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DYNAMIC LATERAL LOADS ON MARK II MAIN VENT DOWNCOMER-CORRELATION OF INDEPENDENT REFERENCE DATA

J. E. Borhaug - Pretech

Reviewed by: R. J. Muzzy, Manager
Mark II Containment Design

Approved by: P. W. Ianni, Manager
Containment Design

Approved by: J. Jacobson, Manager
Reactor and Containment Design

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NUCLEAR POWER SYSTEMS DIVISION • GENERAL ELECTRIC COMPANY
SAN JOSE, CALIFORNIA 95125

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NOMENCLATURE

Symbol	
A	Lateral Load Amplitude (lb_f)
c	Constant, exponent in nonlinear damping term
E	Modulus of elasticity ($lb_f/in.^2$)
F_j	Force vector (lb_f)
f	Instantaneous value of forcing function (lb_f/ft)
f_n	Natural frequencies (Hz)
G	Modulus of elasticity in shear ($lb_f/in.^2$)
g	Constant, local gravitational acceleration
I	Moment of inertia ($in.^4$)
k'	Cross-sectional shape factor (value: 1.25)
k_B	Equivalent torsional spring constant for bracing joint flexibility (lb_f-ft/rad)
k_s	Equivalent torsional spring constant for floor flexibility (lb_f-ft/rad)
l	Reference lengths along spatial coordinate x (ft)
l_S	Distance to lateral support
$l_{PS,t}$	Distance to instantaneous pool surface
$l_{FB,t}$	Distance to instantaneous tube liquid level
l_D	Total downcomer length
S	Cross-sectional area of structural member ($in.^2$)
t	Dimensional time (sec)
u	Continuous variables transverse displacement of the structure (ft)
w(t)	Lateral distributed chugging load (lb_f/ft)
x	Continuous variable, spatial coordinate (ft)

NOMENCLATURE (Continued)

Symbol (Continued)

γ	Specific weight of material ($lb_m/in.^3$)
ζ	Coefficient of structural damping (lb_f/ft^2)
ξ	Coefficient of viscous damping [$(lb_f\text{-}sec/ft^2)^{1/c}$]
τ	Period of forcing functions
ω	Circular frequency (rad/sec)
ω_n	Natural circular frequency of structure (n = 1,2,3 ...)

Subscripts

i,j,k	Refer to the discrete variables in the x_1 direction
n	Refers to the discrete variables in the time domain

ABSTRACT

This report presents an independent verification of the dynamic lateral load function as generated from the 4T data base. The correlation and comparison with results from independent tests show specifically the extent which maximum dynamic loads predicted by 4T tests bound other full scale test results within a range of parameters common to both the experiments and Mark II operating plant conditions. This work explains the test results and procedures used, and in particular presents the previously uncorrelated data bases in consistent formats and units.

1. INTRODUCTION AND SCOPE

The initial test program started in 1975 at the General Electric Nuclear Energy Division, San Jose site studied the Mark II containment suppression pool loading during a postulated Loss-of-Coolant Accident (LOCA). The tests were performed in the Temporary Tall Test Tank (4T) Facility and simulated the dynamics of a Mark II single cell downcomer vent during the steam low mass flux regime of the depressurization cycle. The test results were presented in three previous reports (see References 1, 2, and 3). Reference 3 contains discussion and reanalysis of data gathered from the 1975 4T test program and addresses the lateral forces on the downcomer caused by chugging which occurs during the low mass flux regime. In this regime, rapidly collapsing steam bubbles exert lateral forces onto the downcomer exit and associated containment structure which ultimately must be designed to withstand these loads as experienced during a postulated LOCA event.

The specific task of defining the mathematical form and maximum bounding parameters of the dynamic transient lateral load forcing function based on the 4T test results is addressed in Reference 3. The following mathematical form in the time domain (t) was found to apply:

$$F(t) = A \sin \frac{\pi}{\tau} t \qquad \text{for} \qquad o < t < \tau$$

where (τ) and (A) are the half period of a full sine wave and its maximum amplitude, respectively.

The parametric bounding values for (τ) and (A) were as follows: (τ) increases linearly from 3 to 6 ms with maximum chug load amplitude (A) linearly decreasing from 30,000 lb_f to 10,000 lb_f.

Because of the complexity of the fluid-structure interaction in the system, a mathematical correlation model describing the transient response of the downcomer system was formulated and programmed for digital computation. This model was specifically used to correlate test results and formulate the mathematical expressions for the forcing function shown above. It reproduced the entire response range measured in the 4T test facility with acceptable accuracy.

The 4T data investigated in References 1, 2 and 3 represents the principal dynamic data base simulating Mark II main vent downcomer response to lateral loads during chugging. Full scale and single cell tests have also been performed by other investigators to develop dynamic load criteria as required. Specifically, tests performed under Mark II license agreements have been made and reported which provide independent data bases for lateral load determination and comparison with the 4T results. To this effect, two General Electric employed tests of relevance to the range of operational and structural parameters simulated by 4T were identified, and thereafter will be referenced as Test 1 and Test 2.

The principal objective of this work was to obtain independent verification of the dynamic load definition generated from the 4T data base. The correlation and comparison with experimental results from Reference Tests 1 and 2 show specifically to what extent the maximum dynamic loads predicted by 4T test bound other full scale test results within the range of parameters common to the experiments and to Mark II operating conditions. This report explains the results and procedures used and presents the previously uncorrelated data bases in consistent formats and units.

2. SUMMARY AND RECOMMENDATIONS

The purpose of this investigation was to verify the 4T dynamic lateral load function through system simulation and comparison with chugging response data from independent tests. The two independent data bases selected for comparison included data from large tank, small tank, steady state mass flux tests, and transient blowdown tests. Statistical and bounding value evaluations of all data were performed for the complete range of pool temperature and mass fluxes covered by the 4T tests and postulated Mark II LOCA conditions.

The dynamic transient forcing function defined by the original 4T correlation work had the following mathematical form in the time domain (t):

$$F(t) = A \sin \frac{\pi t}{\tau} \qquad \text{for} \quad o < t < \tau$$

for which A and τ are defined on page 1-1.

Based on the present investigation and inclusion of independent data bases, the proposed mathematical form and bounding parameters are concluded as being well supported by results obtained in separate test facilities.

The following are summaries, primary observations and conclusions:

a. The independent data base confirms the maximum lateral load amplitudes predicted by the 4T tests to within 16 and 4 percent of the single bounding values in Reference Data 1 and 2, respectively (see Subsections 5.3 and 6.3).

b. The discrepancy observed in Reference Test 1 is considered a good correlation with 4T test data considering the detail of data available in Reference Test 1.

c. The 4 percent difference in Reference Data 2 is considered insignificant in terms of experimental accuracy.

d. The minimum load function period observed during any of these tests was 3 msec which corresponds closely to load periods observed in the 4T tests (see Section 3).

e. The maximum load function period observed was 5.5 msec for low intensity chugs which is close to 4T data, which show periods of 6 msec for 10,000 lb_f amplitude events (see Subsection 6.3).

f. The nearly inverse linear functional dependency between load amplitude and period observed in the 4T data was confirmed by both sets of Reference Data (see Section 3).

g. Statistical distributions of both load amplitude and load period for all three data bases show similar stochastic properties and trends. Generally, the probability of exciting a low amplitude dominates the distribution function, and the probability of a high amplitude chug (bounding value) was extremely low (see Subsections 5.4 and 5.6).

h. Mean values of lateral load amplitude for Reference Data 1 and 2 are significantly lower than observed in corresponding 4T data. The following numerical comparison encompasses the full range of experimental parameters tested.

