } 8.9\%) \qquad (8)$$

$$\frac{EI_R}{(EI_R)_{New}} = 1.0 - (3.306 \times 10^{-4})d \qquad (9)$$

$$\frac{EI_F}{(EI_F)_{New}} = 1.0 - (6.585 \times 10^{-5})d \qquad (10)$$

C. T-2B Unit

$$\frac{J_R}{(J_R)_{New}} = .103 + \frac{45.905}{d} \qquad (2.1 \text{ to } 28.9\%) \qquad (11)$$

$$\frac{J_F}{(J_F)_{New}} = 8.405d^{-.539} \qquad (2.0 \text{ to } 7.9\%) \qquad (12)$$

$$\frac{EI_R}{(EI_R)_{New}} = 1.0 - (3.710 \times 10^{-4})d \qquad (13)$$

$$\frac{EI_F}{(EI_F)_{New}} = 1.0 - (3.016 \times 10^{-4})d \qquad (14)$$

To further illustrate the transportation effect on mobile homes, these equations were plotted as shown in Figures 1 and 2. As noted, substantial torsional degradation occurred during the early life of both the single- and double-wide units.

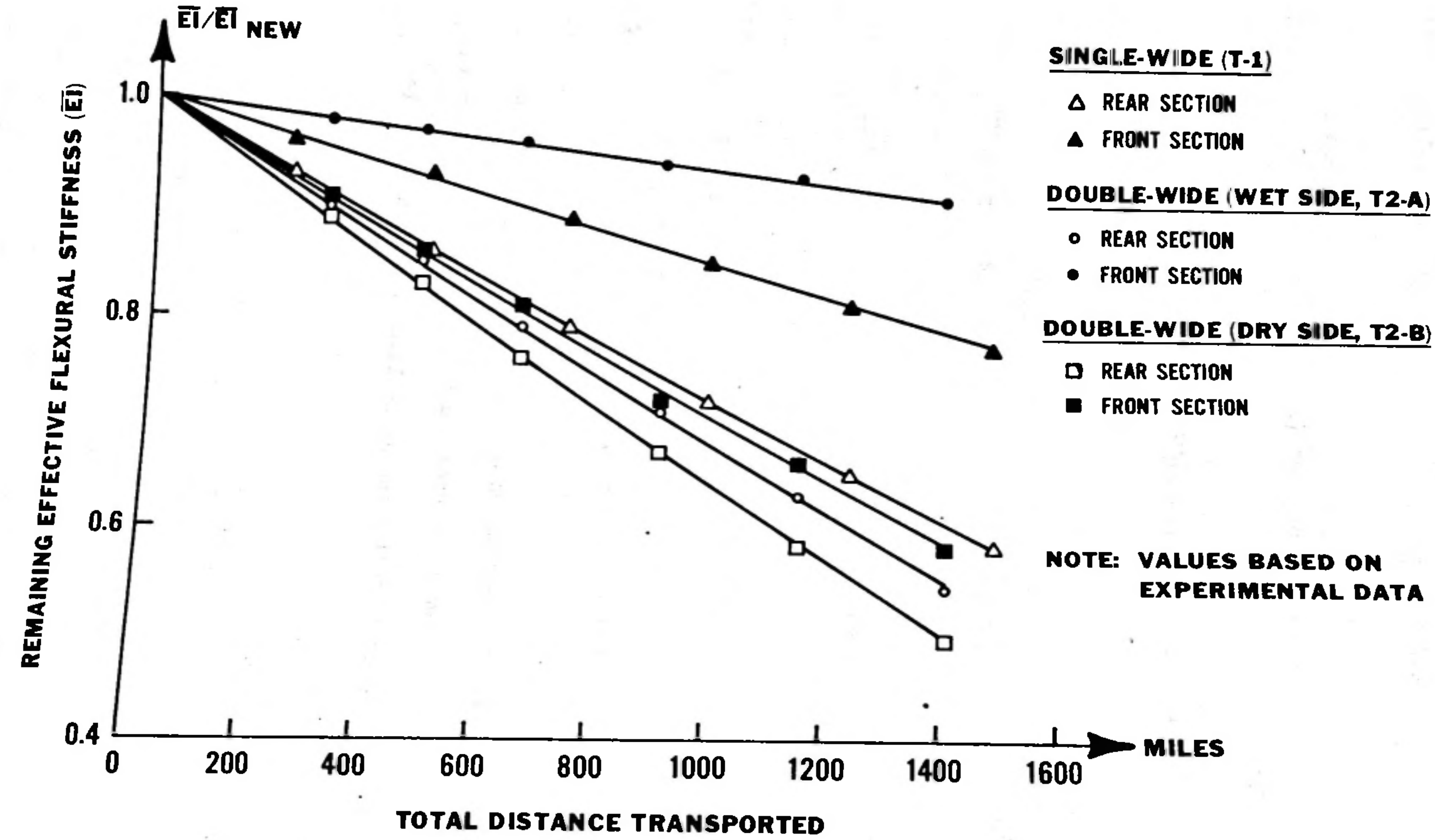

FIGURE 1 EFFECT OF MOBILE HOME DISTANCE MOVED ON EFFECTIVE FLEXURAL STIFFNESS*

*INCLUDING SETUP-TAKEDOWN DEGRADATION

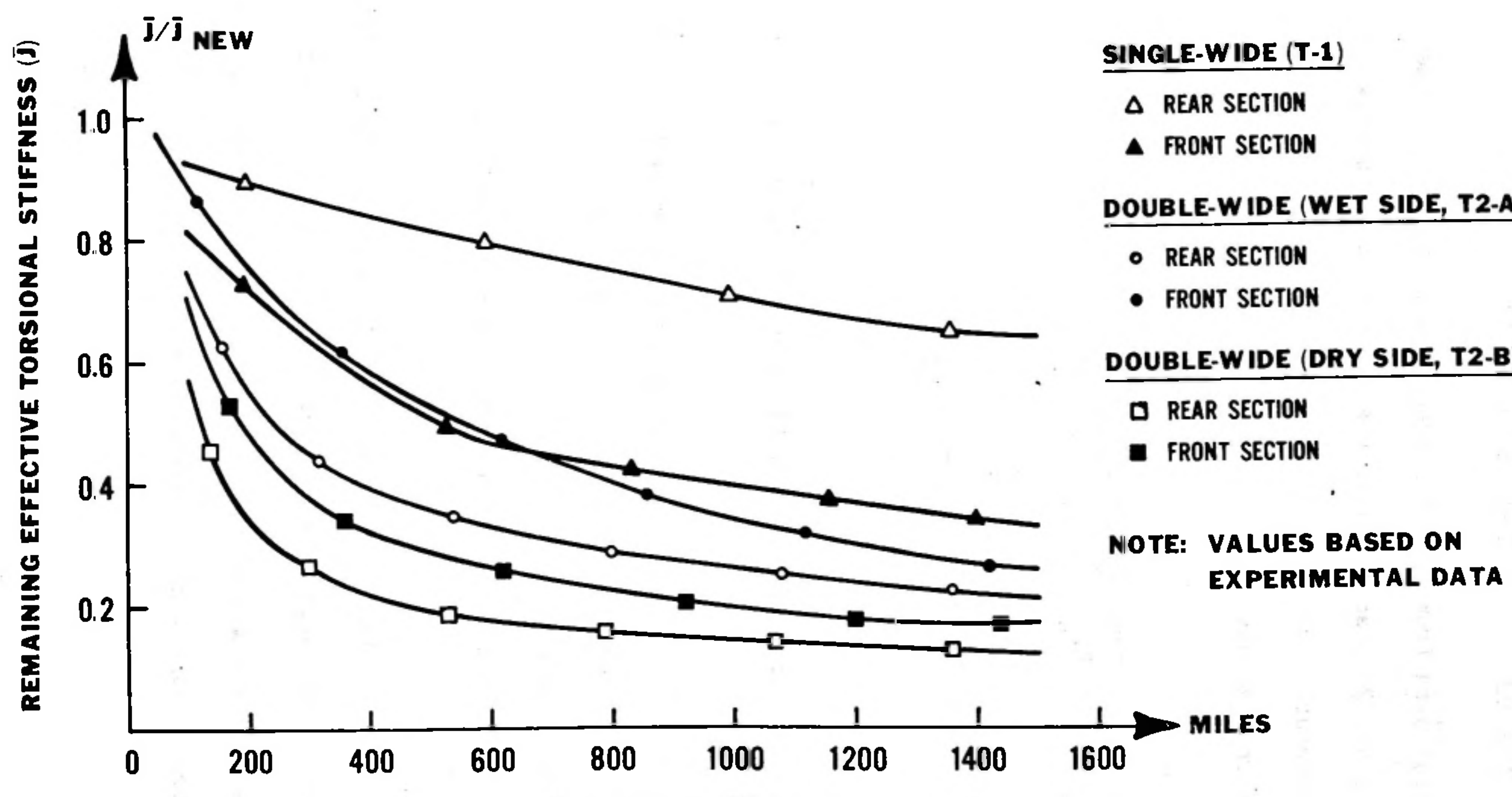

FIGURE 2 EFFECT OF MOBILE HOME DISTANCE MOVED ON EFFECTIVE TORSIONAL STIFFNESS*

*INCLUDING SETUP-TAKEDOWN DEGRADATION

V. RE-EVALUATED PREDICTIVE EQUATIONS

The experimental data from Task III necessitated changes in the predictive Equations 1 and 2 in addition to the changes in the mobile home (T-1 and T-2) structural properties. The new expressions for the mobile home acceleration response are:

$$\sigma_R = 6.42 \times 10^4 \frac{V^{0.734}\,\overline{rc}}{EI_R^{0.468}\,C_{DR}^{0.363}\,(\text{Ln } J_R)^{2.046}} \qquad (15)^*$$

$$\sigma_F = 7.13 \times 10^{-3} \frac{EI_F^{0.208}\,V^{0.530}\,\overline{rc}}{C_{DF}^{0.448}\,(\text{Ln } J_F)^{1.610}} \qquad (16)$$

where,

- σ_R - is the RMS vertical acceleration (G units) of the mobile home rear corner,
- σ_F - is the RMS vertical acceleration at an upper side wall location approximately midpoint between front axle and hitch,
- V - is transport velocity (mph),
- EI_i - is the effective vertical flexural stiffness (lb-in^2), i = R (rear), F (front),
- J_i - is the effective torsional stiffness (in^4), i = R (rear), F (front),
- C_{Di} - is the structural damping of the unit ($0 < C_{Di} \leq 1.0$), i = R, F.

In addition, the $\overline{rc}$ expression was also altered. In place of Table 1, Table 2 should be used in conjunction with Equations 15 and 16.

*Ln refers to natural logs.

TABLE 2

RE-EVALUATED ROAD CONDITIONS

ROAD CONDITION	$\overline{rc}$
Paved (smooth)	1.0
Paved (waves)	1.2
Paved (rough)	1.7
Unpaved (waves)	2.0
Gravel	2.5
Unpaved (rough)	10.0

VI. REMAINING USEFUL LIFE (RUL) EVALUATION

The overall procedure for the user to estimate the RUL of a mobile home remains basically as defined in the Task I report. The slight difference occurs in the methodology with the inclusion of the evaluation of the effective flexural (EI) and torsional (J) stiffnesses calculated by the field test procedures described in the Task VI report. The RUL equation has been redefined in terms of percent trip degradation, i.e.:

$$PTD_i = \frac{(7.2 \times 10^5)\ f\ d\ P(\sigma_i > \sigma_B)}{VN_B} \qquad i = R \text{ or } F \tag{17}$$

$$RUL_i = 100 - \sum_n (PTD_i); \ n = 1 \text{ to } m; \ m = \text{the total number of trips} \tag{18}$$

where,

R,F- Refer to the rear and front sections of the unit,

f - "apparent" response frequency of unit (Hz),

V - planned velocity of unit (mph),

d - distance between sites (miles).

$P(\sigma_i > \sigma_B)$ is the probability of the unit exceeding the "base" RMS acceleration and N_B is the estimated number of times the "base" RMS value will be exceeded per 1000 miles traveled by the unit.* [The aforementioned "base" values are input by the user and are assumed to be the RMS vertical acceleration response (σ_B) and number of occurrences (N_B) that a totally degraded (zero useful life) unit would experience.]

The overall procedure for evaluating RUL is hence as given below. Based on limited available experimental data, it is recommended that unless better values are available, the following be used in conjunction with this overall procedure:

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* The 1000 miles value has replaced original 100 miles value defined in Task I.

$\sigma_{RB} = 0.28$ G's

$\sigma_{FB} = 0.40$ G's

$f_B = f_{FB} = f_B = 5$ Hz

$f_R = f_F = f = 5$ Hz

$C_{RB} = C_{DFB} = C_{DB} = 0.12$

$C_{DR} = C_{DF} = 0.12$

A. Basic Requirement Data

(1) The user specifies the "base" structural parameters of a proposed "zero" life unit as well as planned velocity and probable road conditions. He then utilizes Equations 15 and 16 to estimate the RMS acceleration (σ_B) at the rear corner and midpoint wall locations between axle and hitch. (If typical σ_B values are available, one would use these values in lieu of this calculation.)

(2) The user estimates the number of occurrences (N_B) - (per 1000 miles traveled by the "zero" life unit) - that σ_B will be exceeded. This is obtained from:

$$N_B = 7.2 \times 10^6 \frac{f_B}{V_B} [P'(\sigma_B)]*$$

where f_B and V_B are estimated "base" frequency of response (Hz) and "base" velocity (mph). (If typical N_B value is available, it would be used in place of this calculation.)

(3) The field tests for defining EI_i and J_i are made on the unit.†

(4) Utilizing the corresponding "new" unit structural properties,

*The probability [$P'(\sigma_B)$] of the "base" unit exceeding σ_B is simply 0.317 or approximately 32 percent. (Definition of Standard Deviation)
†Procedures for evaluating $\overline{EI}$ and $\overline{J}$ are given in Task VI report.

$(EI_i)_{New}$, $(J_i)_{New}$*, the user forms the appropriate quotients, using the field test evaluated stiffnesses; i.e.:

$$\frac{EI_i}{(EI_i)_{New}} \quad ; \quad \frac{J_i}{(J_i)_{New}}$$

These values are then input into the appropriate equations (Equations 3-14) or into Figures 1 and 2 to define the equivalent distance transported d_e (in miles) that the mobile home has experienced. (It is noted that there will be two values of d_e; one pertaining to torsional degradation; the other, to flexural degradation.)

B. Calculation of RUL of Unit in Present Condition

(1) Knowing d_e, the RUL for the unit prior to the move is estimated by substituting an equivalent transport speed V_e = 45 mph and an equivalent road condition $rc_e = 1$ into predictive Equations 15 and/or 16 to estimate the equivalent RMS acceleration response, (σ_{ei}). †

(2) The equivalent RMS accelerations (σ_{ei}) for the mobile home and the "base" unit values (σ_B) are then used to estimate the probability of exceeding σ_B, i.e., $P(\sigma_{ei} > \sigma_B)$.**

(3) The user inputs $P(\sigma_{ei} > \sigma_B)$ and equivalent frequency f_e = 5 Hz into Equation 17 to obtain an estimation of the pre-move RUL for the mobile home.

*Taken from available data such as given in Section IV of this volume.
† This procedure allows for the RUL evaluation of a mobile home which has no record of past moves or which will not be transported at all.
**Assuming a Gaussian or normal distribution, $P(\sigma_{ei} > \sigma_B)$ can be found in a standard statistical handbook (e.g., Burington & May, "Probability and Statistics," pp. 267-274).

C. Calculation of Anticipated RUL after Move

(1) Knowing d_e and the planned transport distance d (in miles), the total distance $d_T = d_e + d$ is then input into the appropriate regression equations (Equations 3-14) or Figures 1 and 2 to estimate the flexural and torsional stiffness values of the unit upon reaching its final destination.

(2) The average or mean stiffness values (along with anticipated road condition and in-transit speed) are then input into the predictive Equations 15 and 16 to estimate the RMS acceleration response. (As a safety factor, it is recommended that the lower or anticipated degraded stiffness values be used as input.)

(3) Having determined the anticipated RMS accelerations (σ_i) for the mobile home, the probability of exceeding σ_B [i.e., $P(\sigma_i > \sigma_B)$] can be obtained from any standard statistical handbook (as in Step B-2).

(4) Finally, the user inputs $P(\sigma_i > \sigma_B)$ into Equations 17 and 18 to obtain an estimation of the RUL of the unit when it reaches its proposed setup site.

Example:

A mortgage company needs to evaluate the risk or feasibility of making a secondary loan on a (single-wide) mobile home that will be moved 350 miles over secondary roads. There are no available data on the past history of the unit with respect to previous moves, setups and takedowns. Before a loan can be made, they would like to know the pre-move RUL and the anticipated post-move RUL for the unit.

The mortgage company has decided to define a "base" response $\sigma_{RB} = 0.28$ G since "base" structural properties of a "zero" life unit of the type in question are not available.* The corresponding transport speed V_B = 45 mph and apparent frequency f_B = 5 Hz are also used. With these conditions, the aforementioned RUL evaluation procedure is followed, i.e.:

Step A-1 - Not needed (σ_{RB} defined)

Step A-2 - The user estimates the number of occurrences N_B, viz.

$$N_B = 7.2 \times 10^6 \; \frac{5 \text{ Hz}}{45 \text{ mph}} \; (0.317) = 253{,}600$$

Step A-3 - Field tests are made on the mobile home to be moved.

Results are:

$$EI_R = 225 \times 10^8 \text{ lb-in}^2$$

$$J_R = 4.00 \times 10^5 \text{ in}^4$$

$$C_{DR} = 0.12 \dagger$$

Step A-4 - Based on available data for the unit in question, its "new" condition structural properties were:

$$(\overline{EI}_R)_{New} = 250 \times 10^8 \text{ lb-in}^2$$

$$(J_R)_{New} = 5.00 \times 10^5 \text{ in}^4$$

$$(C_D)_{New} = 0.12$$

The appropriate quotients are:

$$\frac{EI_R}{(EI_R)_{New}} = 0.9$$

$$\frac{J_R}{(J_R)_{New}} = 0.8$$

These values are then substituted into Equations 3 and 5** (or Figures 1

*σ_{RB} = 0.28 G taken from totally degraded T-2A unit. From study, findings using this value for T-1, T-2A and T-2B units gave good correlation with actual post test conditions (see Section VIII of this volume).

† Based on NBS data.

**T-1 unit transport distance - structural degradation curves assumed applicable.

and 2) to evaluate equivalent transport distance (d_e) based on the present torsional and flexural structural properties. Using the above quotients and Figures 1 and 2, the equivalent transport distance d_e is approximately:

$$(d_e)_{J_R} = 600 \text{ miles}$$

based on torsional degradation to the rear of the unit and

$$(d_e)_{EI_R} = 400 \text{ miles}$$

based on flexural degradation. (As noted, the two values can be quite different.)

Step B-1 - The equivalent rear-section RMS acceleration σ_{eR} is evaluated from Equation 15.

$$\sigma_{eR} = \frac{6.42 \times 10^4 \ (45)^{.734} \ (1)}{(225 \times 10^8)^{.468} \ (.12)^{.363} \ [\text{Ln } (4 \times 10^5)]^{2.046}} = .17 \text{ G's}$$

Hence,

$$\sigma_B = 0.28 \text{ G} = 1.65\sigma_{eR} .$$

Step B-2 - From standard statistical handbook:

$$P(\sigma_{eR} > \sigma_B) = P(\sigma_{eR} > 1.65\sigma_{eR}) = 0.099$$

Step B-3 - The appropriate "equivalent" properties d_e*, V_e and f_e are substituted with $P(\sigma_{eR} > \sigma_B)$ into Equation 17, i.e.:

$$PTD_e = \frac{(7.2 \times 10^5) \ (5 \text{ Hz})(600 \text{ miles}) \ (0.99)}{(45 \text{ mph}) \ (253,600)} = 18.7\%$$

Thus, the mortgage company has estimated the equivalent percent trip degradation of a mobile home prior to the intended move due to past (unrecorded) moves, setup-takedowns and/or climatic conditions. This correlates to an estimated 81-percent RUL (Equation 18) for the mobile home in its present pre-move condition.

Step C-1 - The appropriate total distances $d_T = d_e + d$ for the unit are evaluated as:

*As safety factor, recommend using larger of two d_e values defined.

$$(d_T)_{J_R} = 600 + 350 = 950 \text{ miles}$$

$$(d_T)_{EI_R} = 400 + 350 = 750 \text{ miles}$$

Using these distances and Figures 1 and 2*, the estimated post-trip degraded effective torsional and flexural stiffnesses are:

$$J_R = 0.75\ (J_R)_{New} = 3.75 \times 10^5 \text{ in}^4$$

$$EI_R = 0.78\ (EI_R)_{New} = 195 \times 10^8 \text{ lb-in}^2$$

Step C-2 -- The above are substituted into Equation 15 along with proposed transport speed (V = 40 mph), road condition (rc = 1.2) and assumed constant damping coefficient (C_{DR} = 0.12) resulting in:

$$\sigma_R = \frac{6.42 \times 10^4\ (40)^{.734}\ (1.2)}{(195 \times 10^8)^{.468}\ (.12)^{.363}\ [\text{Ln}(3.75 \times 10^5)]^{2.046}}$$

$$= 0.21 \text{ G}$$

Step C-3 -- With the above anticipated RMS acceleration, the mortgager evaluates the probability of the unit exceeding σ_B, i.e.:

$$P(\sigma_R > \sigma_B) = P(\sigma_R > 1.33\sigma_R) = 0.1836$$

Step C-4 -- The above probability is input into Equation 17 along with d = 350 miles and f = 5 Hz†. Hence,

$$PTD = \frac{(7.2 \times 10^5)\ (5 \text{ Hz})\ (350 \text{ miles})\ (0.1836)}{(40 \text{ mph})\ (253{,}600)}$$

$$= 22.8\%$$

The estimated percent degradation for the move is approximately 23 percent. Utilizing this, along with the previously defined pre-move equivalent PTD, the banker substitutes appropriate variables into Equation 18 to evaluate

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*Using T-1 curves in this example.
†Assumed known value for this example.

remaining useful life upon reaching setup site, viz,

$$RUL = 100 - 18.7 - 22.8 = 58.5$$

Thus, the mortgage company has estimated a particular mobile home's remaining useful life which can now be used as a factor in determining the financial risk involved in making the proposed secondary loan.

VII. EXPERIMENTAL DATA - PREDICTIVE ANALYSIS CORRELATION

The predictive methodology and resulting equations (i.e., Equations 15 through 18) are based on the computer simulations performed during Task I, the experimental data from Task III, and the regression analyses in both Tasks I and III. The methodology's validity is based, in part, on the predictive equations' capability to define anticipated acceleration levels (RMS values) in a transported mobile home. To verify the methodology, comparisons of dynamically induced predictive and actual G levels experienced by the transported single- and double-wide units (T-1 and T-2A and B, respectively) were made as shown in Tables 3, 4 and 5.

In the latter tables, the experimental data were obtained from accelerometers located on the side walls near the back of each unit. The RMS values shown were recorded while the units traveled a well-paved highway at approximately 45 mph. The experimental G levels were evaluated over a 10- and 100-Hz range. This evaluation defined the high frequency domain effect on the overall acceleration response of the unit.

In terms of absolute numbers, good correlations were realized between the predictive G levels (σ_R) and those monitored during the test runs. The predictive analysis, utilizing the "new" structural properties given in Section III of this volume (along with the regression equations in Section IV), resulted in very low anticipated G levels for all the test runs. These results compared favorably with the actual in-field data collected. Furthermore, the predictive G levels were anticipated to be greater than the actual in-field acceleration levels. And, as shown, this correlation proved true for the majority of the tests. The higher predictive values occured when estimated final values (EI_R, J_R) for the trip

TABLE 3

SINGLE-WIDE (T-1) UNIT PREDICTIVE VERSUS EXPERIMENTAL DATA

ACTIVITY	DISTANCE (miles)	TOTAL MILES	EXPERIMENTAL DATA				PREDICTIVE ACCELERATION σ_R (G)
			URRV(G)*		ULRV(G)†		
			10 Hz	100 Hz	10 Hz	100 Hz	
2	77	564	.116	.150	.117	.147	.108
3	107	671	.109	.129	.156	.115	.111
4	316	987	.128	.160	.113	.130	.118
5	317	1304	.105	.141	.101	.120	.123
6	256	1560	.105	.139	.114	.129	.135
7	308	1868	.052	.077	.062	.081	.148

*URRV - Upper Right Rear Vertical Acceleration Reading (RMS).
†ULRV - Upper Left Rear Vertical Acceleration Reading (RMS).

NOTE: 10 Hz and 100 Hz frequency ranges were considered to determine what effect the high frequency domain has on resultant G levels.

TABLE 4

DOUBLE-WIDE (T-2A) UNIT PREDICTIVE VERSUS EXPERIMENTAL DATA

ACTIVITY	DISTANCE (miles)	TOTAL MILES	EXPERIMENTAL DATA				PREDICTIVE ACCELERATION σ_R (G)
			URRV (G)*		ULRV (G)†		
			10 Hz	100 Hz	10 Hz	100 Hz	
2	272	587	.112	.198	.103	.126	.218
3	273	860	.096	.139	.080	.109	.234
4	259	1119	.144	.186	.098	.136	.258
5	264	1383	.120	.176	.090	.113	.281

*URRV - Upper Right Rear Vertical Acceleration Reading (RMS).
†ULRV - Upper Left Rear Vertical Acceleration Reading (RMS).
Note: RMS values (experimental) calculated using a Hewlett-Packard (H-P) 2310C analog to digital converter under program control of an H-P 2100 computer.