Test	Mean Value of Lateral Load, lb_f
4T	3900
Reference 1	2146
Reference 2	885

i. As with 4T the reference facility structures respond in predominantly higher order modes to the transient chugging loads.

j. Due to the existence of a compliant wall section in Reference Facility 1 the transient wall motion had to be included in order to properly model the response in this facility (see Subsection 5.3).

k. No significant temperature stratification was found to be present during any of the Reference 2 tests. Possible stratification in Reference Test 1 could not be verified due to lack of data (see Subsection 3).

l. A lower threshold for development of significant chugs was found to be 0.3 lbm/ft^2-second (see Subsection 3).

m. It is recommended that Reference Data 1 not be considered for load determination since dynamic test records are not available to the extent originally represented.

On the basis of the present comparison of experimental lateral load data and associated analytical simulation of the subject test facilities, it is concluded that the proposed 4T lateral load forcing function may be used as the bounding load for dynamic analysis of main vent downcomers as outlined in Reference 3.

3. DISCUSSION

Verification of an earlier definition (see Reference 3) of the dynamic lateral load function is based on a detailed investigation of data obtained from two independent reference tests. The overall experimental conditions governing these tests differ from those during the 4T test but simulate satisfactorily conditions of vent flow transients in the low mass flux regime.

The present comparison data base consists of a total of 2610 individual chugs with 250 chugs from Reference Test 1 and 2360 chugs from Reference Test 2. All chugs and associated brace strains were investigated statistically, and approximately 15 percent of the highest resultant strain values were selected for evaluation and comparison with analytically predicted strain time histories from the Dynamic Simulation Program (see Reference 3).

Due to the different experimental conditions prevailing during Reference Tests 1 and 2 as compared to 4T, emphasis was placed on presenting and comparing the data on mutually consistent bases with respect to mass flux, pool temperature, submergence and blowdown conditions. Generally, excellent similarity existed between 4T and Reference Test 2 and required only minor normalization* of temperature and mass flux.

Parametric normalization between 4T and Reference Test 1 was considerably more complex and required certain approximations with regard to pool versus bulk temperature and blowdown conditions due to steady state mass flux and lack of temperature stratification records. This problem was handled by segmenting the statistical data from Reference Test 1 into sets of finite temperature and mass flux records. Parametric combinations of the strain data could then be made for constant mass flux or temperature as required. For further details refer to Sections 5 and 6.

*Normalization refers to the process of comparing 4T and reference data under similar test conditions with regard to initial pool temperature, initial mass flux, and instantaneous reference temperature at the time of comparison of the individual chugs.

Figure 3-1 presents the absolute maximum lateral load vectors measured in any of the three tests investigated to date. The data are shown in graphic form as the maximum amplitude of the lateral load at the vent exit with the following numerical values:

Data Base	Load Amplitude	Load Period
4T		
Reference 1		
Reference 2		

The lower value lateral load amplitudes shown in Figure 3-1 are from 4T and Reference Data 2, and demonstrate the increase in load period associated with a decrease in chug amplitude. This was observed in 4T and supported by Reference Data 2. Records from Reference Data 1 were not available to show sufficient evidence of this trend.

Time history temperature records from Reference Data 2 were investigated to evaluate possible effects of thermal stratification in the pool on the data base comparisons. In typical submergence to tank-depth ratios of 0.5 or more, the local temperature at vent exit is very close to average bulk temperatures for the low mass flux flow regime. This is not true for very shallow submergences where the data show that substantial stratification is present below the vent exit and bulk versus vent exit temperature must be normalized for comparison. In summary, as no significant thermal stratification was observed no reference temperature adjustment was required.

Tape records of Reference Data 2 were reviewed to determine the lower limit for significant chugging to occur. The definition of a significant chug was taken as one with brace load amplitude more than 1000 lb_f, and a lower limit of 0.3 $lbm/ft^2/sec$ was established as the minimum flux. Theoretically this limit can also be found from a thermodynamic evaluation when the internal pipewall condensation rate equals the steam flow so that no flux is available to generate an exit bubble.

Statistical summaries in all data reviewed are shown in Figures 3-2 through 3-5. Figures 3-2 and 3-3 represent Reference Data 1, and Figures 3-4 and 3-5 represent Reference Data 2.

In maintaining compatibility with the original 4T data base the statistical presentations show component values of the individual brace loads for each chug. Bounding load correlations were made using the maximum experimental load vector as noted in summary figures.

The cumulative distributions and histograms cover all test conditions in both experiments and as such define the bounding load statistics for the entire correlation effort. The results have been compared with those of 4T and the latter tests bound the entire set of data with the exception of the extremely rare maxima discussed above.

The following Figures are GENERAL ELECTRIC COMPANY PROPRIETARY and have been removed from this document in their entirety.

4. GENERAL CORRELATION BASIS

4.1 DESCRIPTION OF MATHEMATICAL MODELING TECHNIQUE

The main vent downcomers simulated in the experiments are tubular members ranging in diameters from 12 to 24 inches of varying wall thickness. The uniformly distributed elasticity and mass along with the high length to diameter ratio qualify this member of the structural system for mathematical modeling as a Timoshenko beam of finite length. The governing differential equation describing the lateral vibration of uniform prismatic bars is shown by Timoshenko and others to be:

$$- \zeta\, u(x,t) - \xi \left[\frac{\delta u(x,t)}{\delta t}\right]^{c} - \frac{I\gamma}{g} \frac{\delta^4 u(x,t)}{\delta x^2\, \delta t^2} - \frac{EI\gamma}{gk'G} \frac{\delta^4 u(x,t)}{\delta x^2\, \delta t^2}$$

$$- \frac{\gamma^2 I}{g^2\, k'G} \frac{\delta^4 u(x,t)}{\delta x^4} + EI \frac{\delta^4 u(x,t)}{\delta x^4} + \frac{\gamma S}{g} \frac{\delta^2 u(x,t)}{\delta t^2} + k_B\, u(x,t) = w(x,t). \qquad (4\text{-}1)$$

The symbols appearing in Equation 4-1 are defined in the Nomenclature and identification and interpretation of the physical meaning of each of the terms are treated in detail in Reference 3.

The equation of motion described represents a complete dynamic model capable of simulating the transverse response and reaction forces which occur in a single cell Mark II main vent downcomer system that is subjected to a dynamic lateral load forcing function. All dynamically relevant terms in the mathematical formulation were retained and the solution of the resulting fourth order partial differential equation with its boundary and initial conditions provides a mathematical tool with which experimentally measured data from the real systems (4T, Reference Facilities 1 and 2) may be compared and correlated under the various experimental conditions.