TABLE 5

DOUBLE-WIDE (T-2B) UNIT PREDICTIVE VERSUS EXPERIMENTAL DATA

ACTIVITY	DISTANCE (miles)	TOTAL MILES	EXPERIMENTAL DATA				PREDICTIVE ACCELERATION σ_R (G)
			URRV(G)*		ULRV(G)†		
			10 Hz	100 Hz	10 Hz	100 Hz	
2	171	486	.110	.156	.108	.129	.168
3	180	666	.130	.169	.126	.144	.178
4	247	913	.170	.211	.167	.185	.192
5	246	1159	.117	.164	.116	.140	.209

*URRV - Upper Right Rear Vertical Acceleration Reading (RMS).
†ULRV - Upper Left Rear Vertical Acceleration Reading (RMS).

were used instead of average values. Differences in anticipated G levels primarily consist of a monotonic increase in predicted values not observed in the experimental data. This is due, in part, to low level "noise" as well as the simplifying aspects of the computer model. Nonetheless, SwRI believes the overall results are very good.

VIII. PREDICTED DEGRADATION

In the previous sections, it was observed that both the actual and predicted RMS vertical acceleration levels for the rear of each unit were small because of the actual structural properties ($\overline{EI}$ and $\overline{J}$) and the well-paved road over which the data were collected. This finding does not affect the predictive methodology. It does, however, require a reconsideration of the "base" unit assumptions made in Task I (Volume II) for the RMS vertical acceleration levels and apparent frequency. This is warranted because the initially assumed low structural properties resulted in artificially high "G" level accelerations.

As a result of the experimental test phase of the present study, Institute researchers believe that the post-test condition of the T-2A unit is at a level that would provide minimal living conditions. Hence, it was decided that in its present state, the T-2A could be considered a good example of a "base" unit with minimal remaining useful life. For a well-paved road condition, this correlates to a predicted rear and front section mobile home response of:

$$\sigma_{RB} = 0.28 \text{ G's*}$$

$$\sigma_{FB} = 0.40 \text{ G's†}$$

(Taken from Table 4)

From the accelerometer data collected during Test 5, the correlating apparent frequency was estimated at:

$$f_{RB} \simeq 5 \text{ Hz**}$$

The average transport speed (V_B) for each test was 45 mph.

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*It is noted that the predictive value is used because it represents a monotonic increase in structural degradation of the unit which is not apparent from the experimentally collected G levels.
†Based on degraded structural properties for front section of T-2A.
**When available, a frequency based on actual data should be used in lieu of an analytical value based on methodology presented in Task I report.

The "base" acceleration (σ_{RB}), velocity and frequency were used to define predicted degradation of the T-1, T-2A and T-2B for each trip described in Tables 3, 4 and 5. The rear section of each unit was used to monitor degradation because degradation was found to be more prevalent in the rear section of the units tested. This evaluation was made using Equations 17 and 18, where N_B, the number of occurrences (per 1000 miles) σ_B would be exceeded, was determined as:

$$N_B = \frac{7.2 \times 10^6 \text{ (5 Hz) (0.317)}}{\text{(45 mph)}} = 253{,}600$$

and where the apparent frequency (f) for each unit was assumed as 5 Hz. Since it was not possible to delineate the exact road conditions for each trip, the analysis was made first, assuming each trip was over well-paved highway ($\overline{rc} = 1$)* and then over paved (waves) secondary roads ($\overline{rc} = 1.2$).*

The results shown in Tables 6 and 7 indicate what SwRI believes, based on visual inspection, are the present conditions of each unit. Specifically, the T-2A was found to be in the worst structural condition of the three units.† From Tables 6 and 7, the RUL predicted after Condition II was 24.7 and -5.4 percent for the well-paved and secondary road conditions, respectively. The negative RUL percentage emphasizes that, if such road conditions existed for all the trips, the T-2A would have been in a worse condition than its present state.

The predictive post-Condition II RUL for the T-2B was determined as approximately 69.8 percent for the well-paved road assumption. For the more hostile secondary road condition (Table 7), the corresponding RUL was evaluated as 49.4 percent. SwRI believes this reflects the actual condition of the T-2B.

*See Table 2.
†See Task III, Volume I, Part II.

TABLE 6

PREDICTED DEGRADATION: ASSUMED WELL-PAVED ROAD CONDITION*

T-2A

ACTIVITY	CONDITION †	TRIP DISTANCE (miles)	TOTAL DISTANCE (miles)	PTD(%)	RUL(%)
1(Delivery)	I	315	315	15.8	84.2
2		272	587	17.2	67.0
3	II	273	860	19.8	47.2
4		259	1119	22.5	24.7
5		264	1383	26.4	-2.0

T-2B

ACTIVITY	CONDITION †	TRIP DISTANCE (miles)	TOTAL DISTANCE (miles)	PTD(%)	RUL(%)
1(Delivery)	I	315	315	7.3	92.7
2		171	486	5.1	87.6
3	II	180	666	6.6	81.0
4		247	913	11.2	69.8
5		246	1159	14.0	55.8

T-1

ACTIVITY	CONDITION †	TRIP DISTANCE (miles)	TOTAL DISTANCE (miles)	PTD(%)	RUL(%)
1(Delivery)	I	487	487	1.4	98.6
2		77	564	0.2	98.4
3	II_1**	107	671	0.4	98.0
4		316	987	1.8	96.2
5	II_2	317	1304	2.3	93.9
6		256	1560	3.1	90.8
7		308	1868	5.7	85.1

*Includes setup/takedown degradation (rc = 1.0). See also Task III, Volume I, Part II.
†Typical example of mileage correlating to Conditions I and II defined in Task I report.
**Subscripts refer to initial and second secondary moves.

TABLE 7

PREDICTED DEGRADATION: ASSUMED PAVED (WAVES) ROAD CONDITION*

T-2A

ACTIVITY	CONDITION†	TRIP DISTANCE (miles)	TOTAL DISTANCE (miles)	PTD(%)	RUL(%)
1(Delivery)	I	315	315	23.6	76.4
2		272	587	24.4	52.0
3	II	273	860	27.3	24.7
4		259	1119	30.1	-5.4
5		264	1383	-33.9	-39.3

T-2B

ACTIVITY	CONDITION†	TRIP DISTANCE (miles)	TOTAL DISTANCE (miles)	PTD(%)	RUL(%)
1(Delivery)	I	315	315	13.3	86.7
2		171	486	8.9	77.8
3	II	180	666	10.8	67.0
4		247	913	17.6	49.4
5		246	1159	20.4	29.0

T-1

ACTIVITY	CONDITION†	TRIP DISTANCE (miles)	TOTAL DISTANCE (miles)	PTD(%)	RUL(%)
1(Delivery)	I	487	487	4.3	95.7
2		77	564	0.8	94.9
3	II_1**	107	671	1.2	93.7
4		316	987	4.9	88.8
5	II_2	317	1304	5.9	82.9
6		256	1560	6.8	76.1
7		308	1868	11.3	64.8

*Includes setup/takedown degradation (rc = 1.2). See also Task III, Volume I, Part II.
†Typical example of mileage correlating to Conditions I and II defined in Task I report.
**Subscripts refer to initial and second secondary moves.

As illustrated by these tables, the T-1 unit faired the best with post-Condition II_2 RUL values of 96.2 and 88.8 percent for the two prescribed road conditions. As noted, the above analysis defines predictive degradation for the above units for two different types of road conditions. Since in actuality each test was performed over both well-paved highway and secondary roads, it can be conjectured that the actual degradation for each unit is between the aforementioned limits. As an example, Table 8 shows the predicted RUL if the a priori assumption is made that each unit experienced 50 percent of well-paved highway and 50 percent of secondary roads. As noted, the RUL for the T-1 under these conditions is approximated at 84 percent (post Condition II_2). For the T-2A and T-2B, the corresponding post-Condition II RUL's are 10 and 60 percent, respectively. These predicted estimations of the remaining useful life for each mobile home correlated well with visual inspection of the actual units.

The purpose of presenting the above analysis is to illustrate that even though the actual recorded RMS acceleration levels were found to be small, the predictive methodology can still be used to estimate the remaining useful life of a mobile home. It also shows that, while the RMS G levels were predicted to be 0.3 or less, a wide range of degradation can be realized because of the initial structural integrity of each unit (i.e., $\overline{EI}$ and $\overline{J}$ as given in Section III of this volume).

TABLE 8

PREDICTED REMAINING USEFUL LIFE (IN PERCENT)*

Activity		T-1		T-2A		T-2B
1		97.2		80.3		89.7
2		96.7		59.5		82.7
	CONDITION I →		CONDITION I →		CONDITION I →	
3		95.9		36.0		74.0
4		92.5		9.7		59.6
	CONDITION II_1 →		CONDITION II →		CONDITION II →	
5		88.4		-20.7		42.4
6		83.5		--		--
	CONDITION II_2 →					
7		74.9		--		--

*Assumed 50% travel over well-paved highway (rc = 1) and 50% travel over secondary roads (rc = 1.2).

IX. SUMMARIZED FINDINGS

This report has delineated SwRI efforts to modify the original analytical methodology presented in Task I as well as its effort to validate the predictive tools. The pertinent findings from this validation effort associated with the actual units (T-1 and T-2) are as follows:

- The conjecture that the effective torsional stiffness (J_i) has a greater effect on degradation (and RUL) than effective flexural stiffness seems valid based on comparison of structural properties for each unit and the condition of each unit after the experimental mobile home tests.*

- The effective rear section flexural stiffness (EI_R) for each unit was found to be substantially stiffer with respect to each corresponding front section (EI_F).†

- With the exception of the single-wide (T-1), the rear section effective torsional stiffness (J_R) was found to be greater than the corresponding front section stiffness (J_R).†

- The T-1 unit's flexural and torsional stiffness parameters were substantially greater than those of the T-2A or T-2B.†

- Initial stiffness ($\overline{EI}$ and $\overline{J}$) properties of T-2A are significantly less than those of T-1 and T-2B and could result in a shorter useful life.

- Transportation degradation effects were found to be greatest for the rear section of the double-wide (T-2B) dry-side.**

- The smallest reduction in torsional stiffness (J_i) due to transportation was associated with the rear section of the single-wide (T-1).**

- The smallest reduction in flexural stiffness (EI_i) due to transportation effects was associated with the front section of the double-wide (wet side T-2A).**

- Overall, for both the T-1 and T-2 units, the rate of torsional stiffness degradation was determined to be greatest during the early or initial moves.**

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*See Task III, Volume I, Part II and also Section III of this volume.
†See Section III.
**As illustrated in Figures 1 and/or 2.

- The predictive equations defining anticipated RMS G levels were found to give good approximations of actual G levels experienced by transported mobile homes.*

- The predictive methodology predicted the correct ranking in terms of degradation (or RUL) for the T-1, T-2A and T-2B.†

*As shown in Figures 3, 4 and 5.
†See Task III, Volume I, Part II and also Section III of this volume.

CORRELATION OF FINITE ELEMENT ANALYSIS WITH TEST DATA

by

C. R. Ursell, II
E. O. Wiles

ABSTRACT

This volume develops the correlation between the finite element analysis of Task I and the actual test data of this task. The stiffness of the model was tuned so that computer generated deflections would match the actual ones. Subjecting the model to specific load cases, or the static equivalent of dynamic conditions, produced stress and displacement plots of major components of the model. Observed permanent deformations are shown to correspond to the predicted stresses of the finite element model plots. The finite element analysis technique is shown to be an effective predictive tool with few deficiencies.

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DEFINITIONS

The following pages contain definitions of words or terms used in this document.

ANSYS - A large-scale general purpose computer program developed by Swanson Analysis Systems, Incorporated, Elizabeth, Pennsylvania. Analysis capabilities of the program include: (1) static and dynamic, (2) plastic, creep and swelling, (3) small and large deflection, (4) steady state and transient heat transfer, and (5) steady state fluid flow types of problems. The matrix displacement method of analysis based on finite element idealization of the structure is employed in the program. The library of finite element types in the program numbers more than 40 for static and dynamic analyses and 10 for heat transfer analyses. This variety of elements gives the program user the capability of analyzing frame structures, piping systems, two-dimensional plane and axisymmetric solids, flat plates, three-dimensional solids, axisymmetric and three-dimensional shells, and nonlinear problems. In this study, the program is used for static analysis of the mobile home structure, idealized as an assemblage of bar, beam, and membrane elements.

ELEMENT - A component part of a structure for which the relationships between forces and displacements at a finite number of points (or nodes) on the element are known. In this study, elements used are bars, prismatic beams, tapered beams, and membranes.

NODAL POINT - A point in space where two or more elements are connected in the idealization of the structure.

DEGREE OF FREEDOM - The direction of force or displacement at a node. For example, the three-dimensional elastic beam element used in the study has two nodes, one at each end. The element has six degrees of freedom at each node: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z axes.

BOUNDARY CONDITIONS - Specified external loads and/or displacements applied at the nodes of the idealized structure.

RESTRAINT - A displacement boundary condition specified as zero in ANSYS. For example, if the node at the hitch is assumed stationary, displacements in the x, y, and z directions are all specified as zero.

MODULUS OF ELASTICITY - The slope of the stress-strain diagram of a material in the elastic range.

MASS DENSITY - The mass of a body per unit volume. When multiplied by the acceleration of gravity, the mass density becomes the specific weight in pounds per unit volume.

GRAVITY LOAD - Load applied to the structure by the weight of a component part.

EQUIVALENT STATIC LOAD - The load obtained by multiplying the weight of a structural component by its root-mean-square acceleration, as determined from the dynamic analysis (32 percent probability of not being exceeded or multiply by a factor of 3 to obtain 99.9 percent probability).

MAXIMUM/MINIMUM IN-PLANE STRESSES - The maximum and minimum principal stresses acting in the plane of a membrane element. (Note that a membrane element is not capable of resisting a force component applied perpendicular to the plane of the element).

STRESS CONTOUR PLOT - A plot of a membrane element showing contours (or lines) of constant maximum or minimum stress levels.

EXPONENTIAL - Standard form of presentation of a number in E format, showing the number of places the indicated decimal must be moved to the right (plus exponent) or left (negative exponent). For example, 1.4 E + 03 = 1400, and 1.4 E - 02 = 0.014.

CARD SET - A group of input cards used in ANSYS for common input data (e.g., card set D defines the element types and card set E defines the nodes to which the elements are connected). The total conglomorate of all the various card sets forms the specified input data required to conduct a run of the program.

ISOTROPIC - Characteristic of a material that has identical properties in all directions.

I. INTRODUCTION

The purpose of this part of Task III was to develop a correlation between the finite element analysis of Task I and the actual test data of this Task.

The results of the finite element static analysis computed with the ANSYS program in Task I were based, whenever possible, on the actual physical properties and loading conditions relative to each unit. Although the modeling is a static equivalent of dynamic conditions, the finite element analysis conducted in Task I can be considered a correlative analysis. As a predictive tool, the program can be used to model the mobile home unit at different stages in its life by adjustment of certain parameters with the aid of the field test data. Comparison of results obtained from this procedure with that of Task I can be one indication of degradation and the remaining useful life of the unit.

II. BACKGROUND

The initial step in developing the ANSYS computer program in Task I was to provide a detailed floor plan for each unit. With this information, a finite element "mesh" was developed for major components (frame, floor, sidewalls, etc.) of the unit. As discussed in Task I, the determination of the "mesh", and the component technique to simulate the actual construction of each unit, was based on a correlation of test data using the T-5 single-wide mobile home. To further ensure proper data correlation, actual weights and material properties were taken from the vendor's data.

With the physical properties of each mobile home represented in the computer program, the only input remaining was the various loading conditions. The static weight of each mobile home was input for all load cases as a 1-g vertical load. The dynamic load factor, calculated at various times during the life of the unit, was based on the dynamic analysis as well as the acceleration data recorded. The dynamic loads were represented in the finite element analysis as equivalent static loads. With the physical properties and load conditions both represented, the computer program was run, obtaining printed output and deflection/stress plot data. The stress contour plots were a good indication of problem areas in the mobile home. Critical regions where stress concentrations were located corresponded to actual permanent changes and physical damage in the units.

The finite element analysis presented in this task is based on the same factors as the analysis of Task I (Volumes III and IV).

III. FIELD TEST CORRELATION

Tables 1, 2, and 3 show direct correlation between field test data and results obtained from the finite element method (FEM). Experience derived in Task I from the FEM analysis of the T-5 mobile home indicated that the model developed for that unit was stiffer than the actual physical configuration. This reasoning is based upon the fact that the mobile home becomes more flexible with usage. The increased flexibility is primarily the result of the loosening of joints due to the reduction of bonding capability of fasteners (bolts, nails, screws, etc.) which is caused by relative deformation of adjacent structural components (shear walls, beams, sidewalls, etc.). Although increased joint flexibility cannot be accurately modeled in the FEM model, it is possible to make adjustments to certain parameters in the FEM model in order to approximate the overall flexural rigidity (or stiffness) of the degraded mobile home. This procedure was taken with the T-5 analysis by reducing the modulus of elasticity (E) of the lauan paneling from 1.5×10^6 psi (pounds per square inch) to 5×10^4 psi. This new value was used for T-1, T-2A, and T-2B deflection test correlation, along with deflection plot FEM runs for the three mobile home units.

As evidenced by Tables 1, 2 and 3, flexural stiffness of mobile homes is not uniform. The material makeup of each configuration is unique and should be investigated individually. The application of the FEM to the structural complexity of the mobile home units as a qualitative analysis tool is shown in the results to follow.

TABLE 1

T-1 DEFLECTION TEST CORRELATION

Load*	Test	FEM**	% Difference
180	0.046/-0.12†	0.490	965/NA
255	0.064/-0.102	0.693	983/NA
330	0.079/-0.087	0.897	1035/NA
405	0.099/-0.067	1.101††	1012/NA
505	0.118/-0.048	1.373	1064/NA
728	0.156/-0.01	1.980	1169/NA
976	0.243/0.077	2.654	992/3347
1228	0.292/0.126	3.340	1044/2551

* T-1 vertical flexure test No. 5 317/1304 miles with 4000 pounds of furnishings

† First value - difference between deflection at applied load and initial sag; second valve - difference between deflection at applied load and deflection measured after test when all load removed

** Finite element method (FEM) model with modulus (E) of paneling reduced to 5 x 10^4 pounds per square inch

†† FEM model of T-1 run with 405 pound load added; all other values are linearly interpolated or extrapolated

TABLE 2

T-2A DEFLECTION TEST CORRELATION

Load *	Test	FEM†	% Difference
180	.092	.154	67
255	.182	.219	20
330	.276	.283	3
405	.309	.348**	13
505	.407	.433	6

* T-2A vertical flexure test No. 4 259/1119 miles with 4000 pounds of furnishings

† Finite element method (FEM) model with modulus (E) of paneling reduced to 5×10^4 pounds per square inch

** FEM model of T-2A run with 405 pound load added; all other values are linearly interpolated or extrapolated

TABLE 3

T-2B DEFLECTION TEST CORRELATION

Load*	Test	FEM†	% Difference
227	.030	.207	590
302	.044	.275	525
377	.058	.344	493
452	.073	.412**	464
552	.094	.503	435

* T-2B vertical flexure test No. 1 (315 miles)

† Finite element method (FEM) model with modulus (E) of paneling reduced to 5×10^4 pounds per square inch

** FEM model of T-2B run with 452 pound load added; all other values are linearly interpolated or extrapolated

IV. T-1 ANALYSIS METHODOLOGY

The model for the T-1 mobile home is shown in Figures 1 and 2. The use of separate parts for the frame, floor, walls, and ceiling was considered to be more representative of the actual structure. These separate modules were fitted together in the program input by coupling the translational degrees of freedom at the common nodes. The following computer runs were then conducted:

Data check run to generate geometry plots and check boundary conditions, elements, material property definitions, and other input data for completeness and inconsistencies.

Load 1 - Gravity load run to generate the baseline stresses and deformations for the unit under gravity loads of the structure and its furnishings.

Load 2 - Gravity loads of the structure and its furnishings and equivalent static loads from the dynamic analysis (well-paved road, 45 mph, Test Run No. 1).

Load 3 - Gravity loads of the structure and its furnishings and equivalent static loads from the dynamic analysis (well-paved road, 45 mph, Test Run No. 5).

Load 4 - Gravity loads of the structure and its furnishings and a concentrated load of 5000 lb acting on the right longitudinal I-beam at the rear of the chassis (Nodal Point 2 on Figure 1). This loading case, unlike the preceding two cases, was developed to simulate site installation activities where the unit is jacked up at each corner and set on blocks. (For this loading condition, the unit was restrained at the hitch, the three axles, and at the front end at the longitudinal I-beams. This last restraint assumes that the front end was blocked prior to this step in the installation procedure.)

Load 5 - Gravity loads of the structure and its furnishings and equivalent static loads from the dynamic analysis. This load case represents a probabilistic "worst case" condition occupancy once every 1,000 miles traveled over a paved, secondary road.

A summary of the description of Load Cases 1 through 5 is shown in Table 4.

Displacement plots of the mobile home in Load Case 1 qualitatively compare with the actual physical configuration of the unit when it is at rest supported by the hitch and wheels only. In a similar manner, the stress contour plots obtained from the dynamic load cases correlate to permanent deformations and reactions resulting from the road tests, as described earlier. Load Case 4 is similar to Load Case 1 in that it is a static load situation but it has an additional loading of 4000 lb to the right rear corner.