The development of the dynamic model of the main vent downcomer was based on a method of analysis supported by dynamic considerations and includes the effect of the mode of mechanical coupling between the structural components.

In the present work, anal· .s of all three reference structures during chugging loads provided the basis i · the general representation of the single cell structure shown in Figure 4-1 which possesses all the important elements present in each of the test tank configurations investigated. Figure 4-2 shows a structural diagram of the single cell downcomer 4T Facility. Structural diagrams for Reference Facility 1 and 2 are included in Subsections 5.1 and 6.1.

Development of the mathematical simulation for showing the motions of individual elements in the structure is presented in Reference 3, Section 5. Generally, the pertinent coupling and boundary conditions constitute the simulation procedure in terms of defining the system response to typical chugging load conditions. The four major structural members (the downcomer pipe, resilient floor, bracing supports, and bracing sleeves), were modeled for each installation, including the effect of compliant wall response as observed in Reference Facility 1.

4.2 METHOD OF CORRELATION

The objective of this work is to test the validity of the mathematical expression and bounding parameters of the lateral chugging loads predicted by the 4T tests as compared to other existing response data. Because the excitation (tip load) force could not be measured directly in any of the reference facilities, the analytical approach used was to apply the maximum bounding load defined by 4T to the mathematical models of each of the reference facilities investigated. Subsequent direct comparison between analytical response and actual measured response in terms of the measured response variable was then made to determine if the 4T dynamic load function also bounded the reference data under each test parameter investigated.

4.3 DATA REDUCTION AND ANALYSIS PROCEDURE

The dynamic response data recorded during the 4T main vent test program consisted of acceleration and strain time-histories to discrete locations throughout the system. Exact transducer placements for all the tests are documented in Reference 2. The data for this facility consisted entirely of bracing stress measurements as outlined in Sections 5 and 6.

Generally, during each reference test all response data were recorded on magnetic tape and or visicorder monitoring each test run and copies made for laboratory analysis. The test data matrix examined during this investigation covers the full range of 4T and expected Mark II parameters. During this study a total of 2610 individual chugs were investigated and compared with 4T results.

Due to the extremely transient nature of the lateral response data produced during chugging action, the experimental data reduction was accomplished by using two principal methods: 1) Shock Spectrum Analysis, and 2) Time Domain Analysis. Because the second approach provided the most direct mode of comparison between analytical and experimental results it was used as the basic standard for correlation in this work.

Stress-time histories of all major chugs in Reference Test 2 and two maxima in Reference Test 1 were investigated with respect to brace load amplitude and load application period. Specifically, the Dynamic Simulation Program (see Reference 3) was used to simulate bracing reaction and tip acceleration in the given facility as functions of time. The general form of the dynamic forcing function postulated from 4T tests was used to simulate the experimental responses of the two subject tests. Linear scaling was then applied to determine the dynamic lateral load which reproduced the experimentally observed resultant brace stress time histories. All correlation work performed was based on comparison between experimental and analytical bracing loads since tip-motion measurements were not made in Reference Tests 1 and 2.

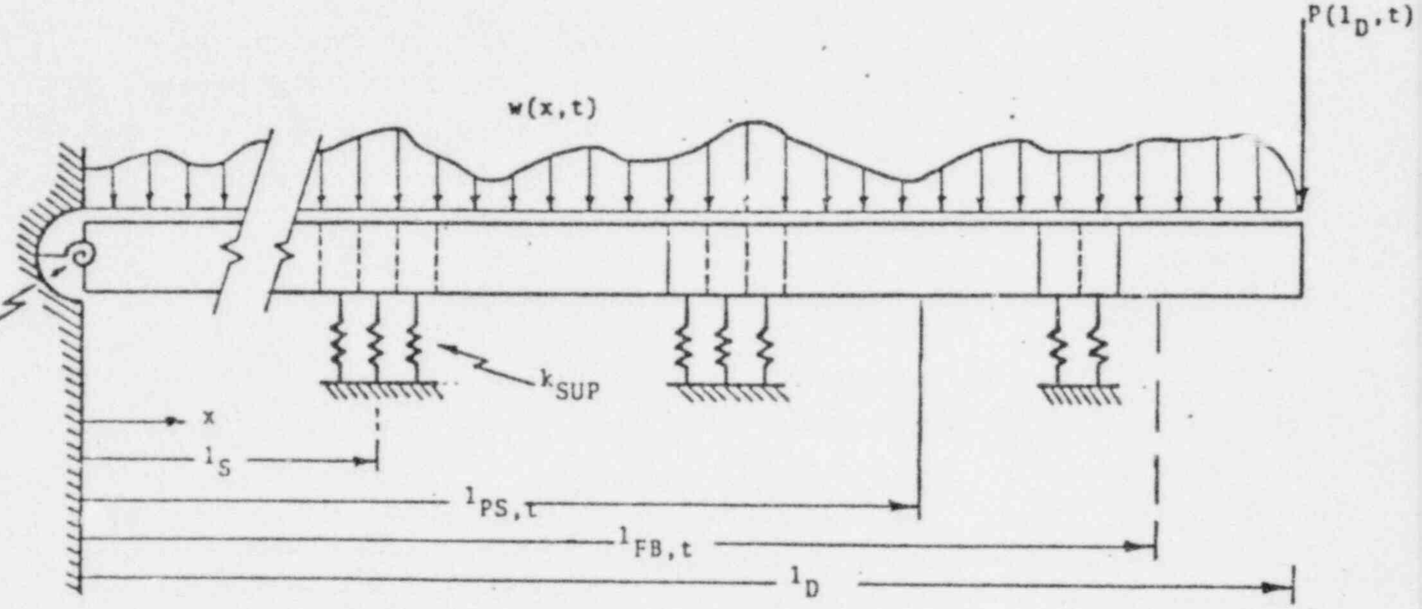


Figure 4-1. Mathematical Model of Single Cell Downcomer

POOR ORIGINAL

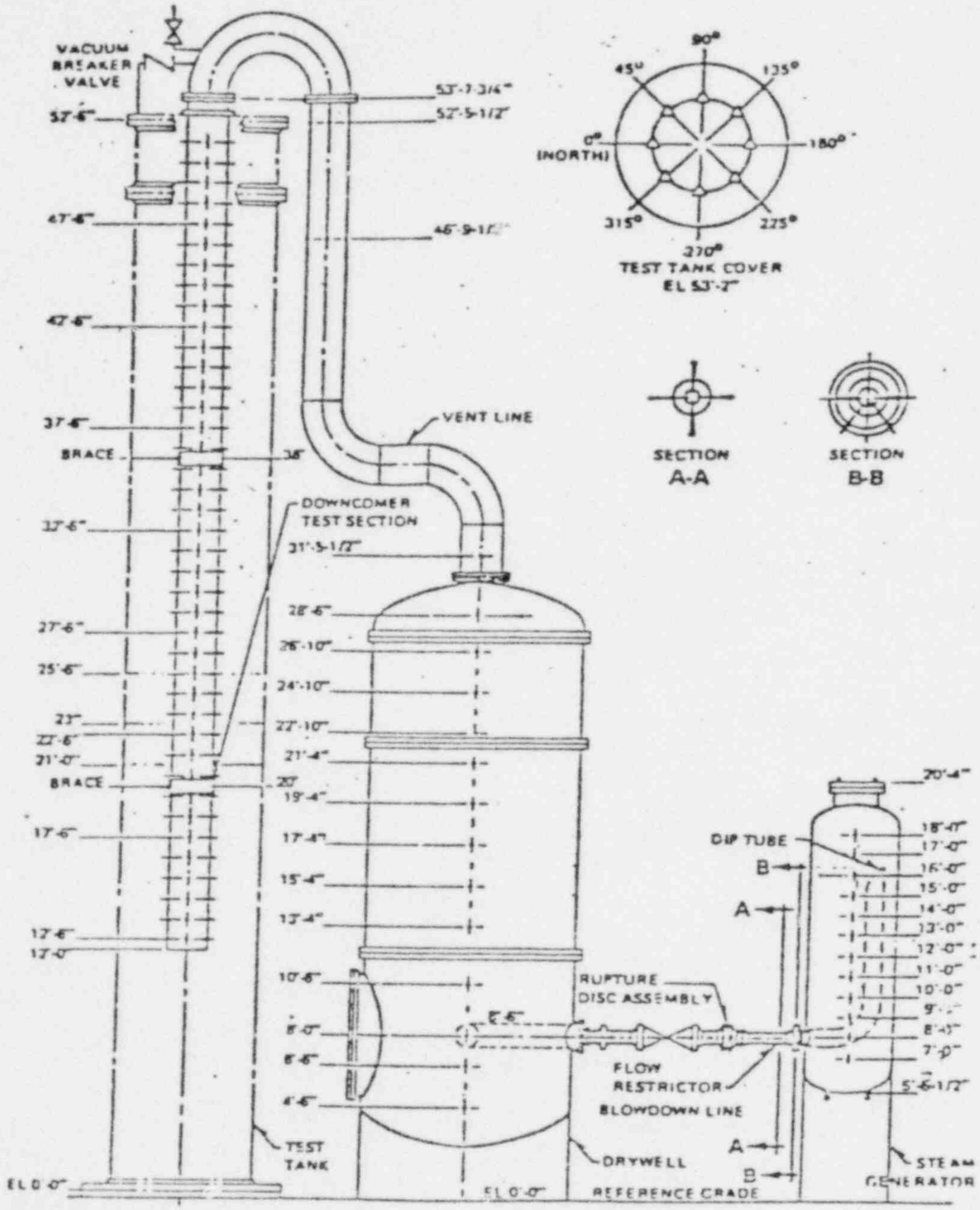


Figure 4-2. 4T Structural Diagram

5. REFERENCE TEST 1

5.1 FACILITY DESCRIPTION

Lateral Load Reference Tests 1 were performed in the large scale vessel (tank) shown in Figures 5-1 and 5-2. The 24-inch (600-mm) vent diameter tests which were compared to 4T data during this investigation consisted of a single vent steam flow response test. The active vent is shown on the right in Figure 5-1, and the applicable test condition consisted of a series of steady state simulated blowdowns with mass fluxes ranging from 1.8 to 6 lbm/ft^2-sec into indicated pool temperatures (TW2) ranging from 86° to 185°F.

The single vent bracing arrangement prevailing during the course of the subject tests is shown in Figure 5-2. Response data in terms of longitudinal stresses in the brace structure was obtained from opposing sets of strain gages for each strut - DMS 1 and 2, and DMS 3 and 4, respectively. Continuous recording of other parameters important to this correlation was also performed and contained specifically the time histories of vent exit temperature, wall pressure and steam mass flux. Reference 5 contains a complete account of the full range of parameters tested. Appendix A contains Reference Data 1.

5.2 DATA FORMAT

The response data assembled during the course of Reference Test 1 consisted of magnetic tape records and strip chart (Visicorder) recordings. All major time varying parameters were tape-recorded while critical response records were also monitored for instantaneous readout using multi-channel strip chart recorders.

The present investigation revealed that the magnetic tape records covering the experimental phases of all the single vent tests within the parametric range of 4T were of poor quality and could not be interrogated with acceptable accuracy. Specifically, almost all strain gage records were lost due to extensive electronic noise which totally masked the data signals for nearly all test runs made.

Although the individual time histories of all chugging strain events were not retraceable, the monitor strip-chart records obtained could be evaluated with respect to strain amplitudes. Approximately 250 individual chugs were tabulated as functions of pool reference temperature and mass flux for statistical evaluation.

5.3 TIME HISTORY CORRELATION

Due to the loss of taped records caused by noise saturation, only a few strain time-history traces were available with sufficient resolution to provide meaningful comparison with the 4T data base and analytical verification through the Dynamic Simulation Program. The records, however, did include the maximum values of strain observed in the subject tests and provided a reasonably accurate account of response period and brace strain amplitude for the 1.8 and 3.2 lbm/ft^2-sec mass flux tests.

5.3.1 Summary

In accordance with the original objective of this work, analytical simulation of the Reference Test 1 facility was made using the Dynamic Simulation Program in a manner analogous to the 4T load determination study outlined in Reference 3. Specifically, all relevant structural members of Reference Facility 1 were described and simulated and the temporal response to an arbitrary lateral load calculated in terms of downcomer tip motion, bending stress and brace reaction stresses. The latter were then scaled to the maximum measured values, thereby determining the lateral load function which would produce the experimentally measured brace loads. Since tip motion measurements were not made during these tests (as they were during 4T tests), all load correlation work used the maximum resultant brace load vector for determining the lateral load.

Due to an observed radial flexure of the tank wall during the chugging tests, a parametric evaluation of effective brace stiffness, wall flexure and effect of lateral load period was performed in order to determine the sensitivity of the dynamic simulation to variations in these parameters. Through this effort, it was shown that the load prediction was sensitive to the transfer function of the particular brace/wall interaction in Reference Facility 1 and modification was made to include the local tank wall transfer function. This had not been required in the 4T structure due to the high wall stiffness and no apparent wall flexure effects at the brace attachment point.

The maximum values of brace load vectors observed in Reference Test 1 under three different mass flux conditions and bulk pool temperatures ranging from 86° to 185°F are summarized in Figure 5-3. These response values are plotted against load function periods calculated from observed response periods measured from the experimental records.

A maximum error of + 0.5 msec has been estimated giving a load period between 3 and 3.5 msec. The lateral load bounding value corresponding to these experimental bracing response maxima are shown in Figure 3-1.