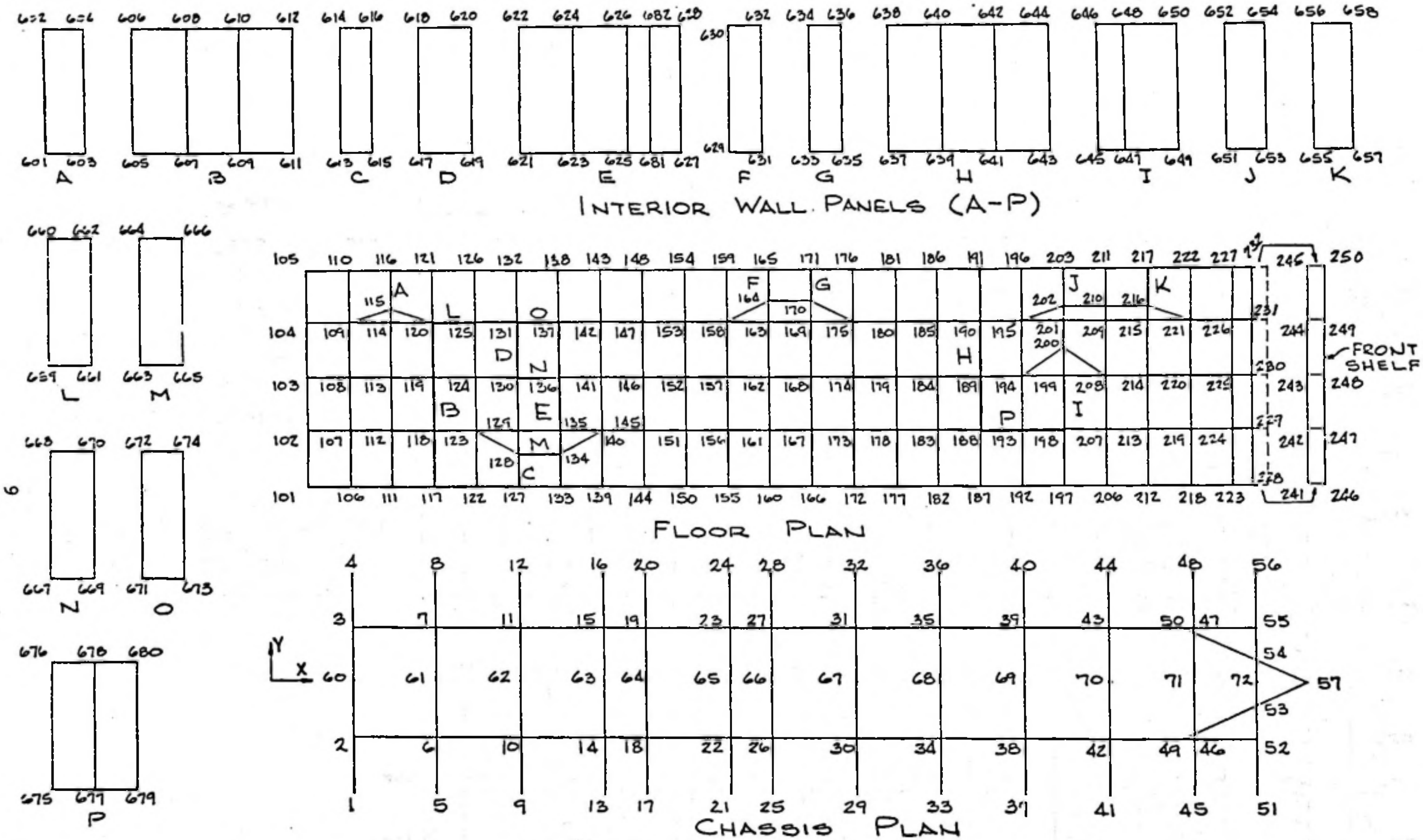


FIGURE 1. FINITE ELEMENT MODEL OF T-1

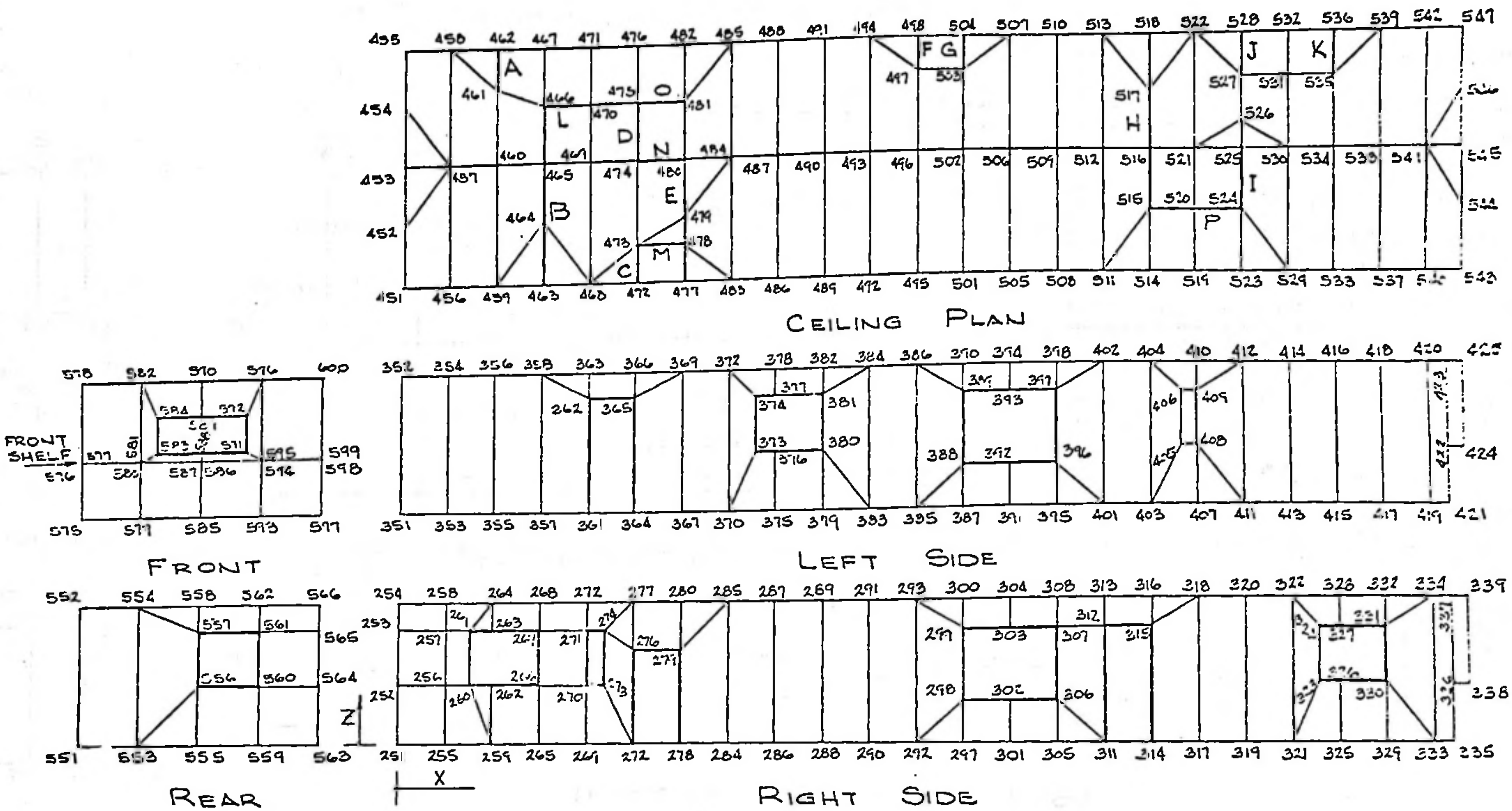


FIGURE 1 (Cont'd)

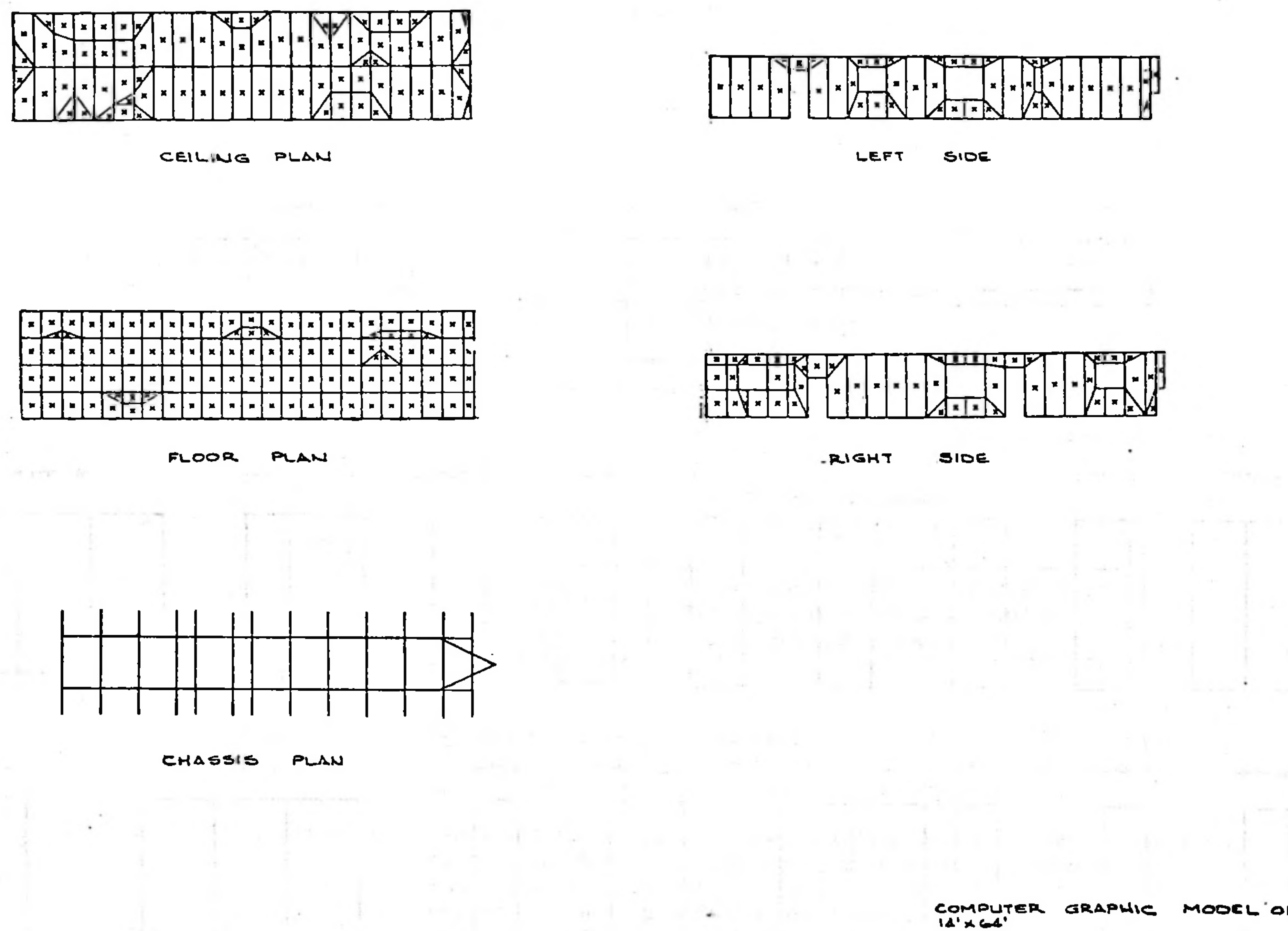
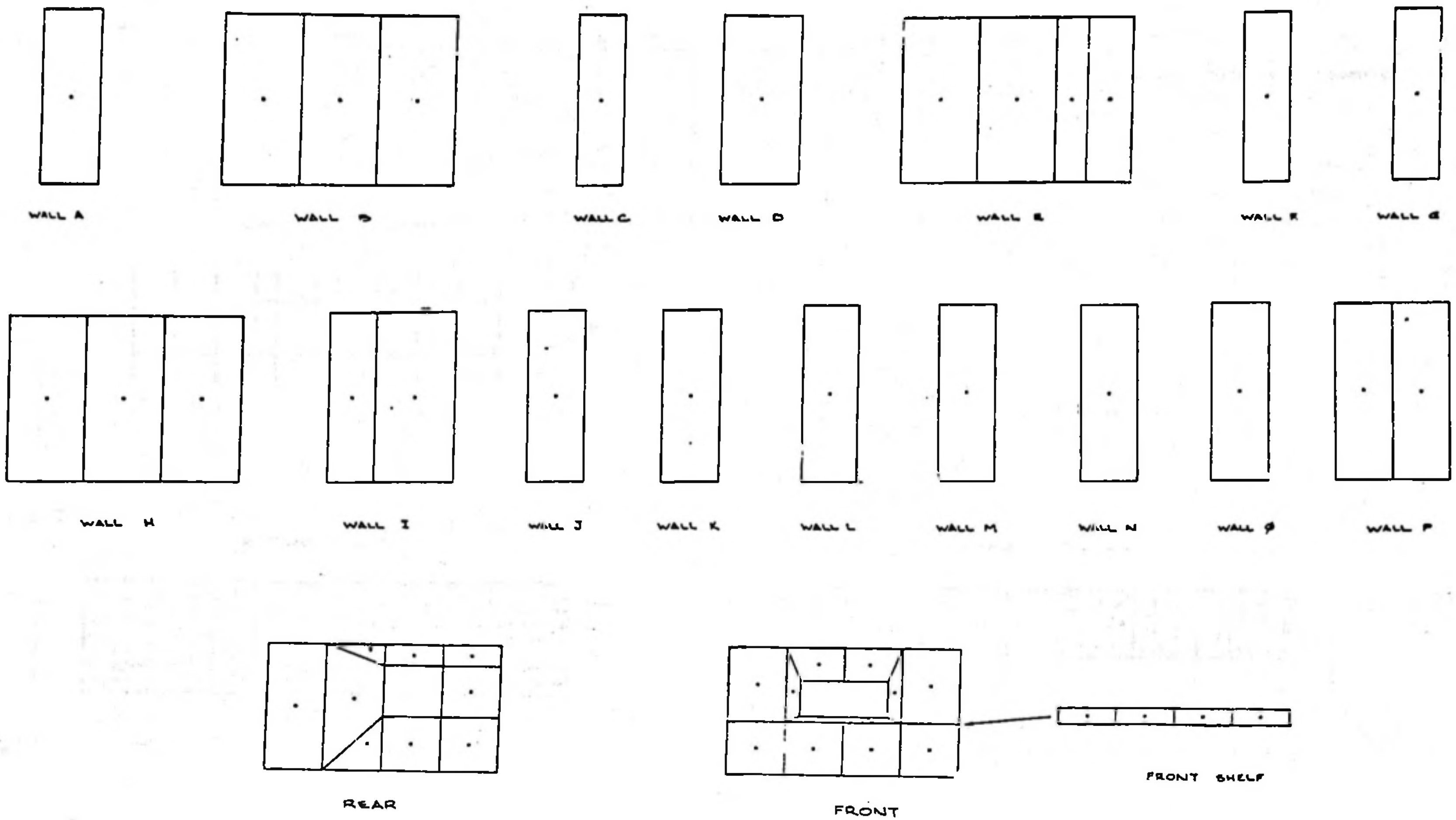


FIGURE 2. COMPUTER GRAPHIC MODEL OF T-1



COMPUTER GRAPHIC MODEL OF 14' x 68'

FIGURE 2 (Cont'd)

TABLE

DESCRIPTION OF LOAD CASES AND LOAD CONDITIONS

CONDITION I	LOAD CASE 1	Gravity Load - Weight of Mobile Home Unit With Furnishings Included
	LOAD CASE 2	Furnishings Added With Dynamic Loading Induced by Well-Paved Road at 45 mph (Test Run No. 1)
	LOAD CASE 3	Furnishings Added With Dynamic Loading Induced by Well-Paved Road at 45 mph (Test Run No. 5)
CONDITION II	LOAD CASE 4	Setup/Takedown (Jackup) Loading with Furnishings Included
	LOAD CASE 5	Worst Case Condition - Furnishings Plus Dynamic Loading Induced by Paved, Secondary Road

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

Condition II: Simulated 15-20 years of use including two or three occupancy periods and one or two secondary transportation movements ranging between 300 to 600 miles; an additional distributed weight of 4,000 lb per unit of occupants' personal effects was included in the transportation calculations.

The equivalent static loads used from the dynamic analysis for Loadings 2, 3 and 5 were based upon 3 x RMS,* or sigma (σ), values calculated in Task I. These values probabilistically assure a 99.9 percentile level that the dynamic loads induced via the road condition are equal to or less than these G values.

Note that in applying the equivalent static loads from the dynamic analysis to the unit, the direction of all vertical loads was assumed acting downward (-z direction), and all lateral loads were applied from left to right looking from the rear to the front of the unit (-y direction). In actuality, the loading directions would be random in nature. The assumed directions, however, shown in Figure 3 below, represent a possible service loading condition.

Complete details of a typical computer run are contained in the appendix of Task I.

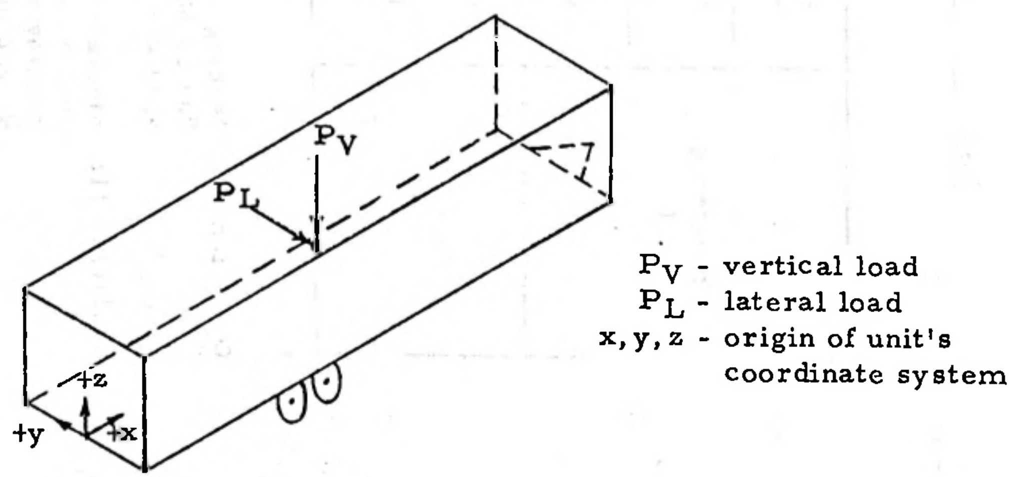


FIGURE 3. T-1 EQUIVALENT STATIC LOAD DIRECTIONAL SENSE

*Root mean square values of acceleration response.

V. CORRELATION OF T-1 RESULTS

Output plots* for the ANSYS program were specified for stress trajectories and displacements of the membrane elements in the floor, wall, and ceiling. The results of all elements of the structure are available in the computer output sheets (available upon request at Southwest Research Institute). The stress trajectories of the analysis for each of the five load conditions of Table 4 are shown in Figures 4 through 9.

These stress plots were useful in:

- Locating areas where stress gradients are high (the lines of equal stress come closer together indicating stress concentrations) in each load case.
- Locating areas of changing stress between load cases due to different load applications.

At this point, it was important to determine whether or not these stress data were identifying possible problem areas in the T-1 mobile home. Thus, it seemed appropriate to investigate areas in the unit where stress concentrations were high. The T-1 mobile home was examined revealing several locations where the predictive analysis was accurately projecting the physical degradation in the structural integrity of the unit.

Above the rear axles of the unit, an area of high stress, the metal siding was buckled along the floor line of the unit. The screws used to fasten the siding remained tightly fastened. The siding, however, was damaged because of the tearing of the metal around the fasteners. Similar buckling was also noted on the left sidewall at the front end of the mobile home.

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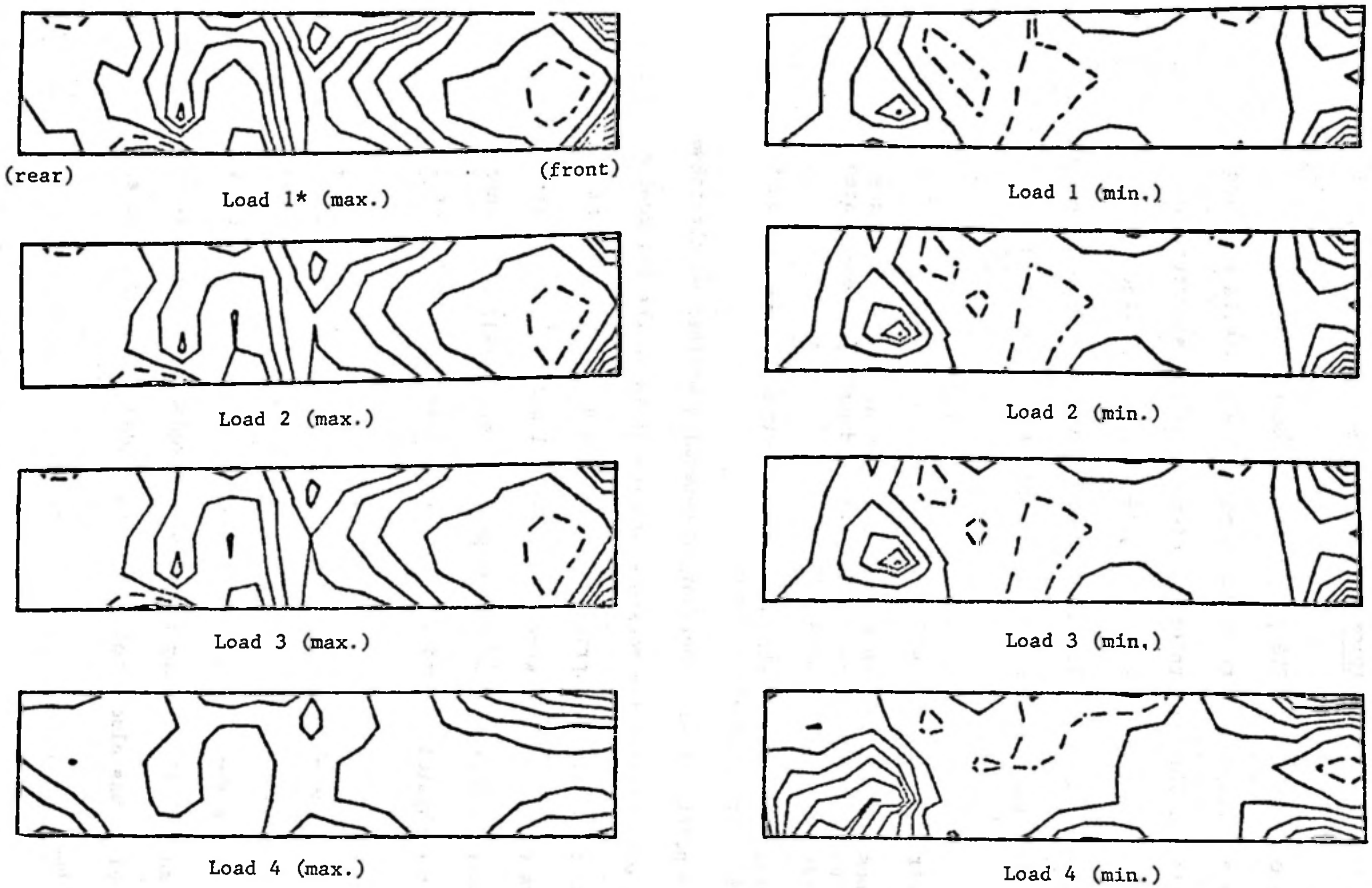
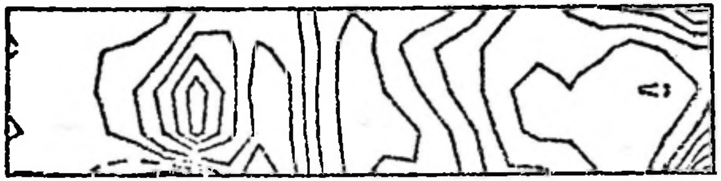
*See Appendix for method of interpretation of these plots.



*Load 1 - Gravity load of structure and furnishings
Load 2 - Gravity load (Load 1) plus equivalent static load from dynamic analysis (well-paved road, 45 mph, Test Run No. 1)
Load 3 - Gravity load (Load 1) plus equivalent static load from dynamic analysis (well-paved road, 45 mph, Test Run No. 5)
Load 4 - Gravity load (Load 1) plus 5000-lb jacking load on chassis rear, right side

FIGURE 4. COMPARISON OF T-1 STRESS PLOTS - FLOOR

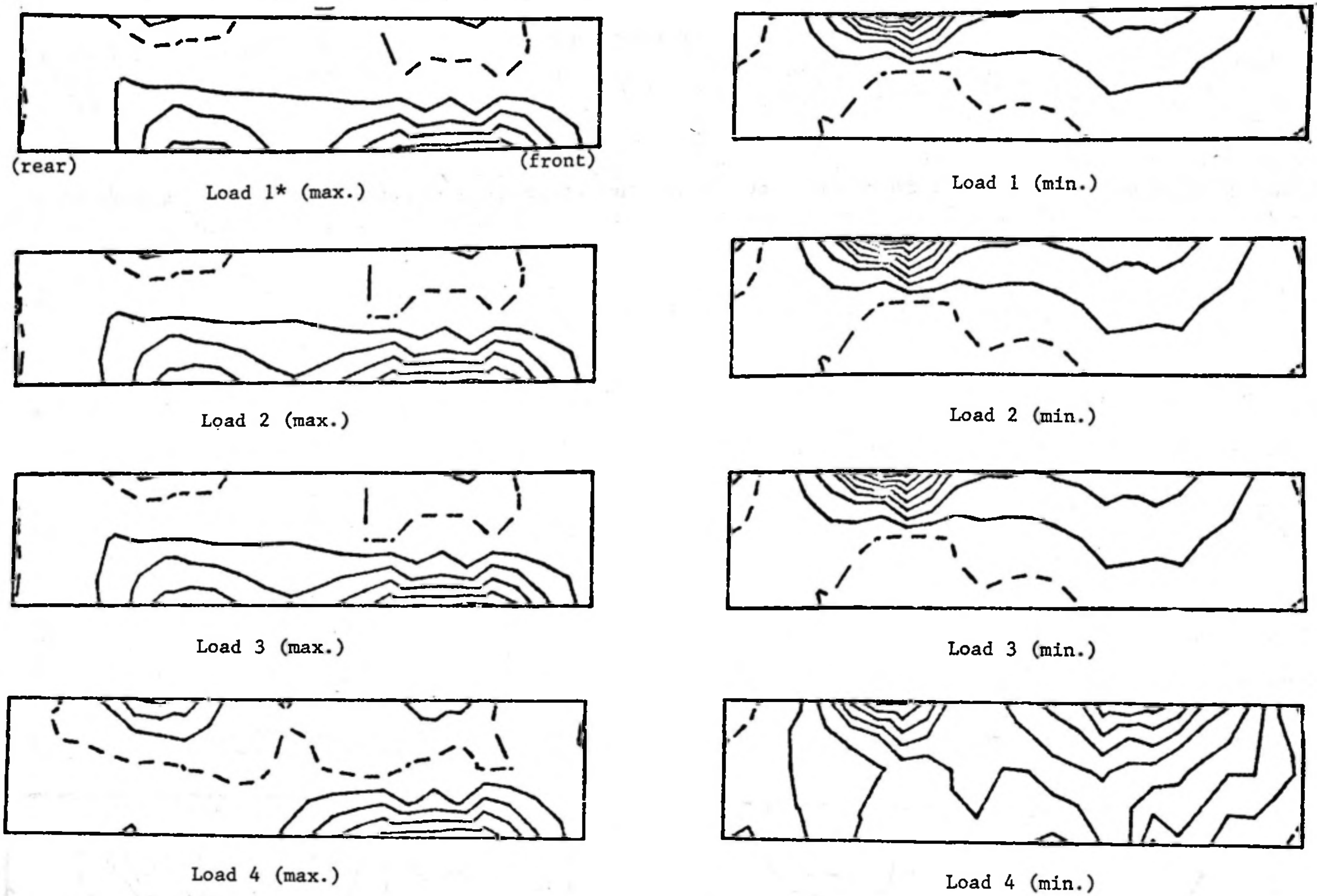


Load 5* (max.)

Load 5 (min.)

* Load 5 - Gravity Load (Load 1) plus equivalent static load from dynamic analysis ("worst-case" condition)

FIGURE 4 (Cont'd)



*For load descriptions, see Figure 4 or Table 4.

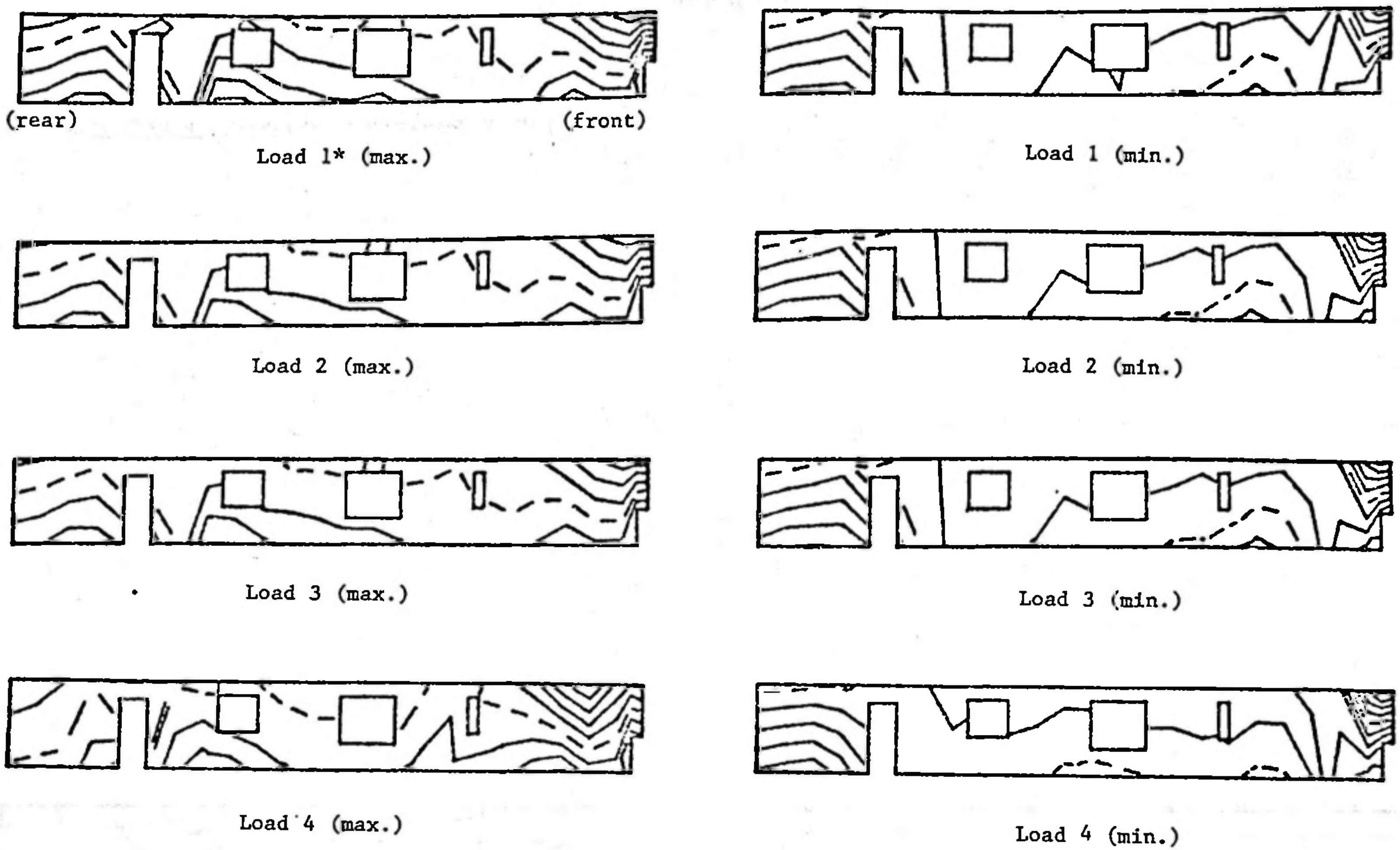
FIGURE 5. COMPARISON OF T-1 STRESS PLOTS - CEILING

Load 5 *   (max.)

Load 5 (min.)

*For load description, see Figure 4 or Table 4.

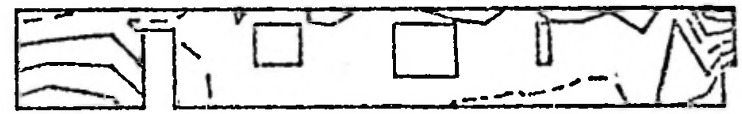
FIGURE 5 (Cont'd)



*For load descriptions, see Figure 4 or Table 4.

FIGURE 6. COMPARISON OF T-1 STRESS PLOTS - LEFT SIDE

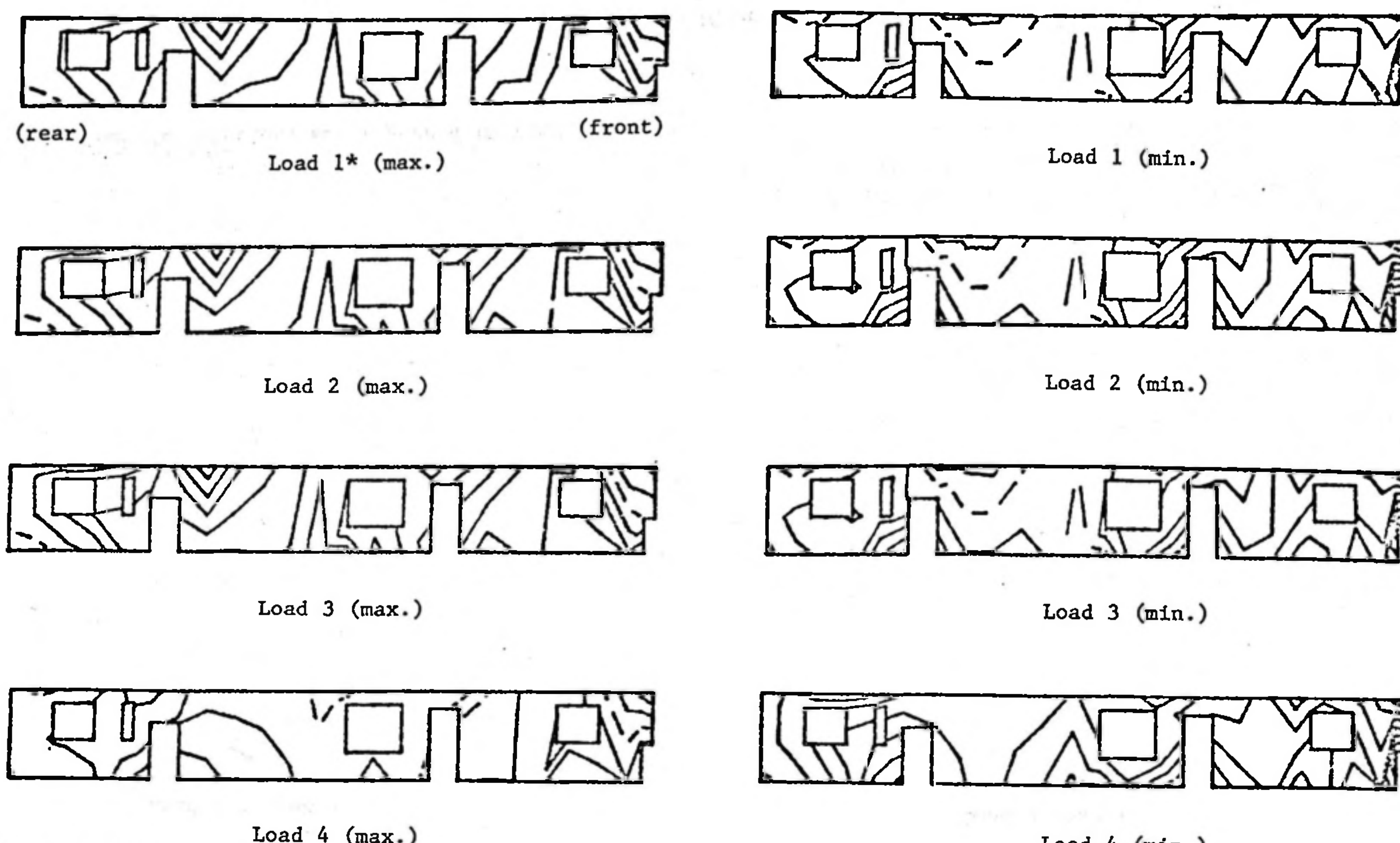
Load 5 * (max.)



Load 5 (min.)

*For load description, see Figure 4 or Table 4.

FIGURE 6 (Cont'd)



*For load descriptions, see Figure 4 or Table 4.

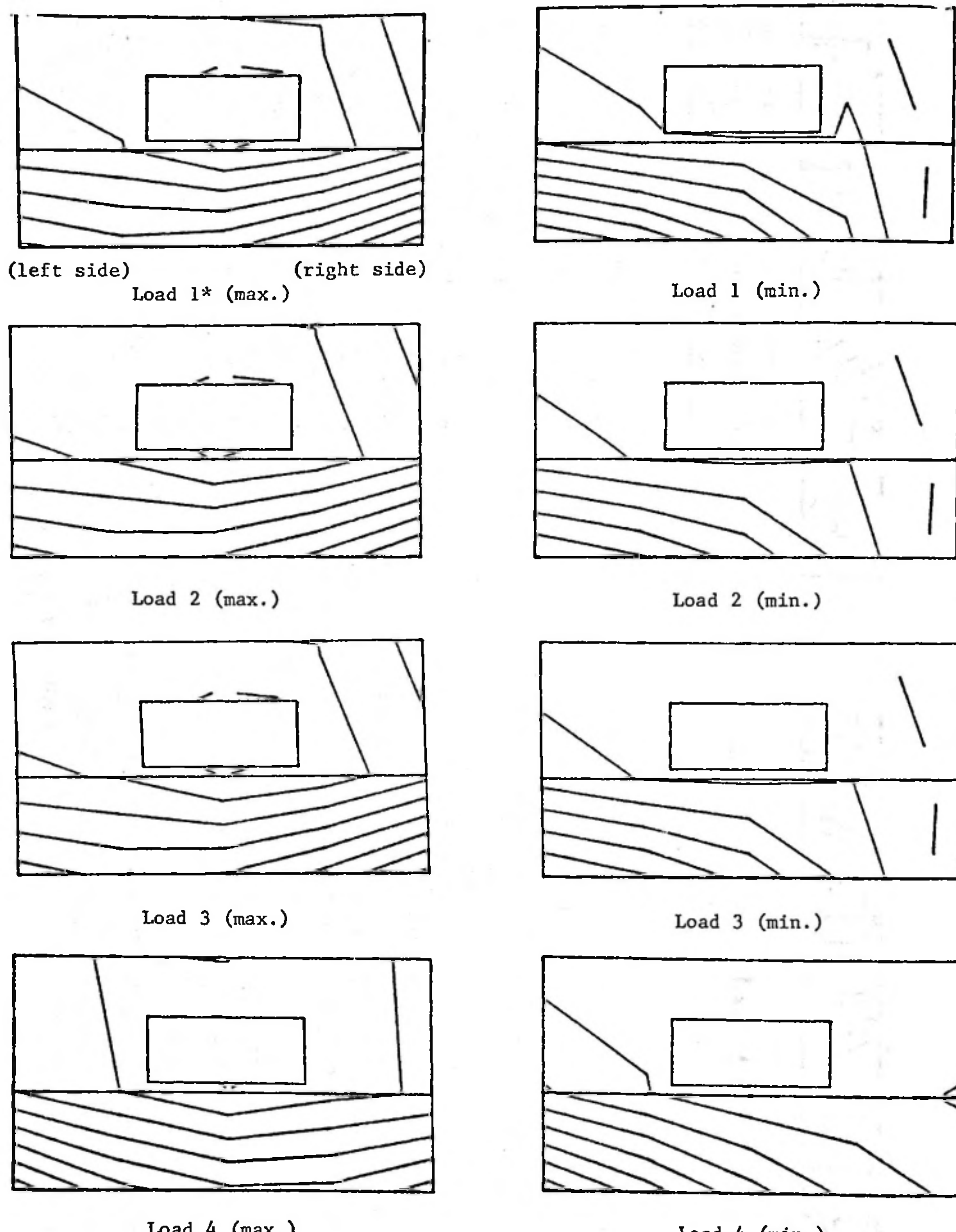
FIGURE 7. COMPARISON OF T-1 STRESS PLOTS - RIGHT SIDE

Load 5 * (max.)

Load 5 (min.)

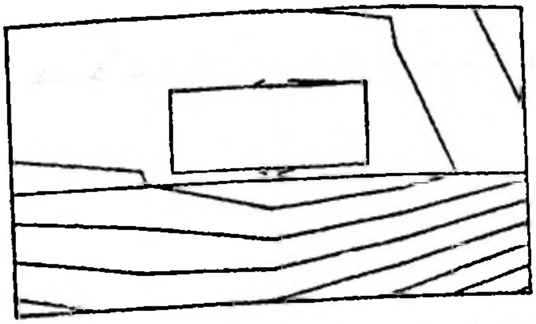
*For load description, see Figure 4 or Table 4.

FIGURE 7 (Cont'd)

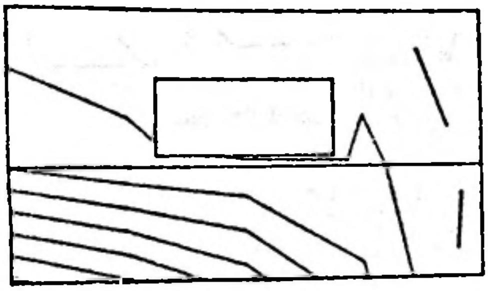


*For load descriptions, see Figure 4 or Table 4.

FIGURE 8. COMPARISON OF T-1 STRESS PLOTS - FRONT



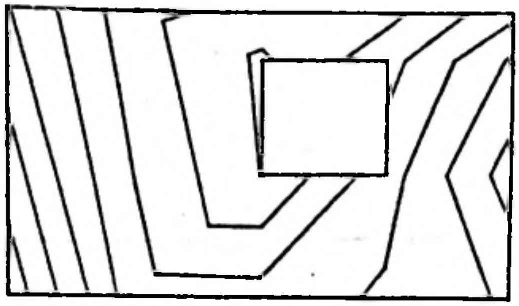
Load 5 * (max.)



Load 5 (min.)

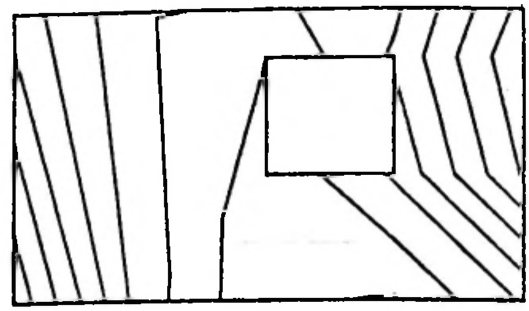
*For load description, see Figure 4 or Table 4.

FIGURE 8 (Cont'd)

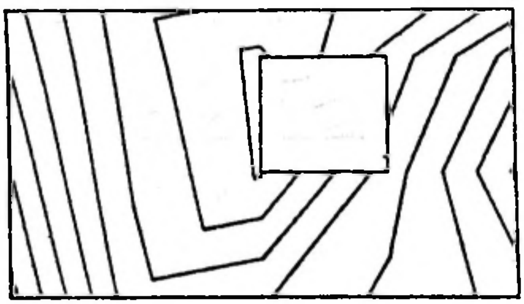


(left side) (right side)

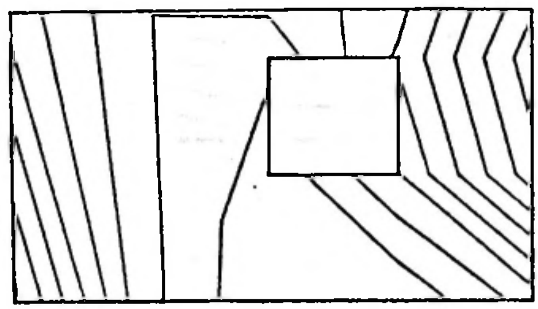
Load 1* (max.)



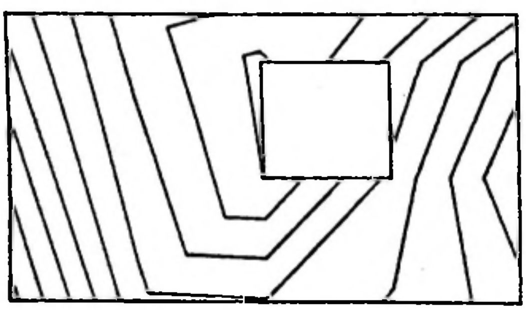
Load 1 (min.)



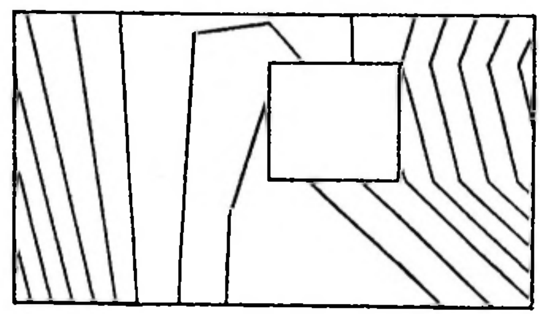
Load 2 (max.)



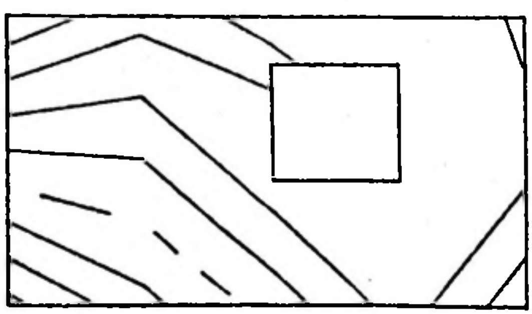
Load 2 (min.)



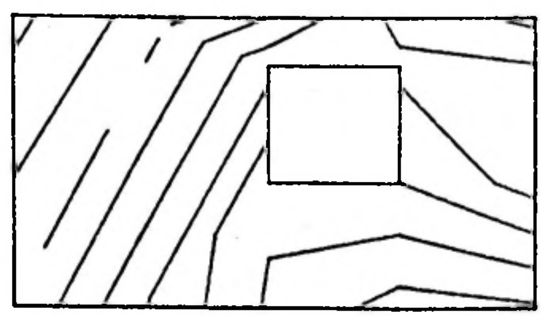
Load 3 (max.)



Load 3 (min.)



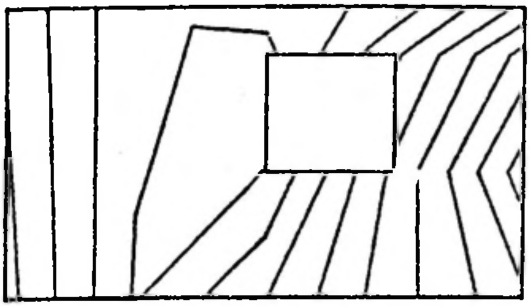
Load 4 (max.)



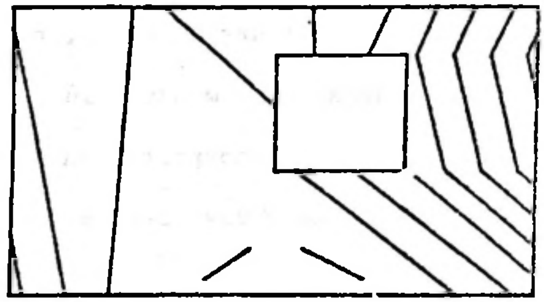
Load 4 (min.)

*For load description, see Figure 4 or Table 4.

FIGURE 9. COMPARISON OF T-1 STRESS PLOTS - REAR



Load 5 * (max.)



Load 5 (min.)

*For load description, see Figure 4 or Table 4.

FIGURE 9 (Cont'd)

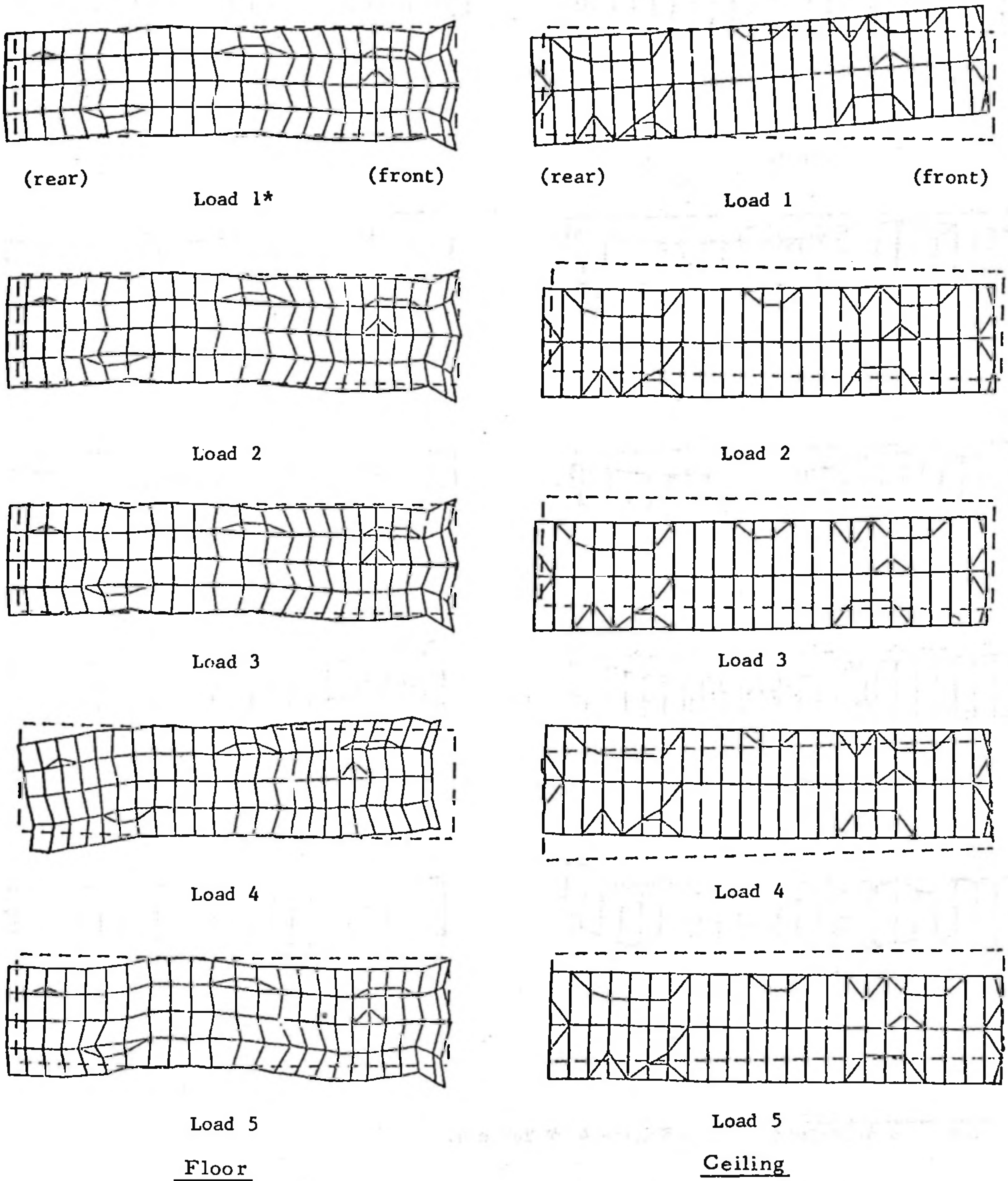
Along the front of the unit, where the siding is fastened at its base, it was evident that the siding attempted to buckle. Although the siding remained fastened, it pulled approximately 1/2 in. outward at each of the screws above the hitch area.

From the stress plots, the doors and windows also appeared to be a problem area. One window, in particular, substantiated this problem. During several transportation runs, the living room window on the right side of the unit was cracked and needed replacement. The frames on several windows and the exterior door on the left side of the unit also suffered damage. Although operable, the frames were no longer square, and any future damage would result in an inoperable situation.

Deflection was also an important consideration in the correlation of the FEM results with actual test data. Predictive deflections for each load case are shown in Figures 10 through 12, and the magnitude of these deflections is defined in Table 5.