5.3.2 Simulated Responses

Typical graphical outputs from the Dynamic Simulation Program are shown in Figures 5-4 and 5-5. The top two traces of Figure 5-4 show the temporal behavior of the downcomer tip and brace location after the vent was subjected to the simulated 4T defined chug at time zero which produced the lateral acceleration time-history shown. The numbers 88 and 100 refer to the spatial location of the brace and tip of the structure, respectively, and the bottom left-hand numbers refer to the following presentation:

1. Time history of tip acceleration following the simulated chug.

2. Time history of brace attachment point following the simulated chug.

3. Provision for additional bracing (not used).

4. Downcomer mode shape at maximum acceleration.

5. Time history of brace stress at attachment point (88).

6. Provision for additional brace (not used).

As noted, traces 4 and 5 from the top show vent mode shape and brace stress time-history, respectively. The former is the instantaneous acceleration at the time of maximum tip acceleration and the latter is the time-history of the bracing stress as the vent undergoes the transient response to the simulated lateral chugging load.

Figure 5-5 illustrates the displacement mode shape at discrete time intervals. The modal bending is shown on a linear scale and is normalized to the maximum value of transverse displacement at each time frame.

5.4 STATISTICAL CORRELATION

The existence of strip-chart recorded strain data throughout all the subject tests provided excellent bases for performing a statistical evaluation of brace response amplitudes for comparison with the 4T stochastic profiles and data distributions. To this effect, all brace load data points in excess of 1000 lb_f were put into a digital computer programmed to develop histograms and cumulative distribution plots over the ranges of temperature and mass flux compatible with 4T.

5.4.1 Summary

Comparison between 4T and Reference Test 1 statistical data shows very similar amplitude distributions and no significant parametric effects of mass flux and temperature. The pool temperature dependency previously reported for Reference Test 1 does not appear to persist when the latter data is normalized to the 4T test conditions.

Reference Test 1 shows considerably higher maximum brace reaction forces than 4T. The higher experimental bracing stresses are, however, mostly caused by the difference in bracing arrangement in the two facilities and can be accounted for within 16% when the equivalent tip lateral load is calculated. Furthermore, Reference Test 1 has a much higher incidence of low amplitude chugs and shows an average chug value nearly 50 percent lower than 4T.

5.4.2 Data Base

Figures 5-6 through 5-13 contain selected cumulative distributions and histograms for Reference Test 1. Various combinations of test parameters are noted on each histogram that can be compared directly with 4T data (see Reference 3).

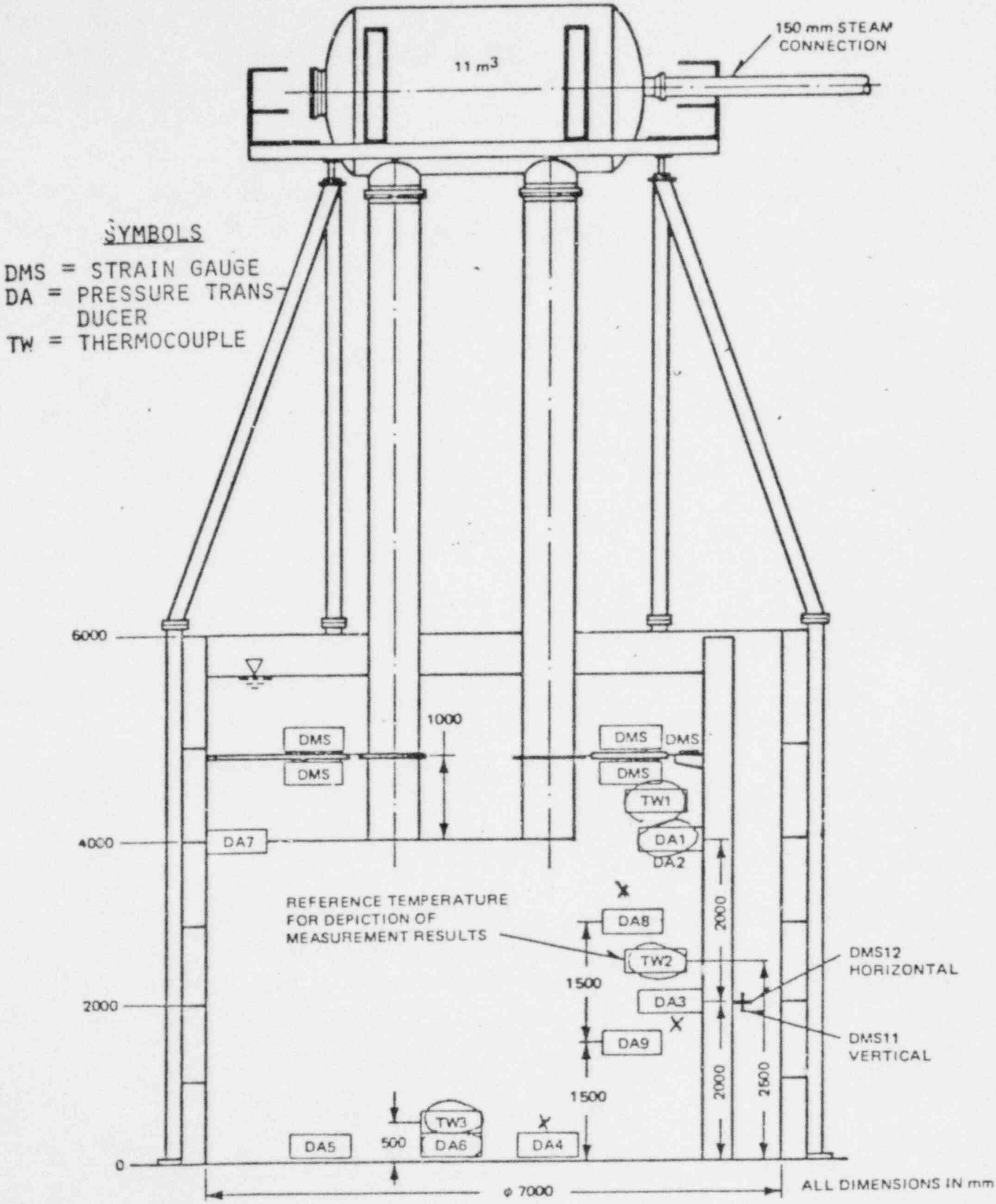
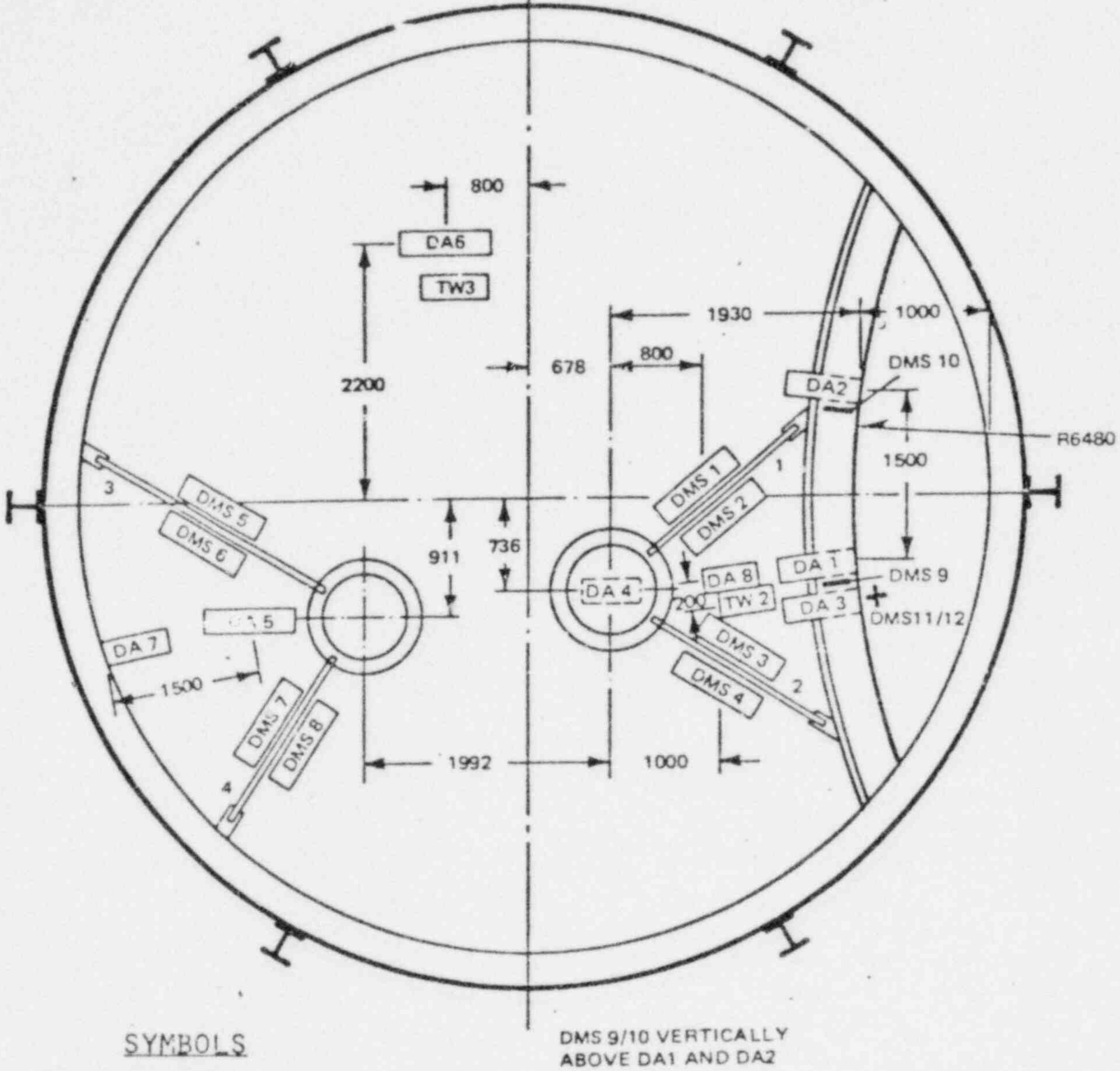