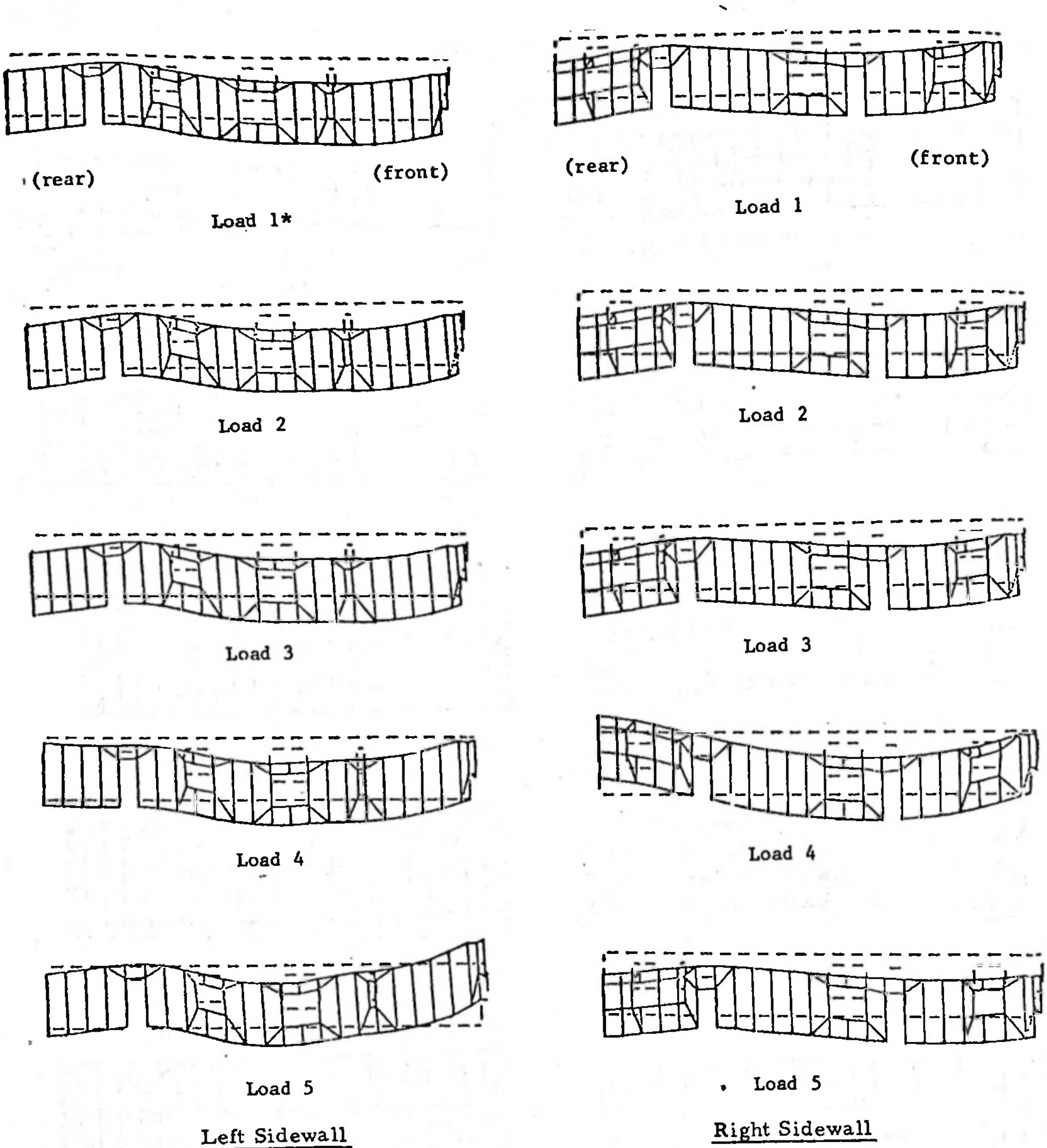
The deflection of the frame was a most important concern. An inspection of the unit in the static condition (Load Case 1) revealed that, as shown in the stress plots, the frame deflected downward between hitch and axle and at the rear of the unit behind the axle, even though the unit was cambered during construction.

In addition to the latter correlation regarding the bending characteristics of the frame, the conditions of Load Case 4 were similar to the conditions of a bending test conducted on the T-1 (Volume I, Task III). In both cases, the recorded upward change in deflection at the point of load application was approximately 1/2 in.



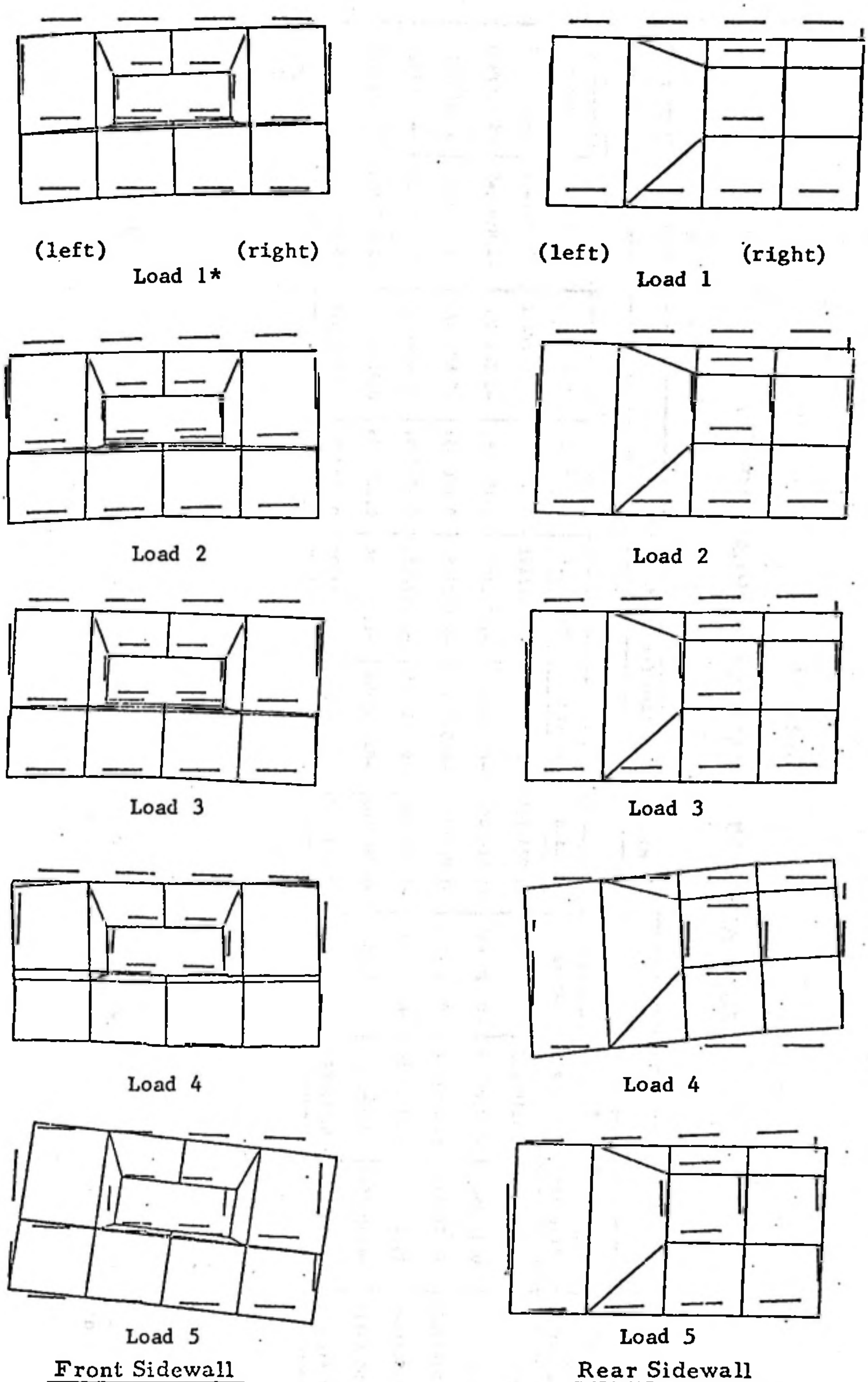
*For load descriptions, see Figure 4 or Table 4.

FIGURE 10. COMPARISON OF T-1 DISPLACEMENT PLOTS - FLOOR AND CEILING



*For load descriptions, see Figure 4 or Table 4.

FIGURE 11. COMPARISON OF T-1 DISPLACEMENT PLOTS - LEFT AND RIGHT SIDEWALLS



*For load descriptions, see Figure 4 or Table 4.

FIGURE 12. COMPARISON OF T-1 DISPLACEMENT PLOTS - FRONT AND REAR SIDEWALLS

TABLE 5

SUMMARY OF T-1 MAXIMUM DISPLACEMENTS

Mobile Home Component	Maximum Deflection (In.)/Node Location†									
	Load Case 1*		Load Case 2		Load Case 3		Load Case 4		Load Case 5	
	Lateral*	Vertical**	Lateral	Vertical	Lateral	Vertical	Lateral	Vertical	Lateral	Vertical
Floor	-0.010/228	-1.210/203	-0.570/241	-1.286/101	-0.886/250	-1.341/101	0.027/250	-0.803/171	-1.180/250	-4.159/197
Ceiling	0.230/543	-1.210/528	-0.329/451	-1.286/451	-0.374/451	-1.342/451	0.181/451	-0.803/504	-2.856/547	-4.160/320
Left Sidewall	0.228/425	-1.210/412	-0.324/352	-1.061/398	-0.369/352	-1.013/398	0.176/352	-0.803/390	-2.856/425	1.191/421
Right Sidewall	0.230/339	-0.969/254	-0.329/254	-1.286/254	-0.374/254	-1.342/254	0.181/254	-0.496/308	-2.852/339	-4.150/320
Rear Sidewall	-0.105/566	-0.969/566	-0.329/566	-1.286/566	-0.374/566	-1.342/566	0.181/566	0.308/566	-1.959/566	-3.650/566
Front Sidewall	0.230/578	-0.712/599	-0.158/600	-0.672/577	-0.171/592	-0.233/600	0.078/600	-0.103/599	-2.856/600	-3.373/577

†For node point locations, see Figure 1.
*For load descriptions, see Figure 4 or Table 4.
**For displacement directional sense, see Figure 3.

For Load Case 1, where no "racking" of the unit had been introduced, other deformations were recorded in the output data that correlated to actual field data. In many cases, the vertical deflection of the outriggers was greater at the sidewall connections than along the longitudinal I-beams. This type of deflection causes the floor of the unit to slope to the sidewalls. This was evident in the inspection of the T-1 unit.

VI. T-2 ANALYSIS METHODOLOGY

The models for the T-2A (wet side) and T-2B (dry side) mobile home units are shown in Figures 13 and 14 and Figures 15 and 16, respectively. Separate parts for the frame, floor, walls, and ceiling were used and integrated in the program input by compiling the translational degrees of freedom at the common nodes. The following computer runs were then conducted for each model, T-2A and T-2B:

> Data check run to generate geometry plots and check boundary conditions, elements, material properties definitions and other input data for completeness and inconsistencies.
>
> Load 1 - Gravity load run to generate the base line stresses and deformations for each unit under gravity loads of the structure and its furnishings.
>
> Load 2 - Gravity loads of each structure and its furnishings and equivalent loads from the dynamic analysis (well-paved road, 45 mph).
>
> Load 4 - Gravity loads of the structure and its furnishings and a concentrated load of 5000 lb acting on the right longitudinal I-beam at the rear of the chassis (Nodal Point 2 on Figure 1). This loading case, unlike the preceding two cases, was developed to simulate site installation activities where the unit is jacked up at each corner and set on blocks. (For this loading condition, the unit was restrained at the hitch, the three axles, and at the front end at the longitudinal I-beams. This last restraint assumes that the front end was blocked prior to this step in the installation procedure.)
>
> Load 5 - Gravity loads of the structure and its furnishings and equivalent static loads from the dynamic analysis. This load case represents a probabilistic "worst case" condition occupancy once every 1,000 miles traveled over a paved, secondary road.

Again, the equivalent static loads calculated from the dynamic analysis were based on 3 x RMS, or sigma (σ) values defined in Task I of this report. Values applied to each side of the T-2 unit were the same, except in directional sense.

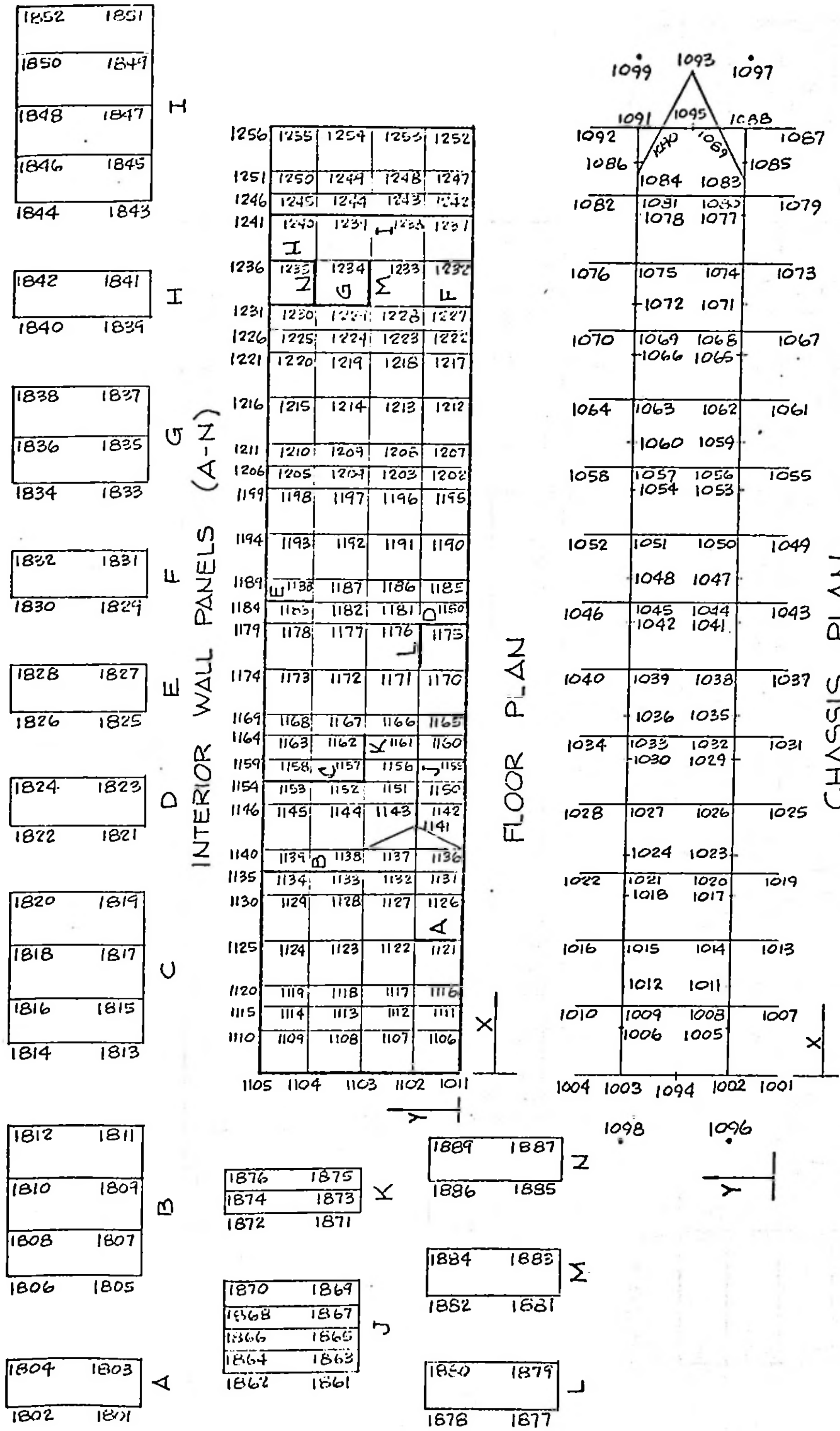


FIGURE 13. FINITE ELEMENT MODEL OF T-2A

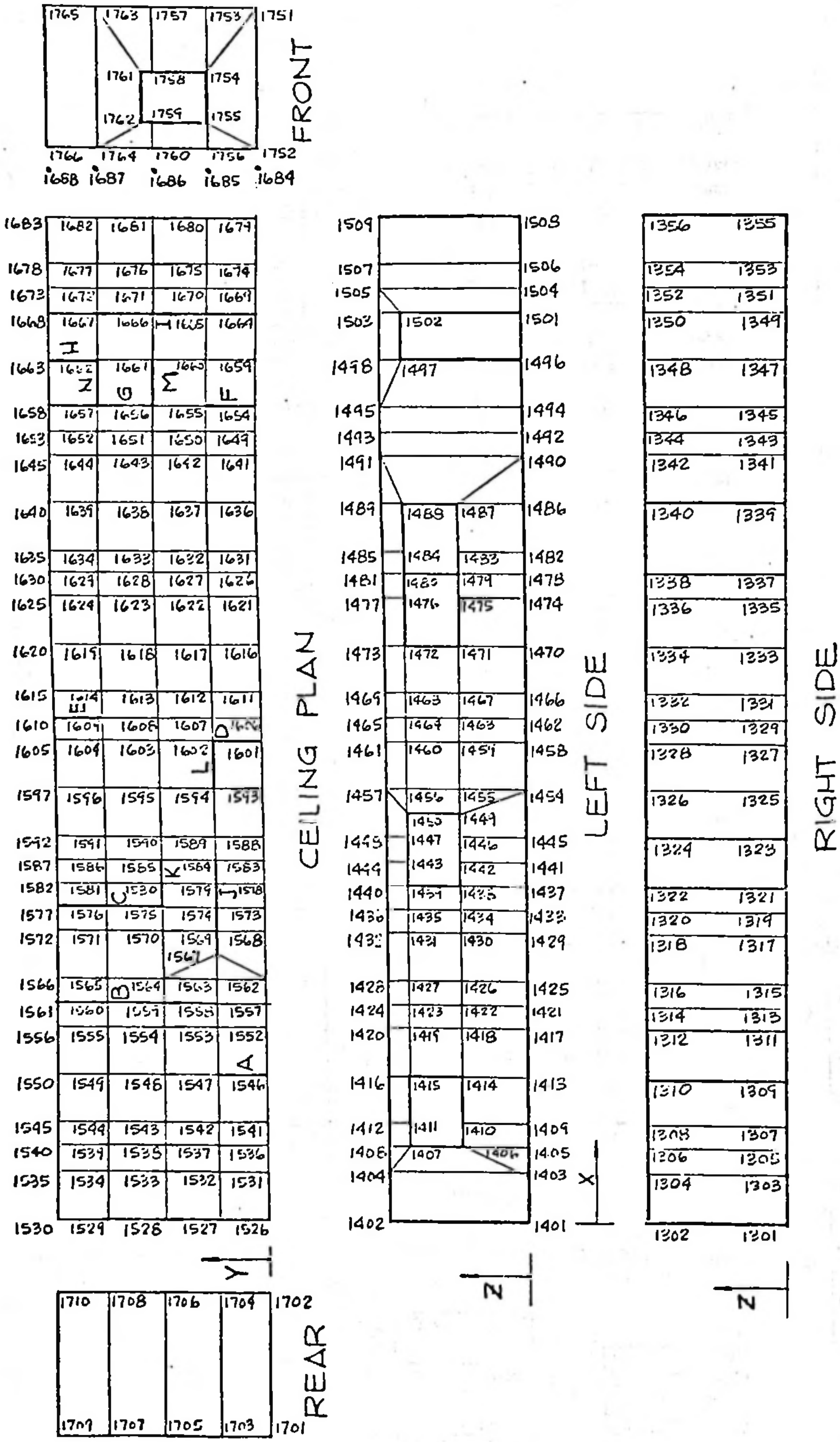


FIGURE 13 (Cont'd)

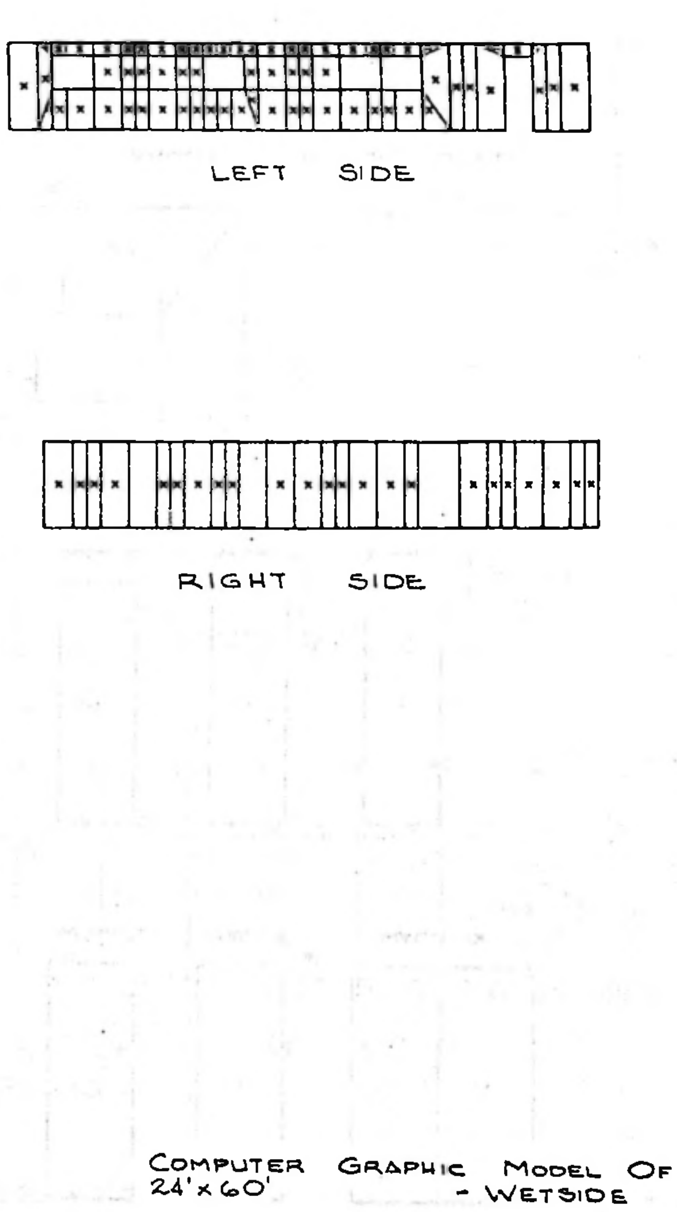


FIGURE 14. COMPUTER GRAPHIC MODEL OF T-2A

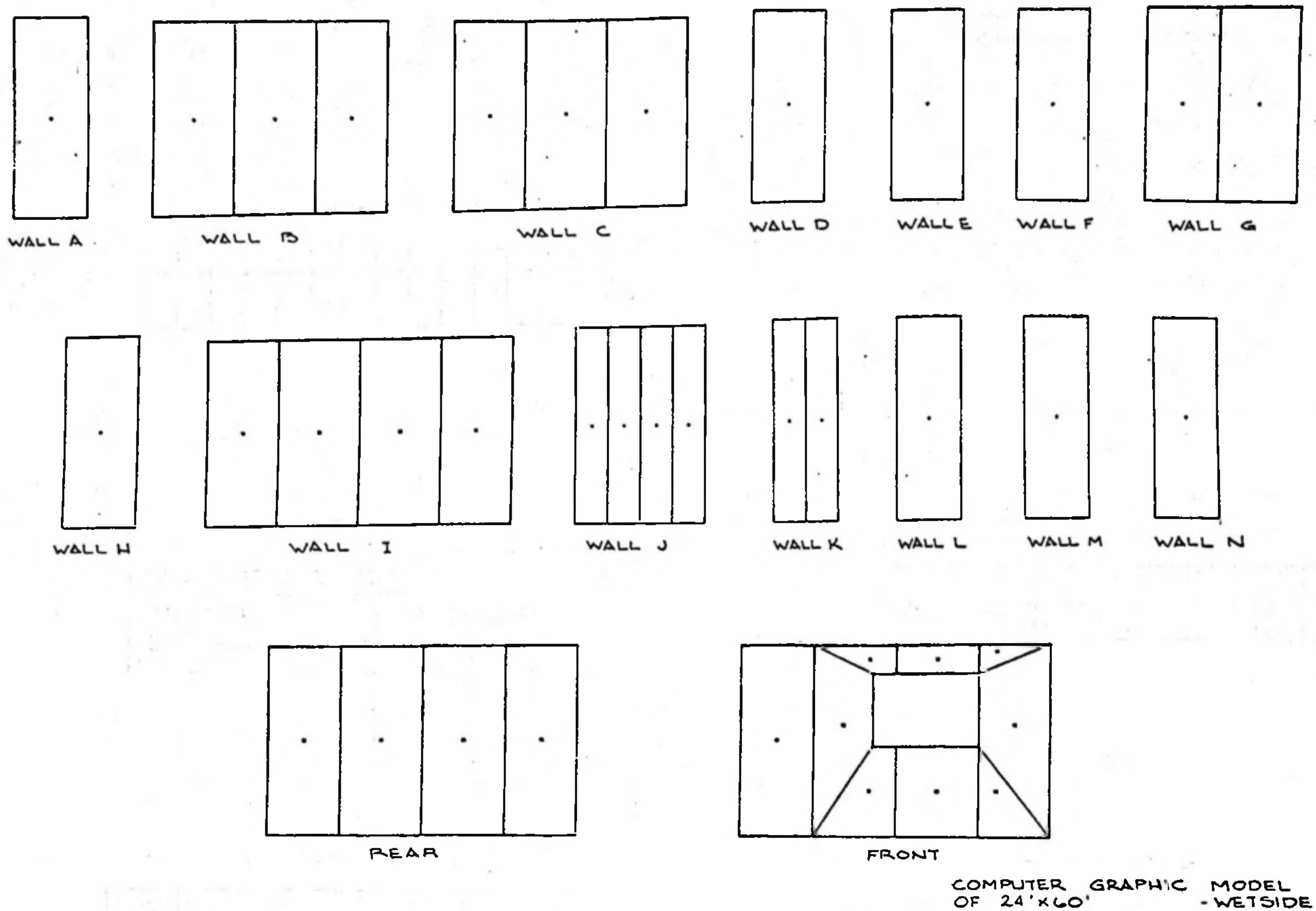


FIGURE 14 (Cont'd)