Figure 5-1. Test Set-up and Instrumentation, 600 mm Vents - Side View



SYMBOLS

DMS = STRAIN GAGE
DA = PRESSURE TRANSDUCER
TW = THERMOCOUPLE

DMS 9/10 VERTICALLY ABOVE DA1 AND DA2

ALL DIMENSIONS IN mm

Figure 5-2. Test Set-up and Instrumentation, 600 mm Vents - Top View

Figure 5-4. Calculated Dynamic Response-Motion Summary
(General Electric Company Proprietary)

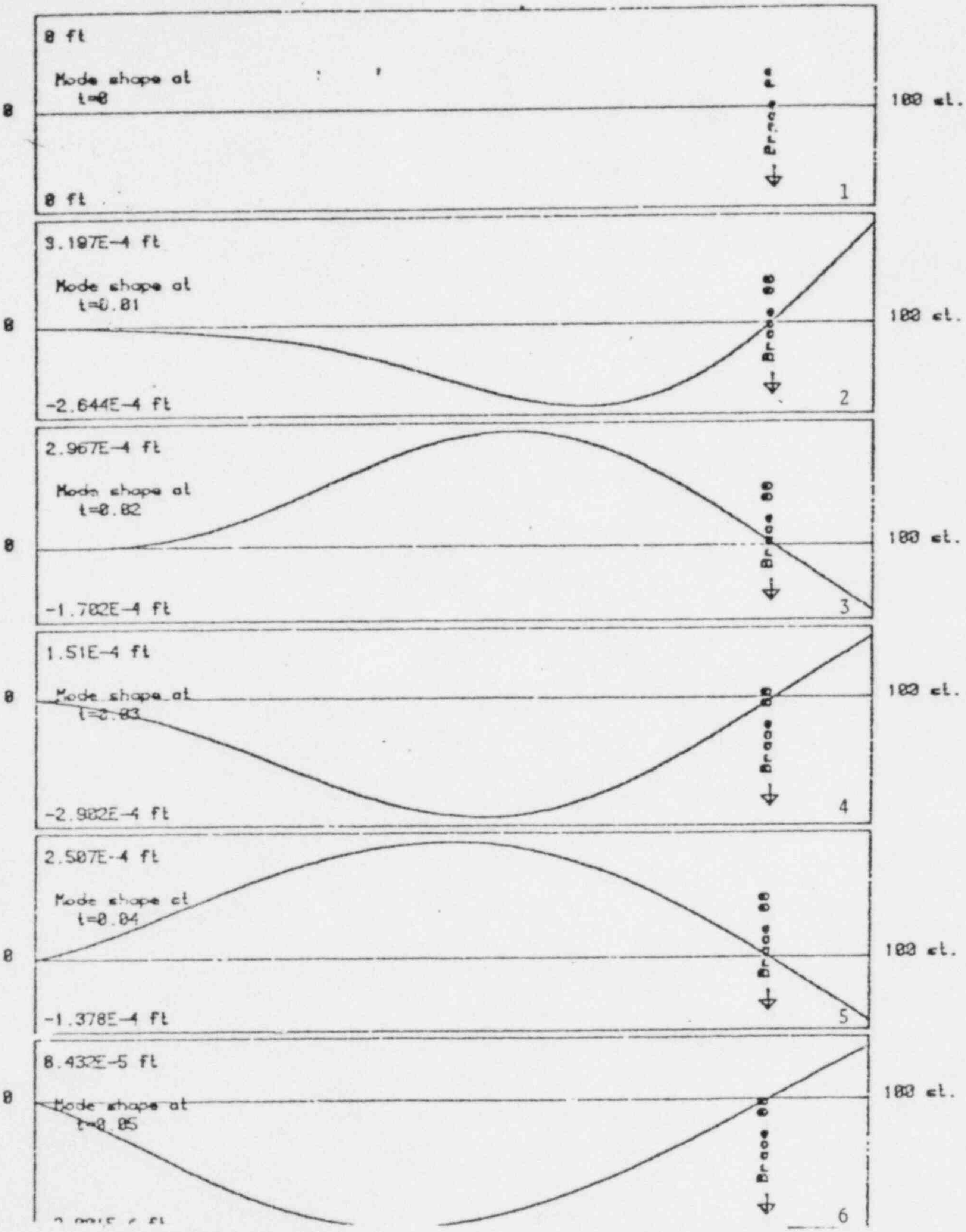


Figure 5-5. Calculated Dynamic Response-Time Histories

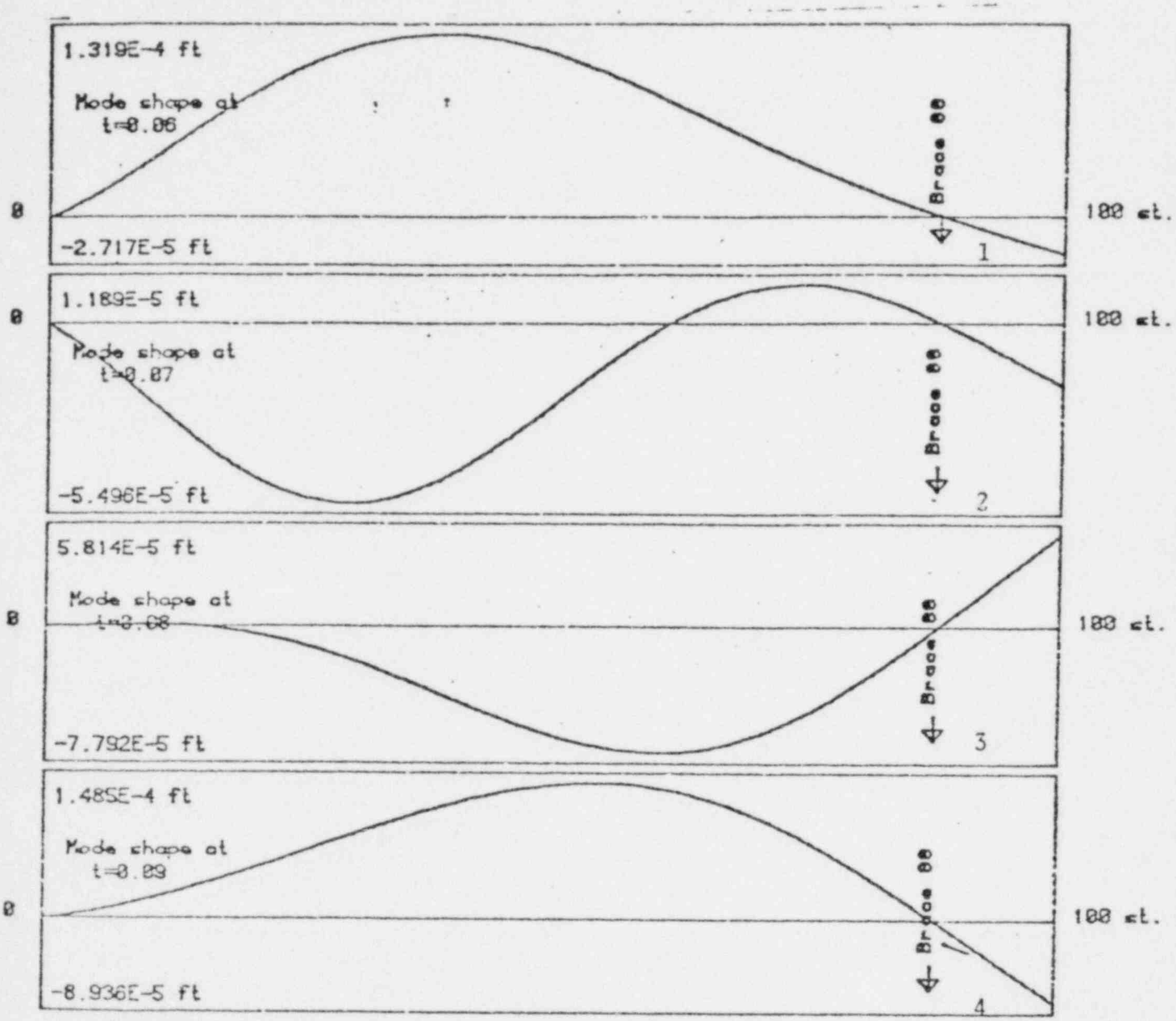


Figure 5-5. Calculated Dynamic Response-Time Histories (Continued)

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6. REFERENCE TEST 2

6.1 FACILITY DESCRIPTION

Lateral load tests of Reference Test 2 were performed in the single cell test stand shown in Figures 6-1 and 6-2. The simulated downcomer vent consisted of a single braced, 24-inch (600-mm) pipe with an exit submergence of 2.8 meters, which is close to that of the 4T tests. The tests consisted of a series of separate blowdowns with starting mass fluxes of 14, 8 and 6 lbm/ft^2 sec into indicated pool temperatures ranging from 87° to 161°F. Relevant conditions were as shown in Table 6-1.

The vent bracing test arrangement present during Reference Test 2 is shown in Figure 6-2. Longitudinal brace stress response data was recorded from strain gages DMS 16 and 17.

Each of the braces was fitted with opposing additive gages on both sides of each strut so that bending components (fiber stress) were eliminated prior to recording of strain data.

Continuous recording of other test parameters required for this correlation work included time histories of exit vent temperature, wall pressures and steam mass flux. Appendix B contains Reference Data 2.

6.2 DATA FORMAT

The strain response to lateral chugging data loads obtained during Reference Test 2 consisted of magnetic tape records covering simultaneous time histories of a large number of test parameters. During the course of the present study, tape copies of the original records were made and investigated in detail with respect to strain, wall pressure, mass flux and vent exit elevation temperature. The original analog strain data from which a time sequence record of brace forces could be developed was also digitized and scanned for individual chugging amplitudes.

6.3 TIME HISTORY CORRELATION

Records of strain versus time history provided by Reference Data 2 allowed a detailed correlation between analytical and experimental results as well as comparisons with 4T experimental data. Good amplitude and time period resolution was available so that very accurate analytical comparisons could be made by the Dynamic Simulation Program.

6.3.1 Summary

In accordance with the objective of this work, the analytical investigation of Reference Facility 2 was made using the Dynamic Simulation Program in a manner completely analogous to the 4T load determination study outlined in Reference 3. No adjustment for wall flexure modes was required for correlation of Reference Data 2. As usual, all structural members of Reference Facility 2 were described and the temporal response to an arbitrary lateral load calculated in terms of downcomer tip motion, bending stress and brace reaction stresses. The analytical stresses were scaled to the maximum measured values, thereby determining the lateral load function which would produce the experimentally measured brace loads. Tip motion measurements were not made during these tests and all load correlation work was done using the resultant brace load vector for determining the equivalent tip lateral load.

The maximum values of the instantaneous brace load vectors observed in Reference Test 2 under all experimental conditions are summarized in Figure 6-3. The maximum strain response values are plotted against load function periods calculated from the observed response period.

A maximum error was estimated for these amplitudes. The lateral load bounding function corresponding to these experimental response maxima is shown in Figure 3-1.

The maximum experimental brace load data point shown in Figure 6-3 has a resultant vector that represents the maximum value of all 57 tests (more than 20,000 chugs with exception of one data point which was investigated separately. That data point has a vector value which occurred during a 6 lbm/ft^2 sec blowdown to a very low pool temperature.