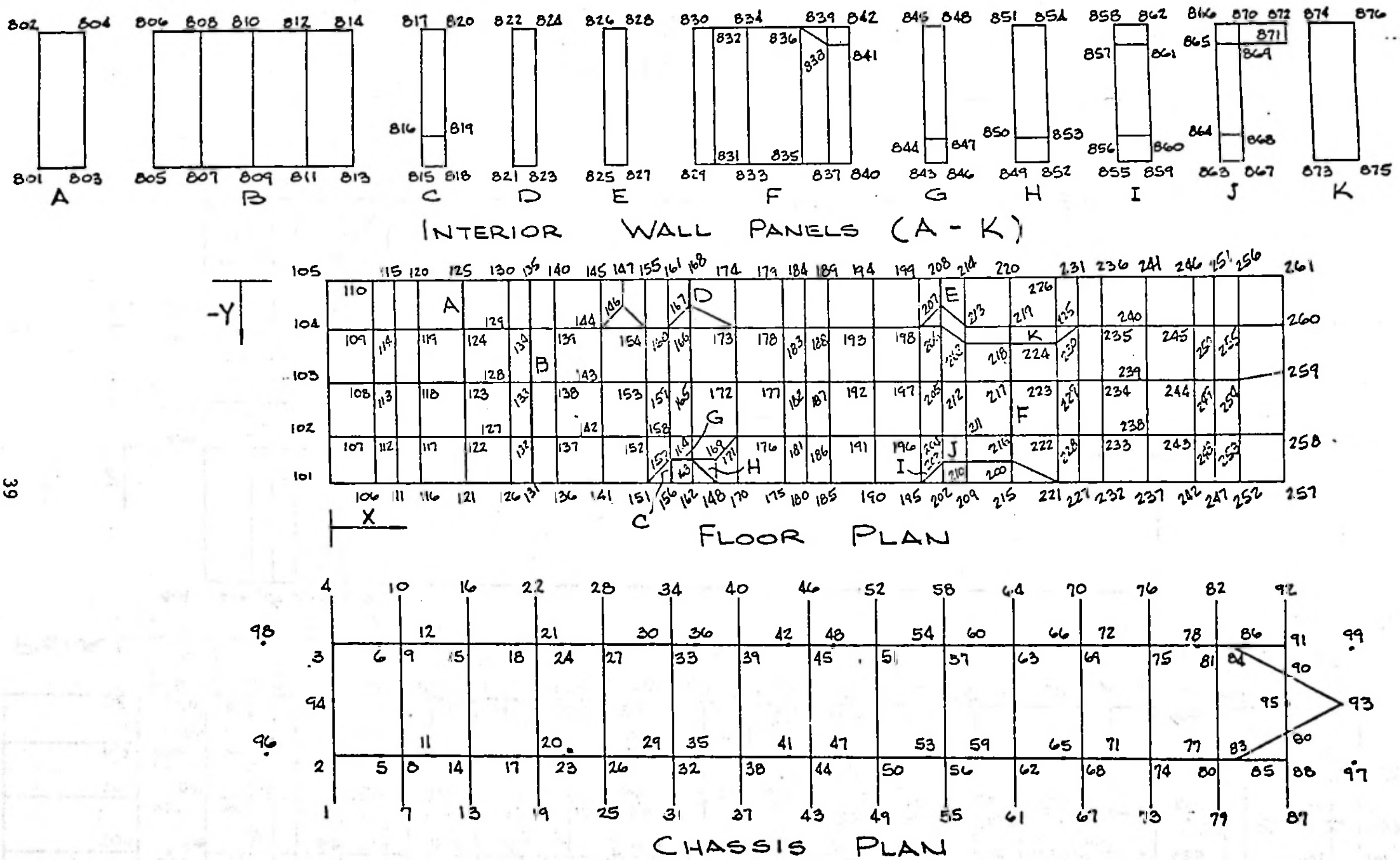


FIGURE 15. FINITE ELEMENT MODEL OF T-2B

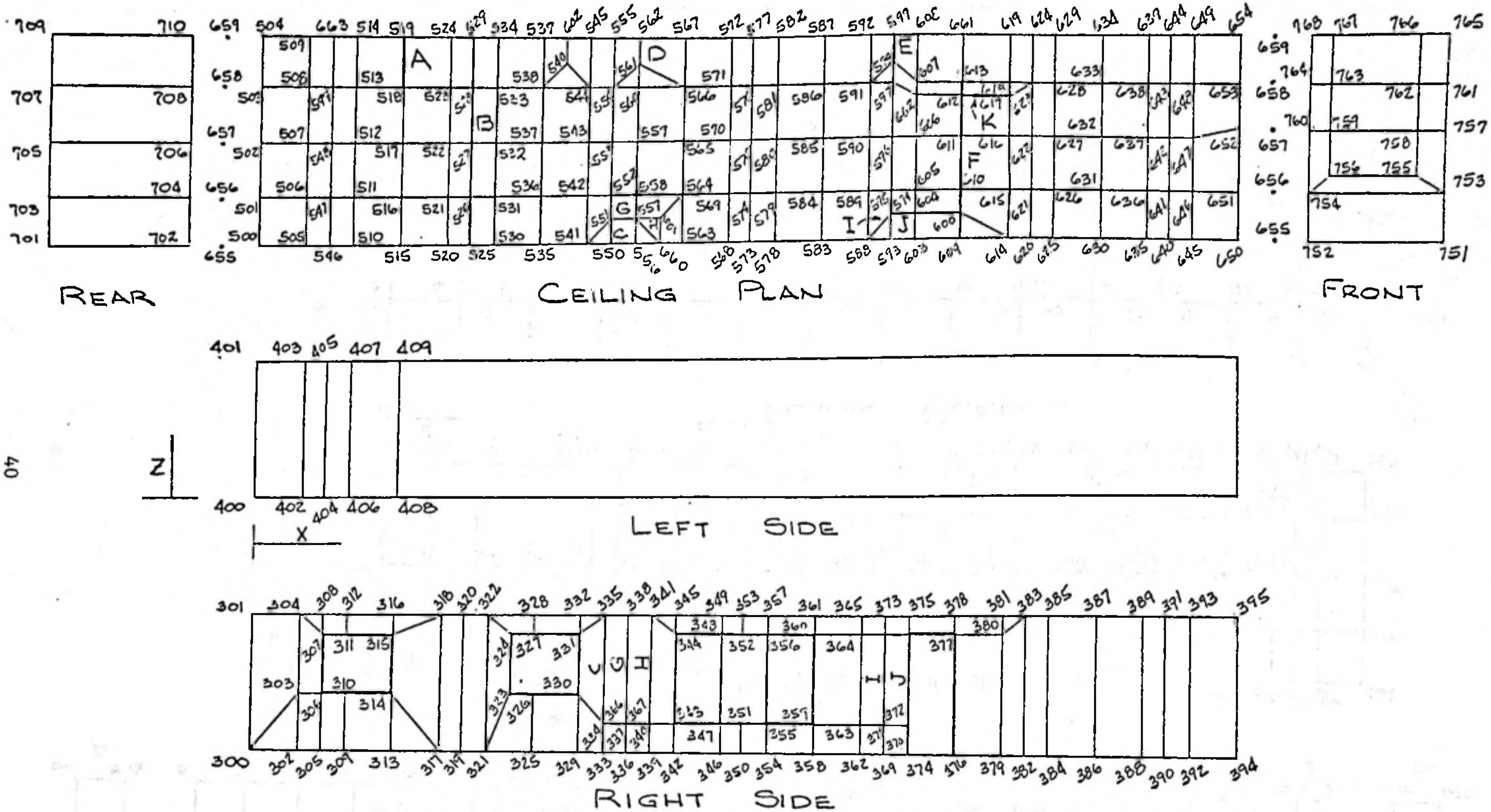


FIGURE 15 (Cont'd)

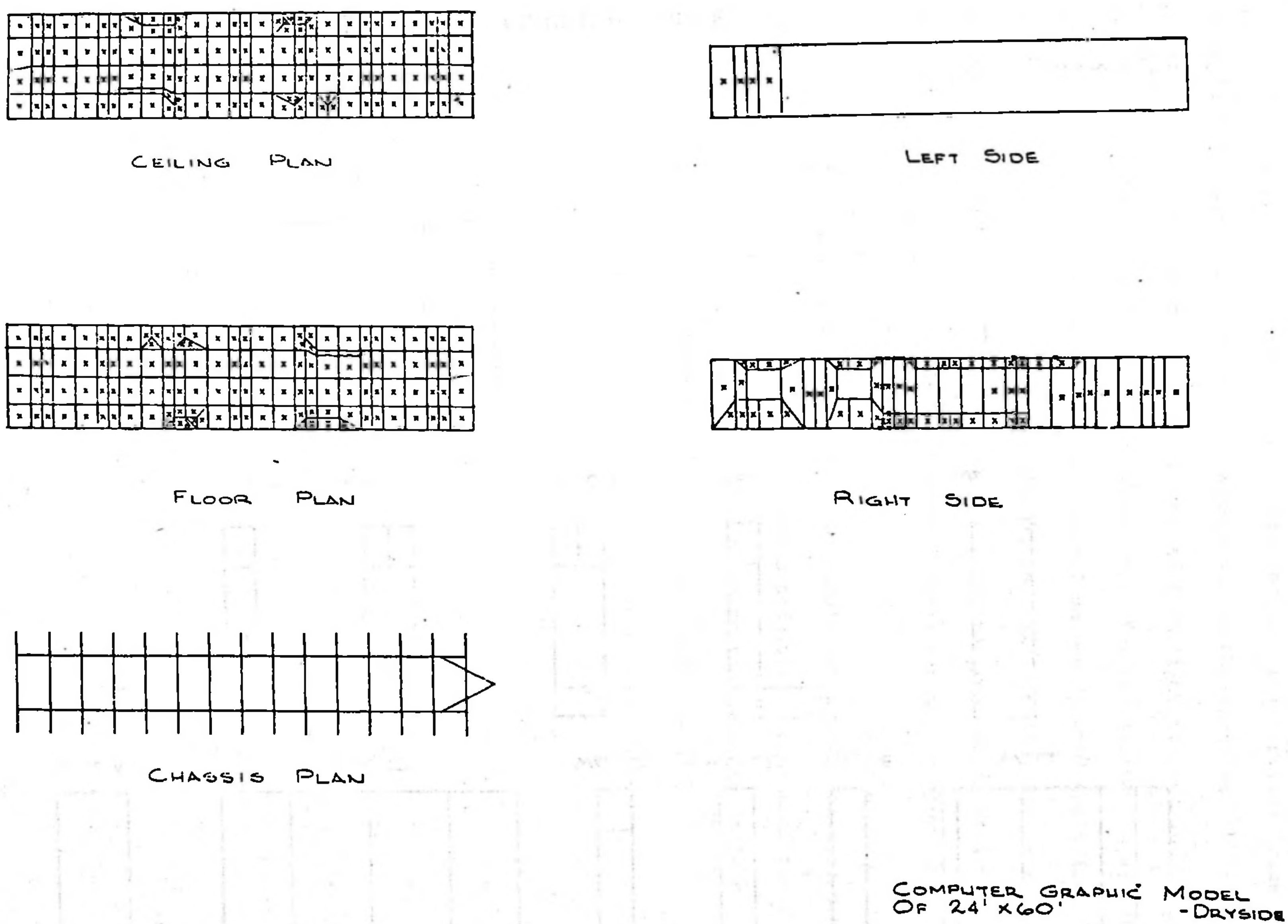
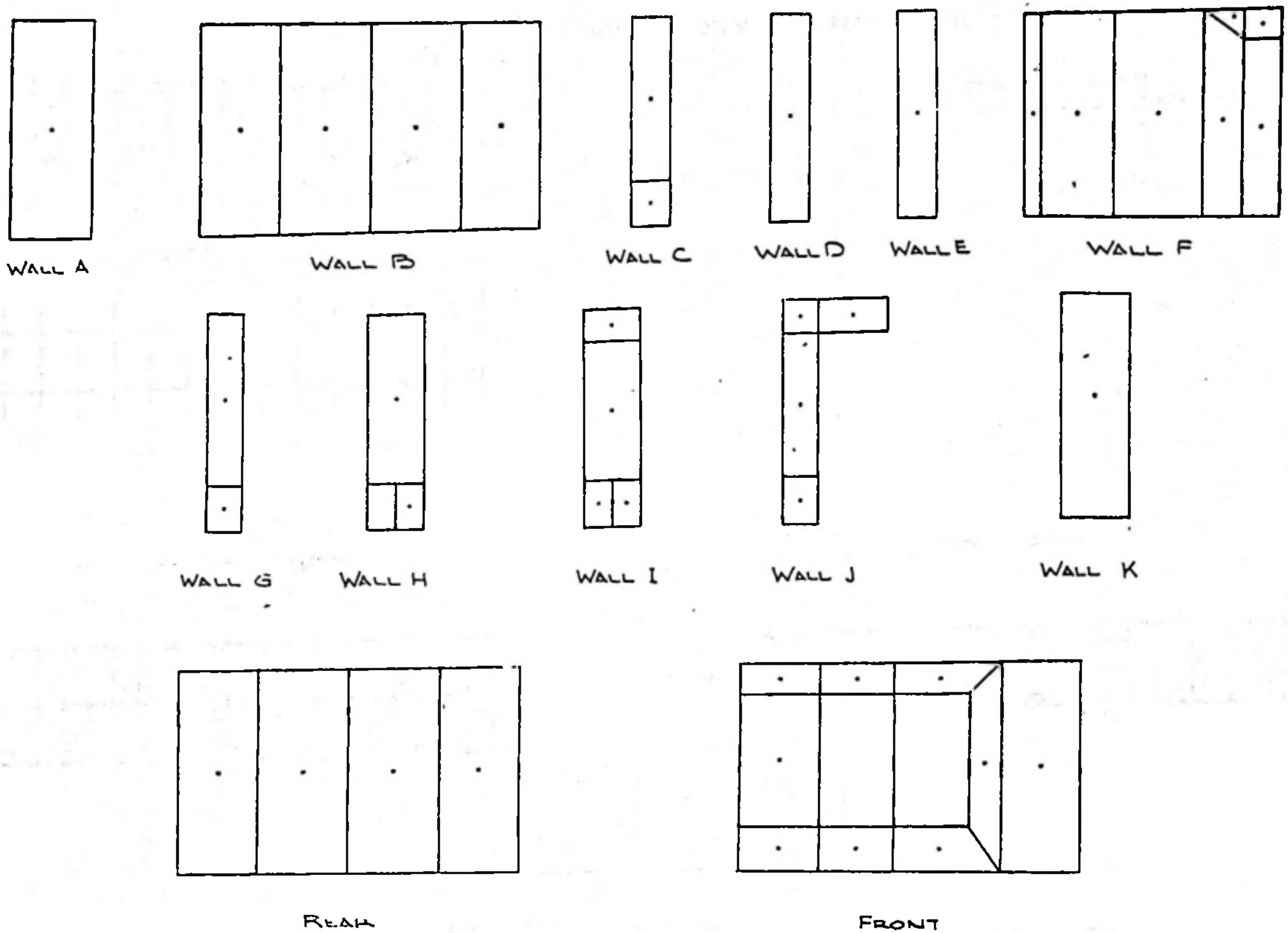


FIGURE 16. COMPUTER GRAPHIC MODEL OF T-2B



COMPUTER GRAPHIC MODEL OF 24'x60' - DRYSIDE

FIGURE 16 (Cont'd)

For the equivalent static loading of the T-2A, all vertical loads input from the dynamic analysis were assumed acting downward (-z direction), and all lateral loads were applied from right to left looking down the unit from rear to front (+y direction). For the equivalent static loading of the T-2B, all vertical loads input from the dynamic analysis were assumed acting downward (-z direction), and all lateral loads were applied from left to right looking down the unit from rear to front (-y direction). The directional sense of these loading schemes is shown in Figure 17.

Again, the loads in each of these two conditions are actually random in nature. The assumed directions represent a possible loading condition.

Datails of a typical computer run similar to that used to analyze these units are contained in the appendix of Task I, Volume III.

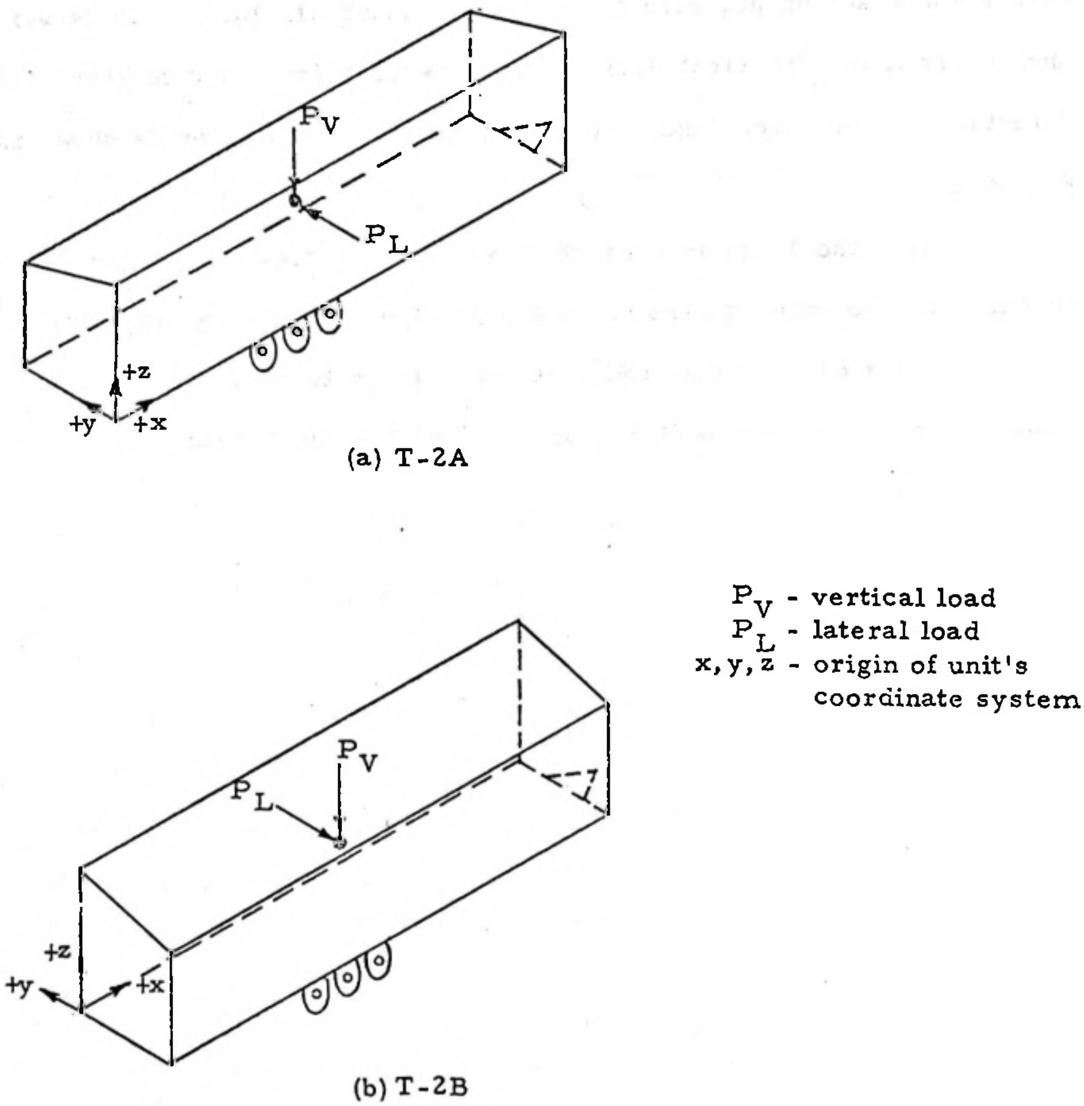


FIGURE 17. T-2A AND T-2B EQUIVALENT STATIC LOAD DIRECTIONAL SENSE

VII. CORRELATION OF T-2 RESULTS

Output plots* for the ANSYS program were specified for stress trajectories and displacements of the membrane elements in the floor, walls and ceiling. Plots could not be developed for walls which contained too few membrane elements. Output results for all elements of the structure are available in the computer output sheets (available upon request at Southwest Research Institute).

The stress results of the analysis for the T-2A (wet side) and T-2B (dry side) sections of the mobile home are shown in Figures 18 through 21. As in the case of the T-1 mobile home results previously discussed, it was assumed that areas of high stress concentration in the finite element analysis would correlate with possible structural weaknesses in the T-2 mobile home. However, in the T-2 units the masonite siding did not show the signs of structural damage the metal siding did in the T-1 mobile home. This correlation, therefore, will concentrate more heavily on the deflection results where degradation exceeded that of T-1.

The deformation of the T-2A and B sections of the unit are shown in Figures 22 and 23. Summaries of maximum deflections generated with each load condition are contained in Tables 6 and 7.

Although cambering was not considered in the chassis for the finite element analysis, it is important to note that the results show a predicted deflection characteristic. This type of deflection correlates with actual field data. The unit deflected vertically downward, maximizing at two locations: between the axles and hitch and at the rear of the unit.

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*See Appendix for method of interpretation of these plots.

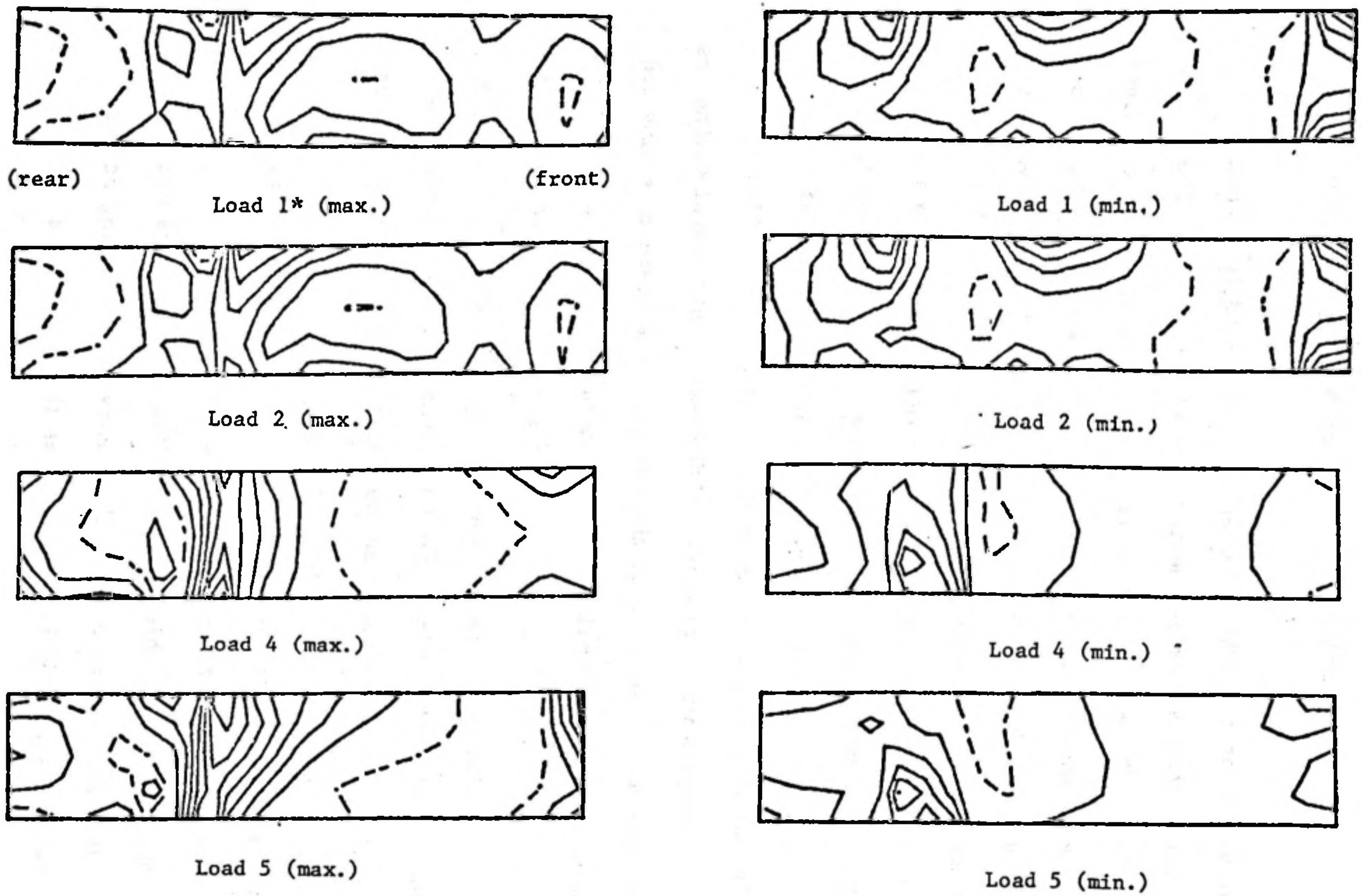


FIGURE 18. COMPARISON OF T-2A STRESS PLOTS - FLOOR

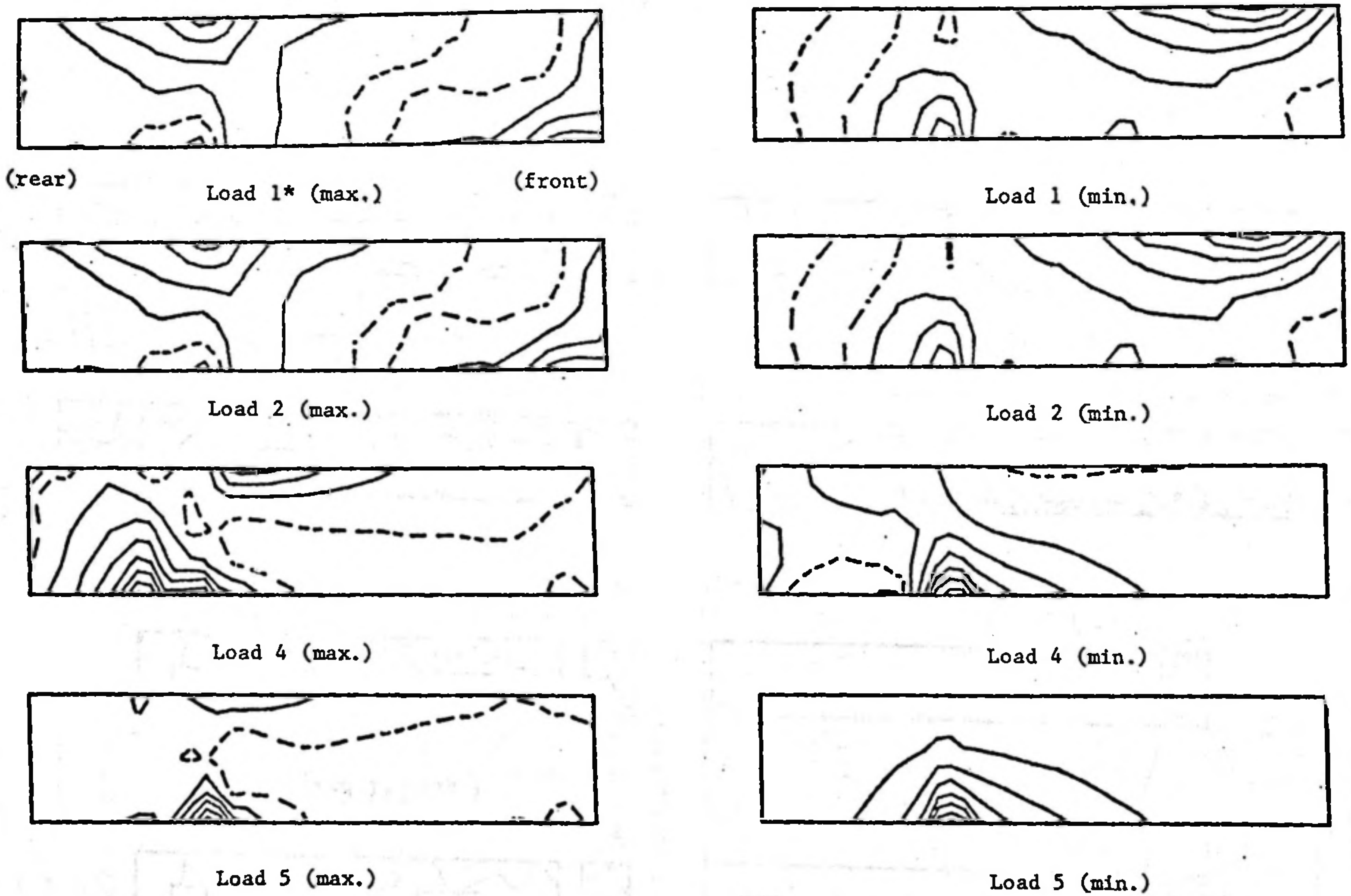


FIGURE 19. COMPARISON OF T-2A STRESS PLOT - CEILING

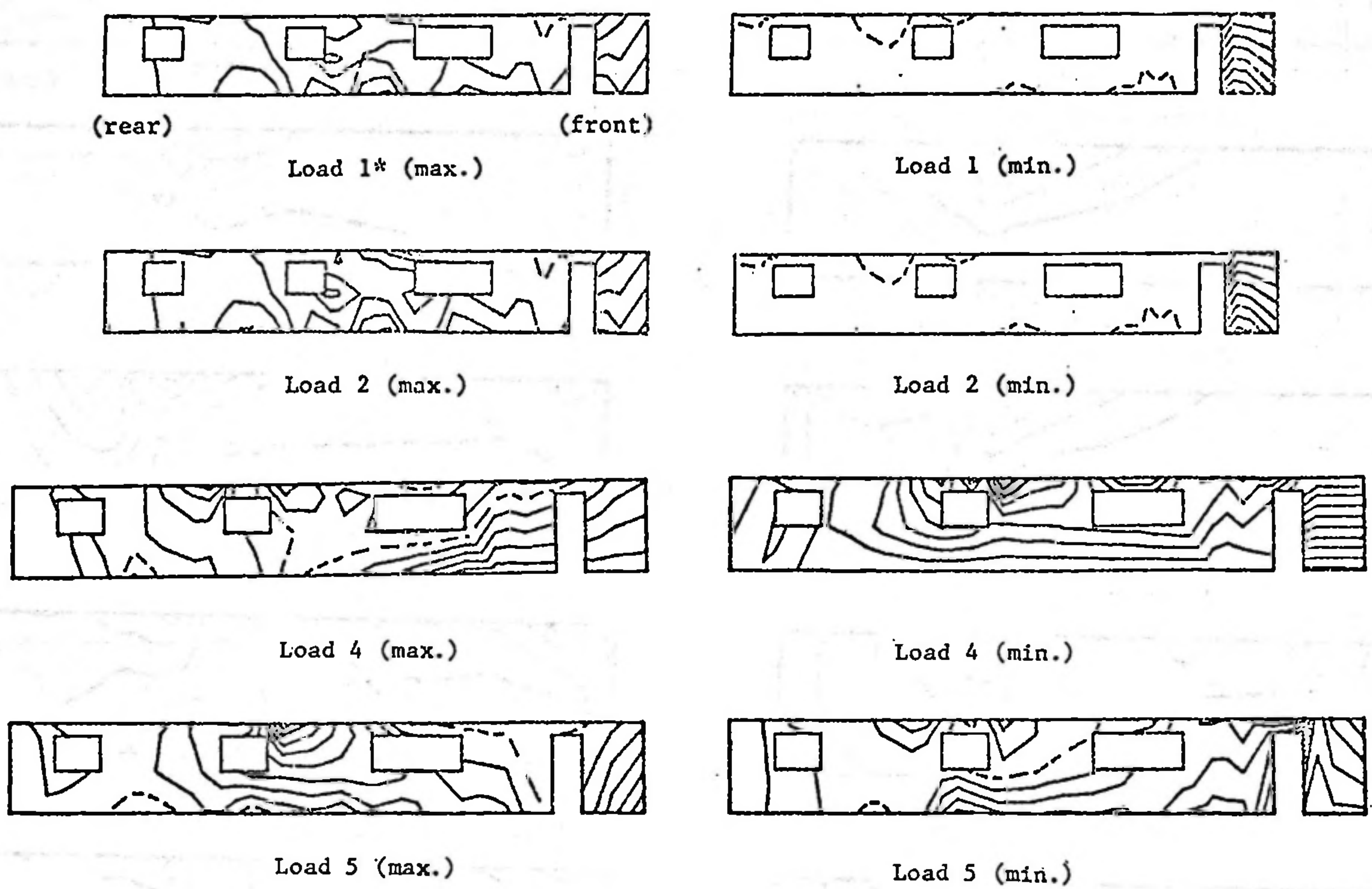
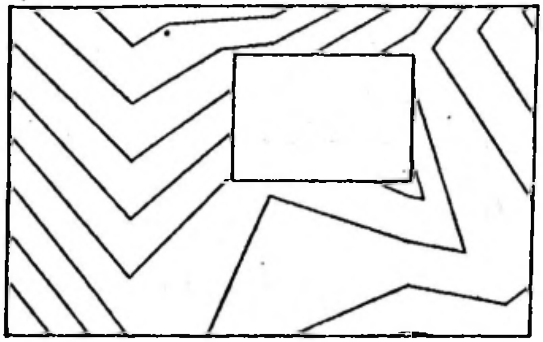
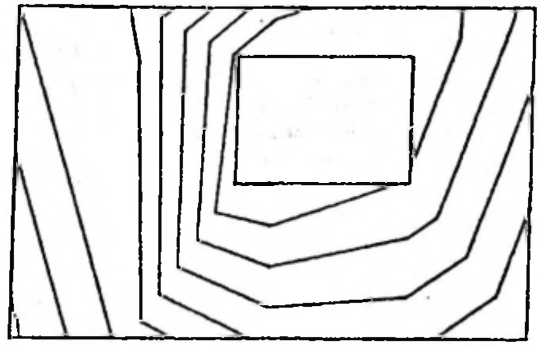


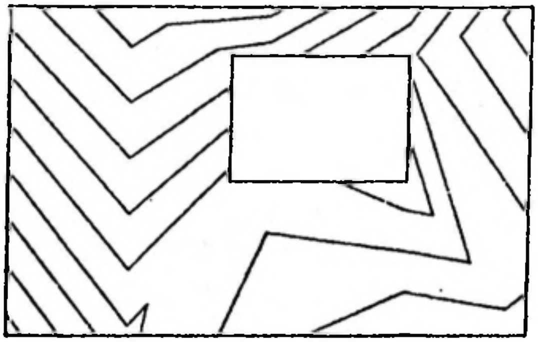
FIGURE 20. COMPARISON OF T-2A STRESS PLOTS - LEFT SIDE



Load 1* (max.)



Load 1 (min.)



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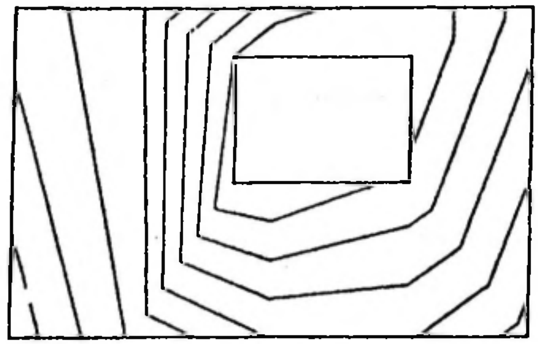
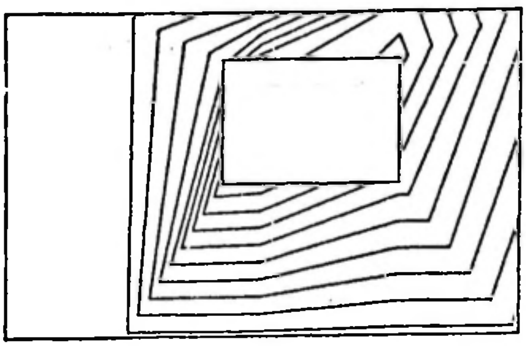
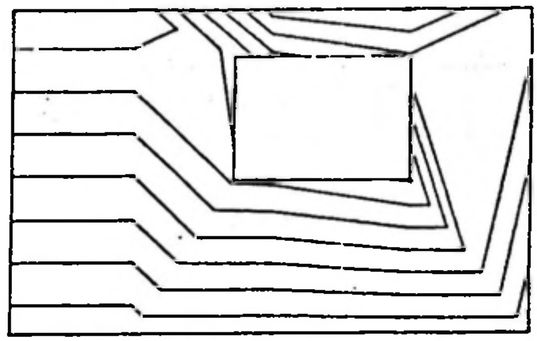


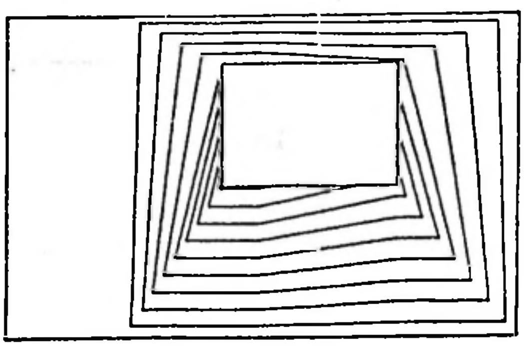
Load 2 (min.)



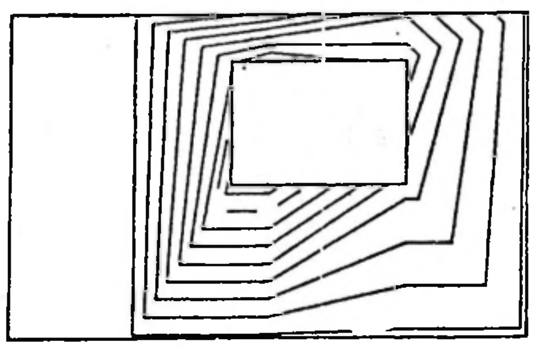
Load 4 (max.)



Load 4 (min.)



Load 5 (max.)



Load 5 (min.)

FIGURE 21. COMPARISON OF T-2A STRESS PLOTS - FRONT END

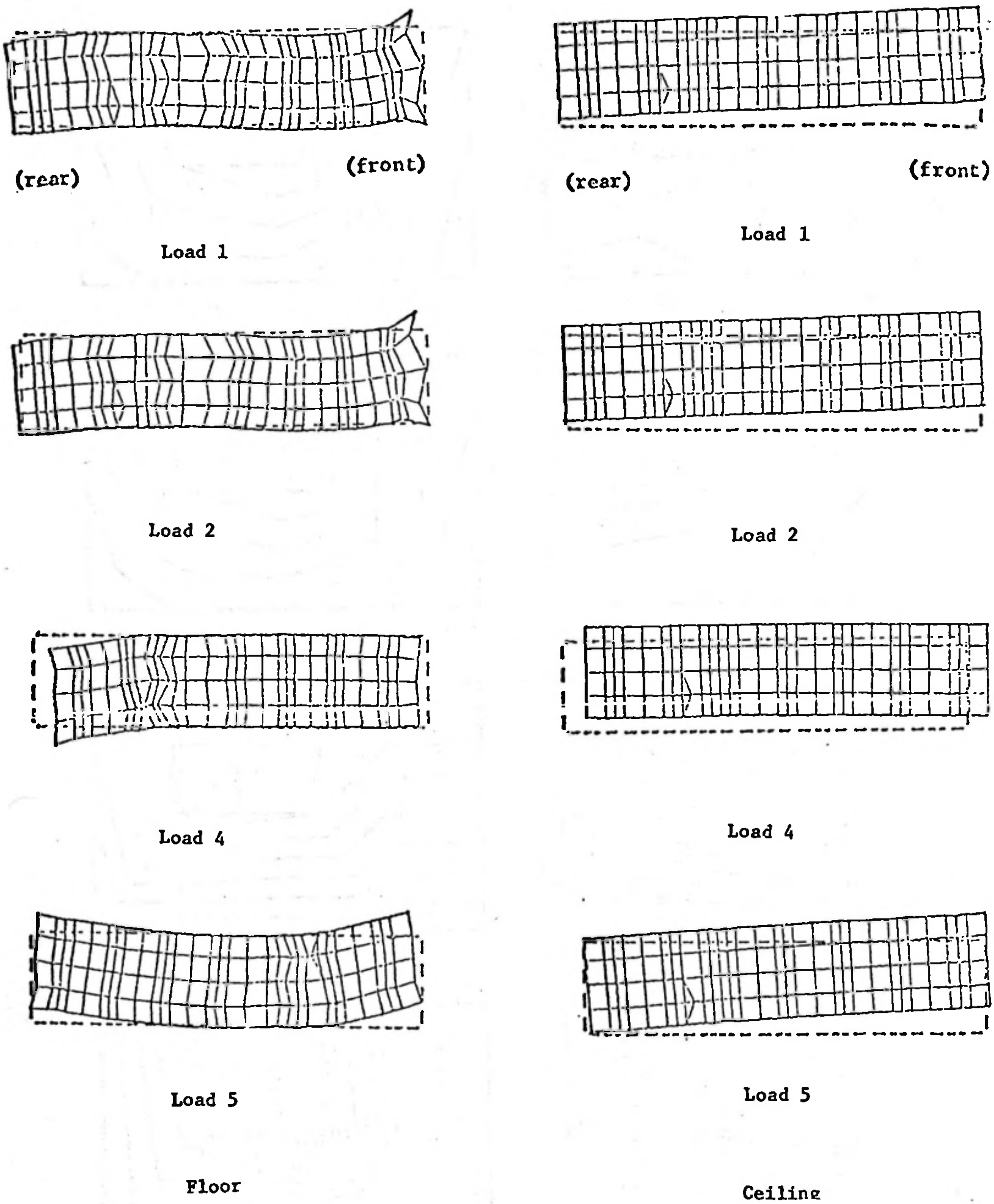


FIGURE 22. COMPARISON OF T-2A DISPLACEMENT PLOTS - FLOOR AND CEILING

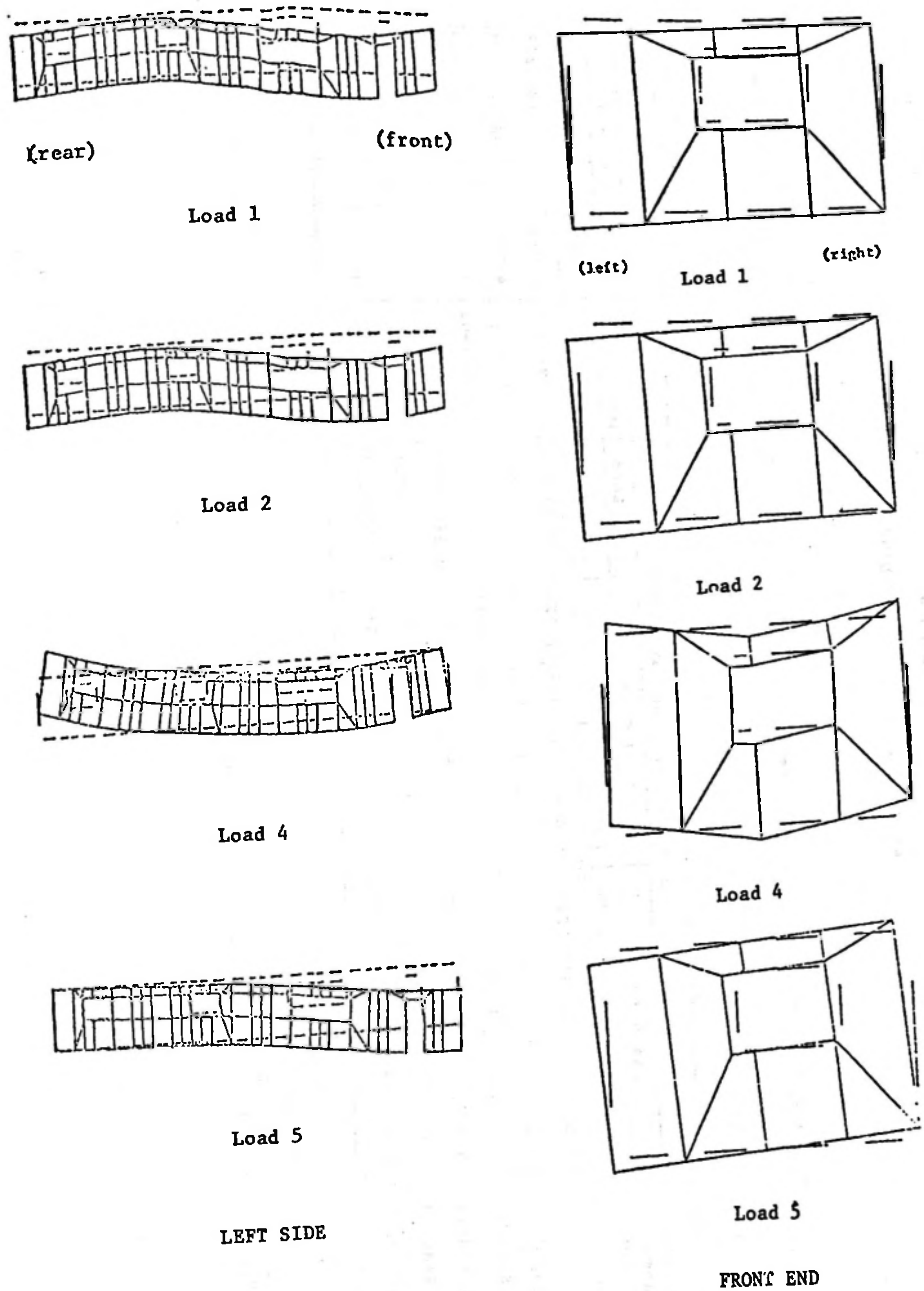


FIGURE 23. COMPARISON OF T-2A DISPLACEMENT PLOTS - LEFT SIDE AND FRONT END

TABLE 6

SUMMARY OF T-2A MAXIMUM DISPLACEMENTS

Mobile Home Component	Maximum Deflection (In.)/Node Location†							
	Load Case 1*		Load Case 2		Load Case 4		Load Case 5	
	Lateral **	Vertical**	Lateral	Vertical	Lateral	Vertical	Lateral	Vertical
Floor	0.005/1256	-0.587/1226	-0.006/1256	-0.661/1226	-0.0162/1101	1.472/1101	-0.0710/110[illegible]	-5.10/1256
Ceiling	0.198/1679	-0.585/1658	0.281/1679	-0.661/1658	0.264/1578	-551/1683	4.93/1679	-8760/1683
Left Sidewall	0.188/1509	-0.587/1492	0.270/1509	-0.661/1492	0.248/1440	0.834/1402	2.37/1440	-5.10/1509
Right Sidewall	0.198/1356	-0.241/1343	0.281/1356	-0.218/1341	0.264/1322	1.472/1301	2.51/1322	3.94/1355
Rear Sidewall	0.057/1710	-0.304/1709	0.089/1710	-0.351/1709	0.247/1702	1.472/1701	0.505/1710	2.33/1702
Front Sidewall	0.198/1752	-0.343/1766	0.281/1752	-0.412/1766	-0.00862/176[illegible]	0.0195/175[illegible]	6.02/1766	-5.10/1765

*For load descriptions, See Table 4.
†For node point locations, see Figure 13
**For displacement directional sense, see Figure 17(a)

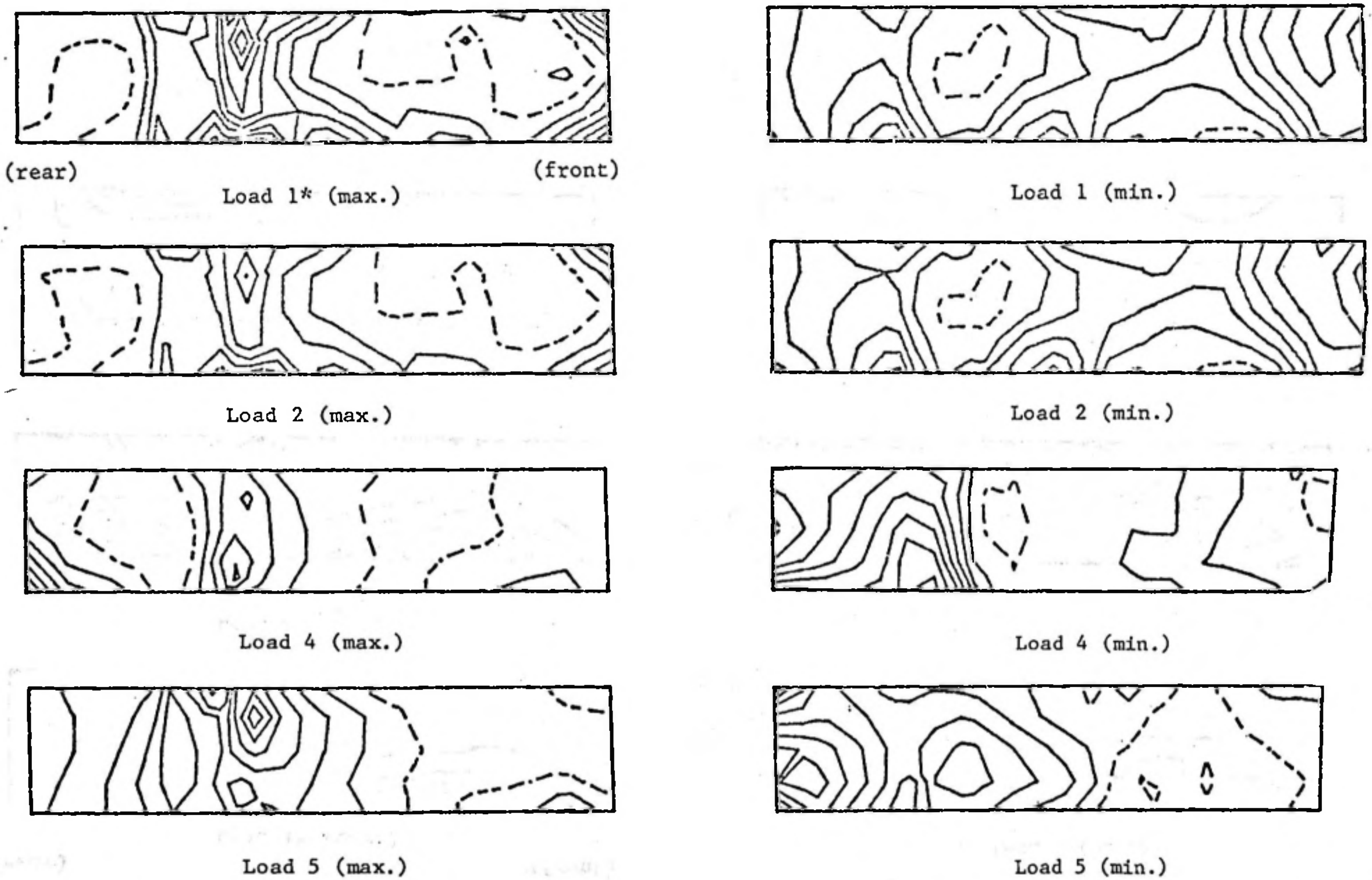


FIGURE 24. COMPARISON OF T-2B STRESS PLOTS - FLOOR

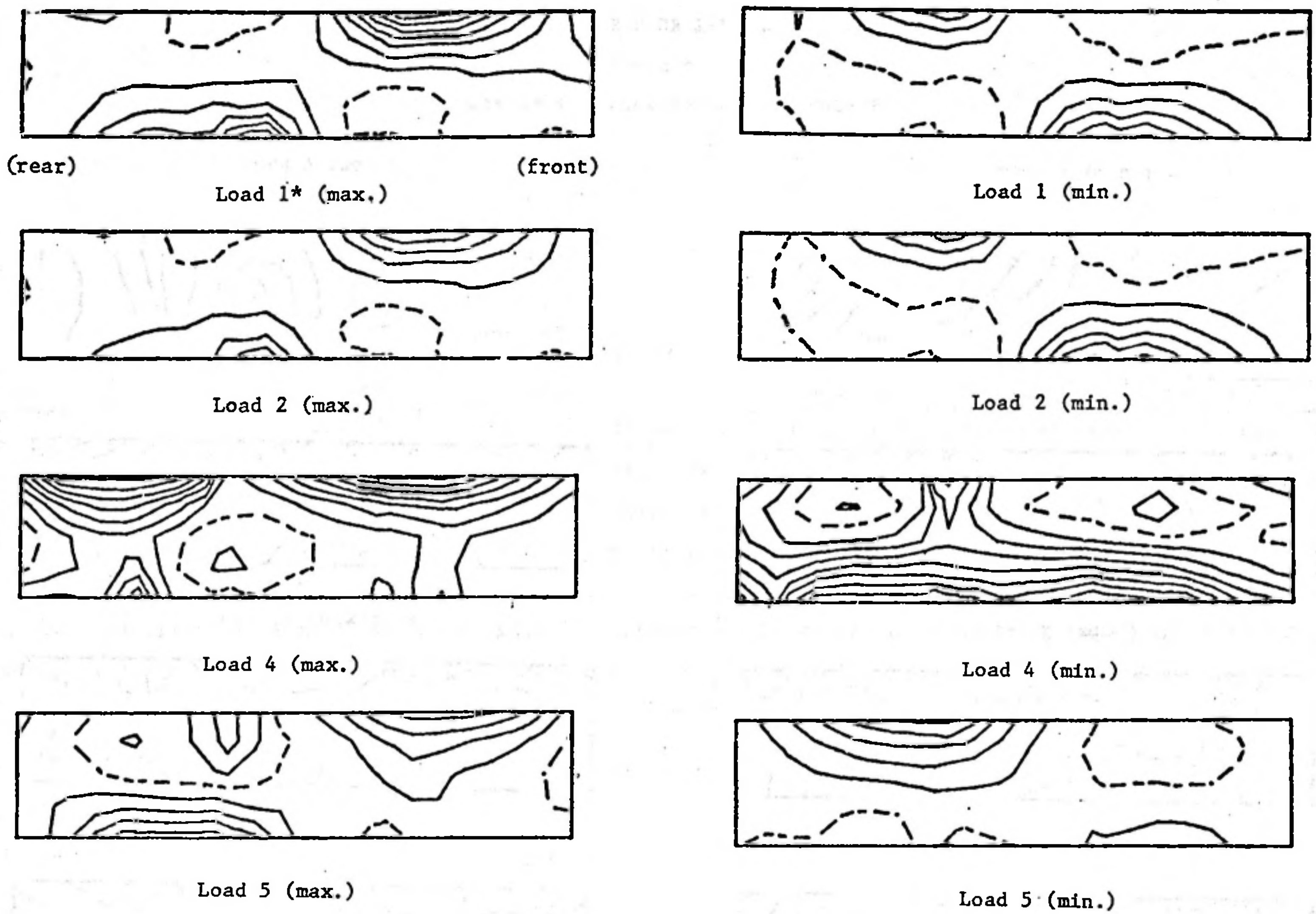


FIGURE 25. COMPARISON OF T-2B STRESS PLOTS - CEILING

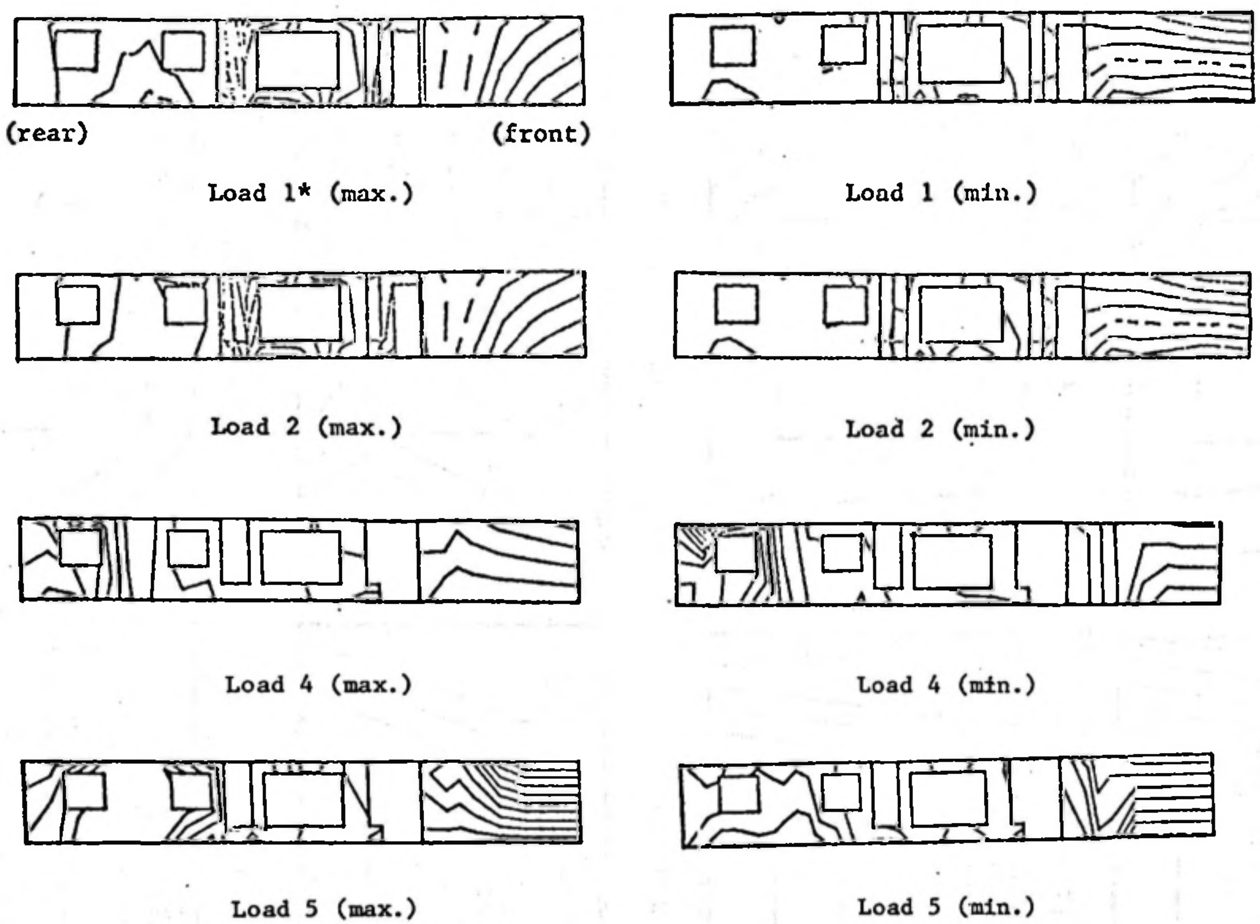


FIGURE 26. COMPARISON OF T-2B STRESS PLOTS - RIGHT SIDE

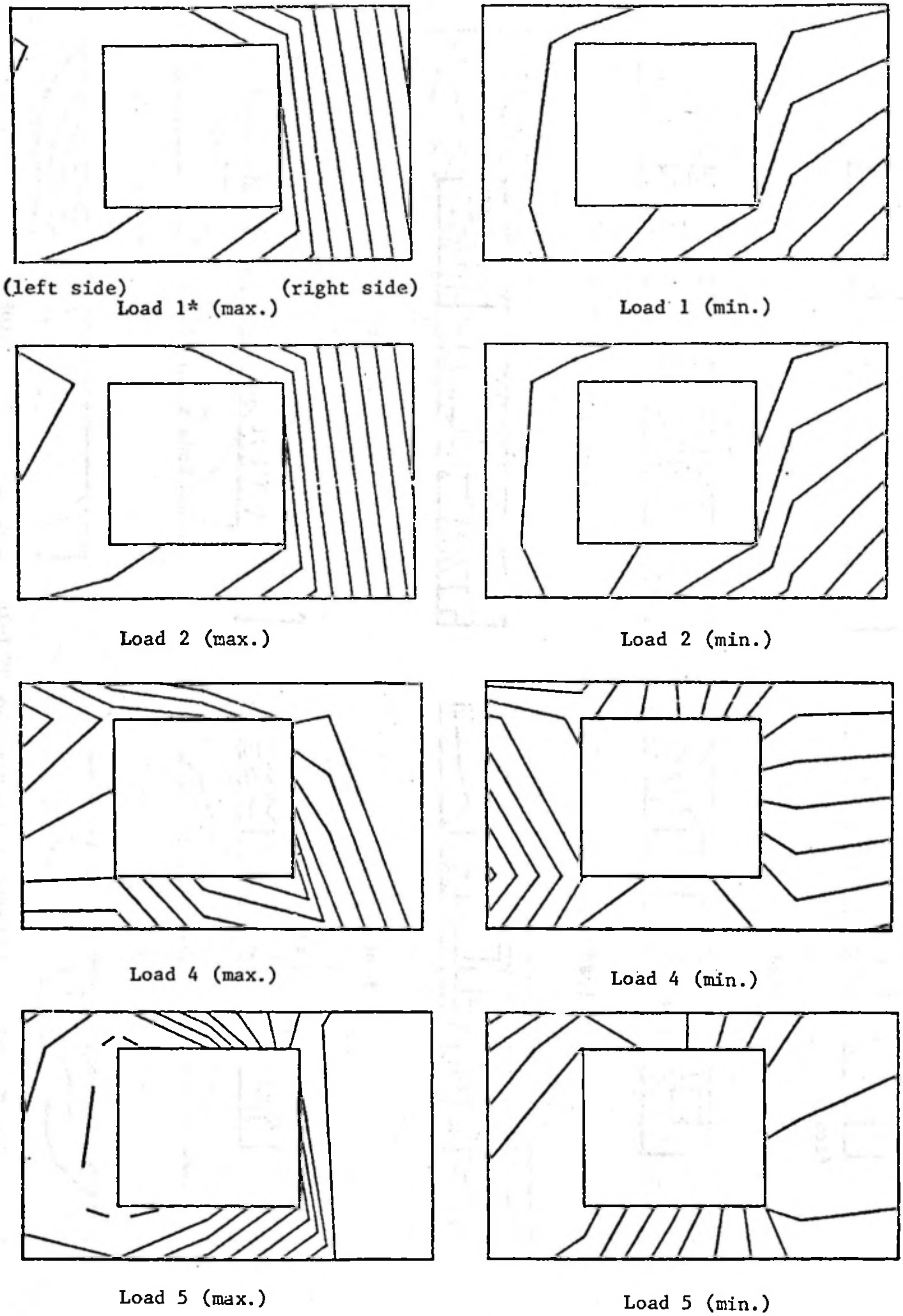


FIGURE 27. COMPARISON OF T-2B STRESS PLOTS - FRONT END

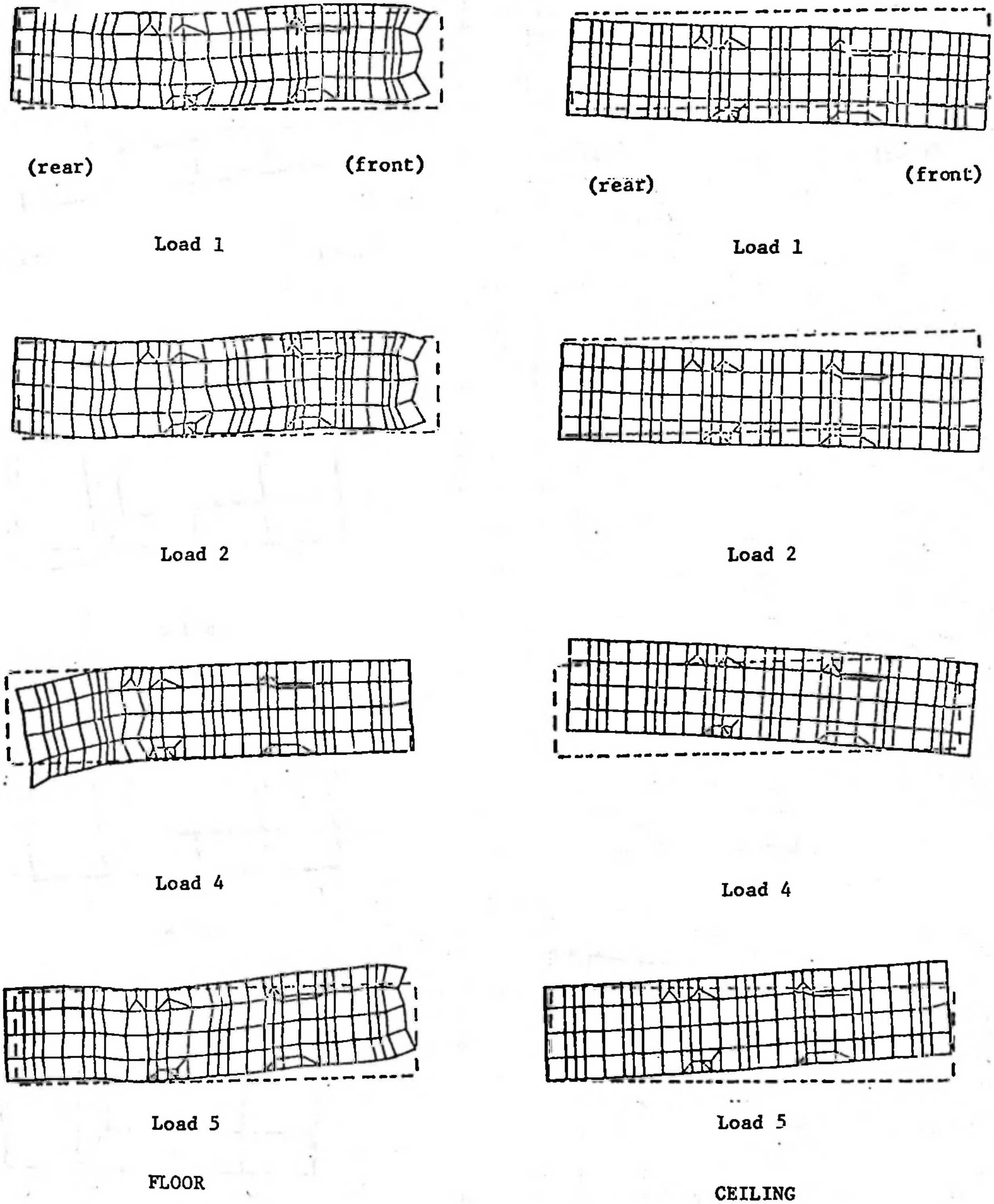


FIGURE 28. COMPARISON OF T-2B DISPLACEMENT PLOTS - FLOOR AND CEILING

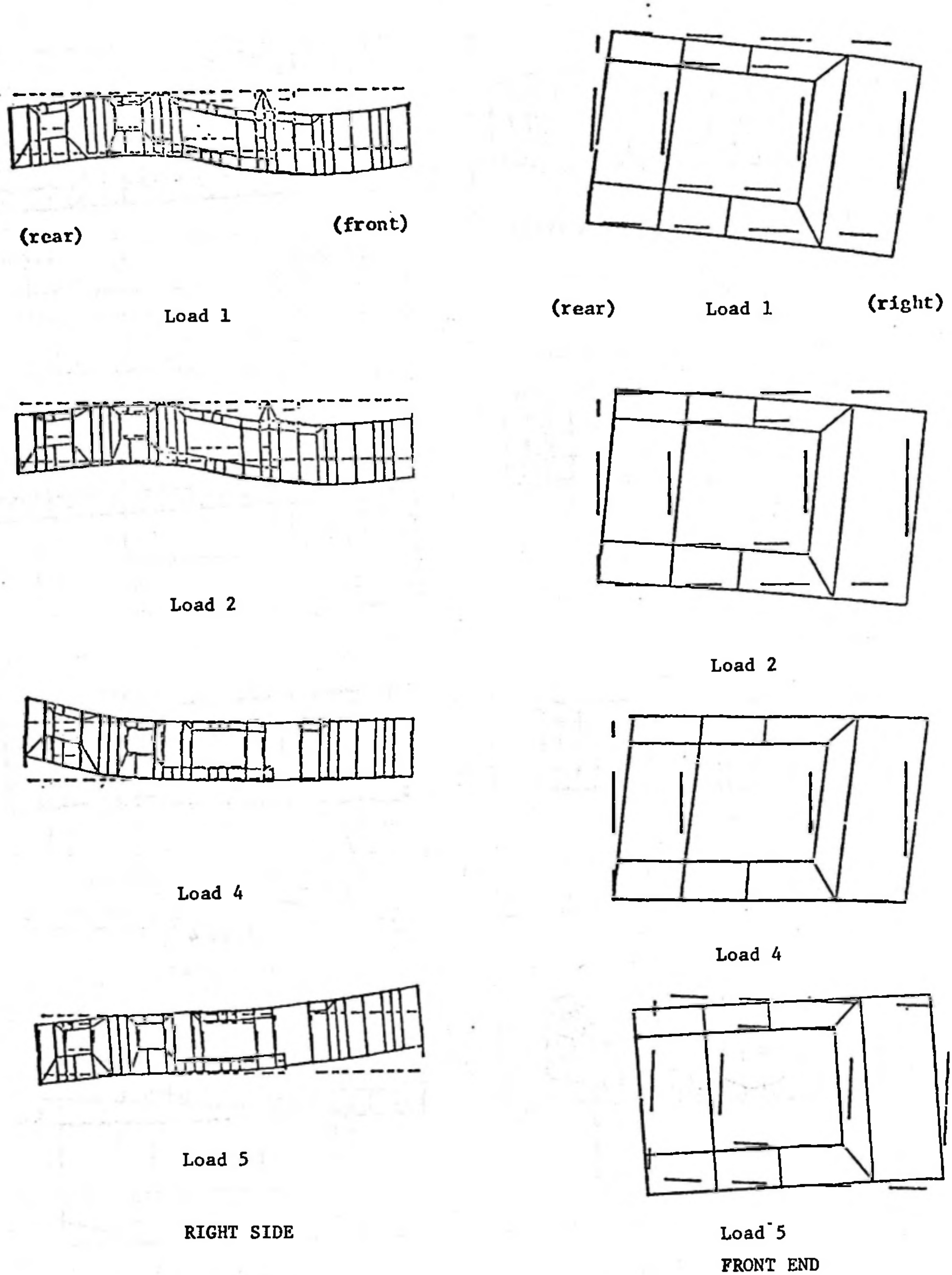


FIGURE 29. T-2B DISPLACEMENT PLOTS -- RIGHT SIDE AND FRONT END

TABLE 7

SUMMARY OF T-2B MAXIMUM DISPLACEMENTS

Mobile Home Component	Maximum Deflection (In.)/Node Location†							
	Load Case 1*		Load Case 2		Load Case 4		Load Case 5	
	Lateral**	Vertical**	Lateral	Vertical	Lateral	Vertical	Lateral	Vertical
Floor	0.005/257	-0.600/221	0.004/257	-0.742/221	-0.0196/101	1.31/101	0.0319/257	-2.75/261
Ceiling	-0.256/654	-0.586/609	-0.458/654	-0.742/613	0.396/500	1.305/500	3.354/650	-2.75/654
Left Sidewall	-0.091/409	0.182/400	-0.127/409	-0.167/400	0.389/401	0.385/401	0.389/409	-0.793/400
Right Sidewall	-0.251/395	-0.600/381	-0.452/395	-0742/381	0.396/301	1.306/300	3.354/395	1.996/394
Rear Sidewall	-0.058/702	-0.337/701	-0.071/703	-0.351/701	0.396/702	1.306/701	0.00583/710	-0.793/709
Front Sidewall	-0.256/768	-0.391/752	-0.458/768	-0548/752	-0.118/764	-0.0130/752	3.35/752	-2.75/768

*For load descriptions, see Table 4
†For node point locations, see Figure 15.
**For displacement directional sense, see Figure 17 (b).

Most importantly, the FEM analysis identified the weakness in the torsional rigidity of the T-2 double-wide units. The "twisting effect" occurring in the T-2A and B because of the imbalance in the structural cross-section, was easily recognized in the finite element analysis (Figures 22 and 23) and by visual inspection of the units.

T-3 and T-4 showed structural damage in the same areas, although it was more extensive.

VIII. CONCLUSIONS

It has been shown how the finite element analysis developed in this program can be correlated with actual conditions that develop over the life of a mobile home structure. In general, the correlations have shown the finite element analysis to be a useful tool in analyzing the structural integrity of the mobile home. Much of the correlation developed in this volume is general in nature. More specific information, as contained in the exploded isometrics of Task I, is available in the computer output data on file at Southwest Research Institute.

There were, however, certain structural deficiencies in the mobile homes with which the finite element analysis was unable to correspond. For example, an assumption of the finite element model throughout all load cases was that the condition of the joints was the same throughout the unit's life; the only condition that changed was the equivalent static loads which are a function of the dynamic analysis at some point in the life of the unit. Based on actual field data and results of the dynamic analysis, this was not the case. The structural capacity of the joints definitely decreased with the life of the unit. This was indicated by the deflections which increased with age and cycles.

Other phenomena, such as local buckling of the exterior paneling, were not available in the finite element analysis. Since the exterior siding was not considered a structural material in the vendor calculations, it was omitted from the finite element analysis. In addition, developments inherent to many mobile homes, such as "room rumble" were not predictable in the finite element analysis. Their occurrence was related more to quality control than to the structural integrity of the unit.

Despite the latter limitations, the finite element analysis is a workable tool for determining the overall strength characteristics of the mobile home as a complete structure. It is a method for analyzing the entire structure of a unit under a variety of conditions without ever actually constructing it. Moreover, this "predictive analysis" method is flexible. Variations in design, such as removal or addition of doors, walkways, partitions or windows, can be accomplished easily with a few changes in the input data. Although correlations with field data are not always as exact or complete as desired, with careful judgement, significant data can be extracted from minimal and/or worst case conditions. It is generally concluded that the stress contour and displacement plots give accurate geographic information even when the associated values of stress and force are questioned. Knowing where deflections and stress concentrations are greatest is extremely useful to the designer enabling him to strengthen those areas of need. An example of component analysis which might be used by a designer is included in Appendix A to Task I, Volume III.

APPENDIX

INTERPRETATION OF STRESS PLOTS

INTERPRETATION OF STRESS PLOTS

One of the output options with the ANSYS finite element analysis program is the plotting of shell and plate stresses. These are the maximum and minimum in-plane stresses calculated by ANSYS for each element of the model. Given information specifying a particular shell or surface of the model, the routine plots the surface and its isostress lines which are contour lines connecting points within the geometric profile having equal stress values. Stress plots are similar to topographic maps; they indicate lines of constant stress rather than constant elevation.

Along with other information in the element summaries produced by ANSYS, the calculated maximum and minimum stresses are tabulated. Similarly, both maximum and minimum stresses can be plotted as they are in this volume. A maximum stress plot presents lines connecting the maximum stresses of all the elements of the desired surface. These lines may be either tensile or compressive stresses since the maximum stress of an element completely in compression would be a compressive stress. Similarly, a minimum stress plot indicates lines of constant stresses which are the minimums of the elements shown and could be tensile as well as compressive. In both cases, dashed stress lines indicate the boundary of tensile and compressive stresses, that is, the line of zero stress. Although in this volume the signs of the stresses are not indicated, they can be determined by comparing the plots of maximum and minimum stresses. Lines parallel in both plots are of the same sign; perpendicular, of opposite sign.

The stress contours, or lines, of the plots are drawn at equal intervals of stress such that each line indicates an increase or decrease of, for example, 100 psi over its neighbor. Where isostress lines are spaced widely, stresses change gradually, similar to how a rolling plain is indicated on a topographic map. As stress lines become more crowded stress concentrations, akin to cliffs topographically, occur. The concentrations may be of compressive or tensile stresses.

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