Examination of the tape records of this test run shows that the subject strain gage channel did not have an active signal during the first 150 seconds of the blowdown test. A significant direct current (DC) offset voltage was also present in the inactive strain brace, and reversed itself twice in the first 30 seconds before settling down to a gradual decay toward zero DC offset before the data channel appeared to become active. Based on the above, it is strongly indicated that a temporary ampilifier short or strain bridge failure occurred during this test and that the channel calibration during the entire test was neither correct nor linear. Additional support for the suspected event is also presented by the fact that a third sharp drop in channel DC level occurred after 350 seconds of this test and that the entire gage failed permanently after two more tests.

In summary , it is concluded that the resultant brace vector is an error caused by gage failure and temporary grounding of the bridge circuit. This would have the effect of changing both gage factor and amplifier gain significantly and probably accounts for obtaining strain data point almost 100% out of range of a sample of more than 20,000 other chugs in the same experimental facility. The data point also happens to be in a mass flux and temperature range in which no other experiments have measured significant lateral loads and was, for the above reasons, discarded.

6.3.2 Simulated Responses

Typical graphics output from the lateral load simulation program is shown in Figures 6-4 and 6-5. The top two traces of Figure 6-4 show the temporal behavior of the downcomer tip and brace location at stations 100 and 88, respectively. Here the vent is subjected to a simulated 4T defined chug at time zero producing the lateral acceleration history shown.

As before, traces number 4 and 5 from the top show vent mode-shape and brace stress time-histories, respectively. The former is the instantaneous acceleration at the time of maximum tip acceleration and the latter is the time-history of the bracing stress as the vent undergoes the transient response to the simulated lateral chugging load.

Figure 6-5 illustrates the displacement mode shape at discrete time intervals. The modal bending is shown on a linear scale and is normalized to the maximum value of transverse displacement at each time frame.

6.4 STATISTICAL CORRELATION

All tape records from the nine Reference 2 Tests were digitally scanned for load amplitudes in excess of 1000 lb_f and treated statistically for comparison with 4T amplitude distributions. Histograms and cumulative distribution plots were generated for all subject tests over the ranges of pool temperatures and mass-fluxes applicable to 4T and general Mark II containments.

6.4.1 Summary

Comparison of 4T and Reference Test 2 statistical data shows almost identical distributions for the two data bases. Specifically, the lateral bounding loads are very close (4 percent) and a predominance of low amplitude chugs is common to both sets of tests. The average value of the correlated lateral load in Reference Data 2 is nearly 75 percent lower than 4T results while the direct comparison between measured brace strains shows Reference Test 2 and 4T to be very close.

6.4.2 Data Base

Figures 6-6 through 6-25 contain selected cumulative distributions and histograms for Reference Test 2. Various combinations of test parameters, as they were normalized for comparison with 4T test parameters, are noted on each plot.

Table 6-1

Test	Initial Temp °F	Initial Mass Flux Lbm/ft^2 sec	Final Temp °F	Test Duration Sec*
1	95	8	123	380
2	118	8	155	390
3	139	8	160	250
4	88	14	131	240
5	117	14	161	240
6	140	14	161	170
7	88	6	115	300
8	113	6	139	360
9	139	6	153	240

*Time of last chug above threshold value.

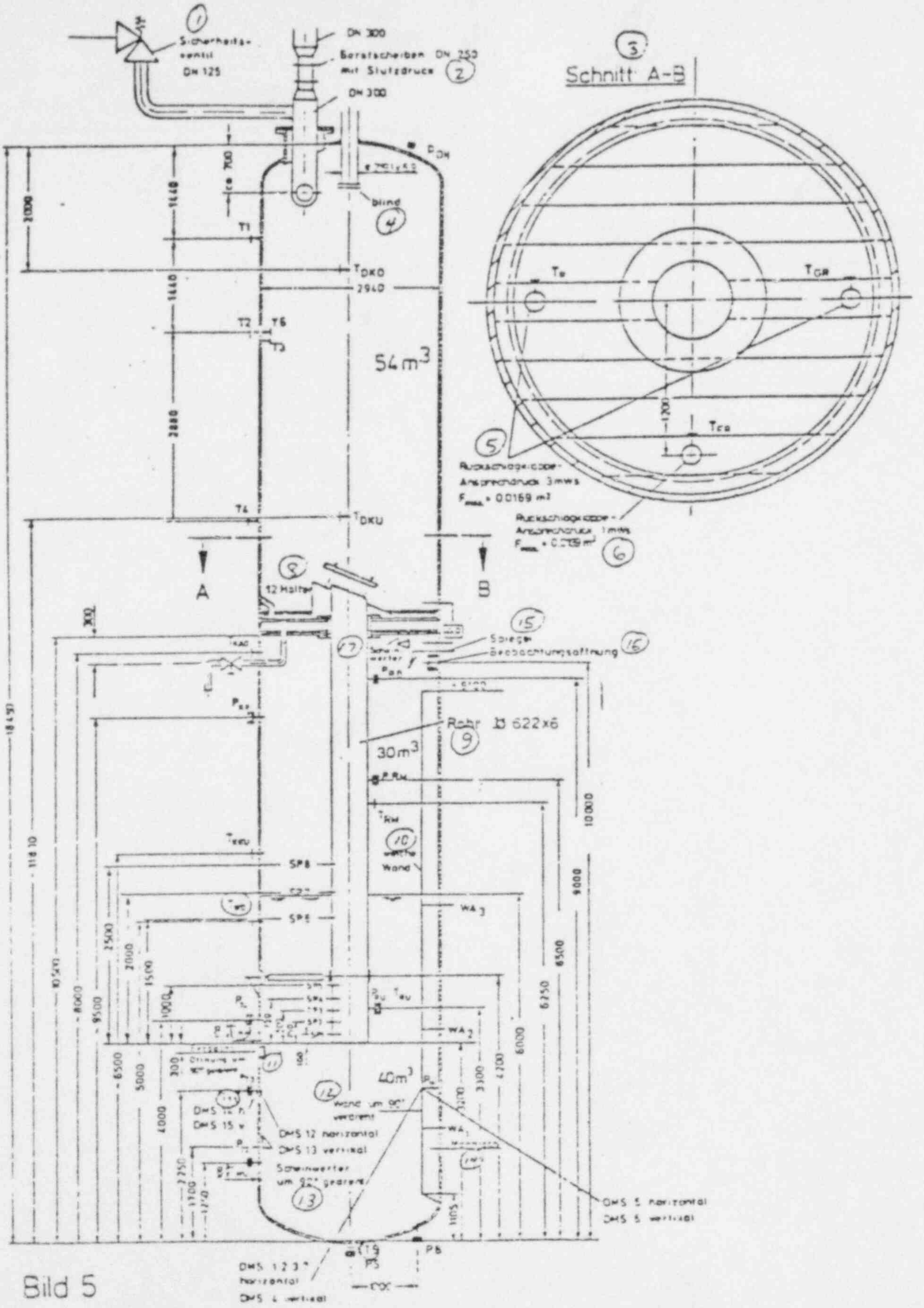

Figure 6-1. Test Set-up and Instrumentation, 600 mm Vents - Side View

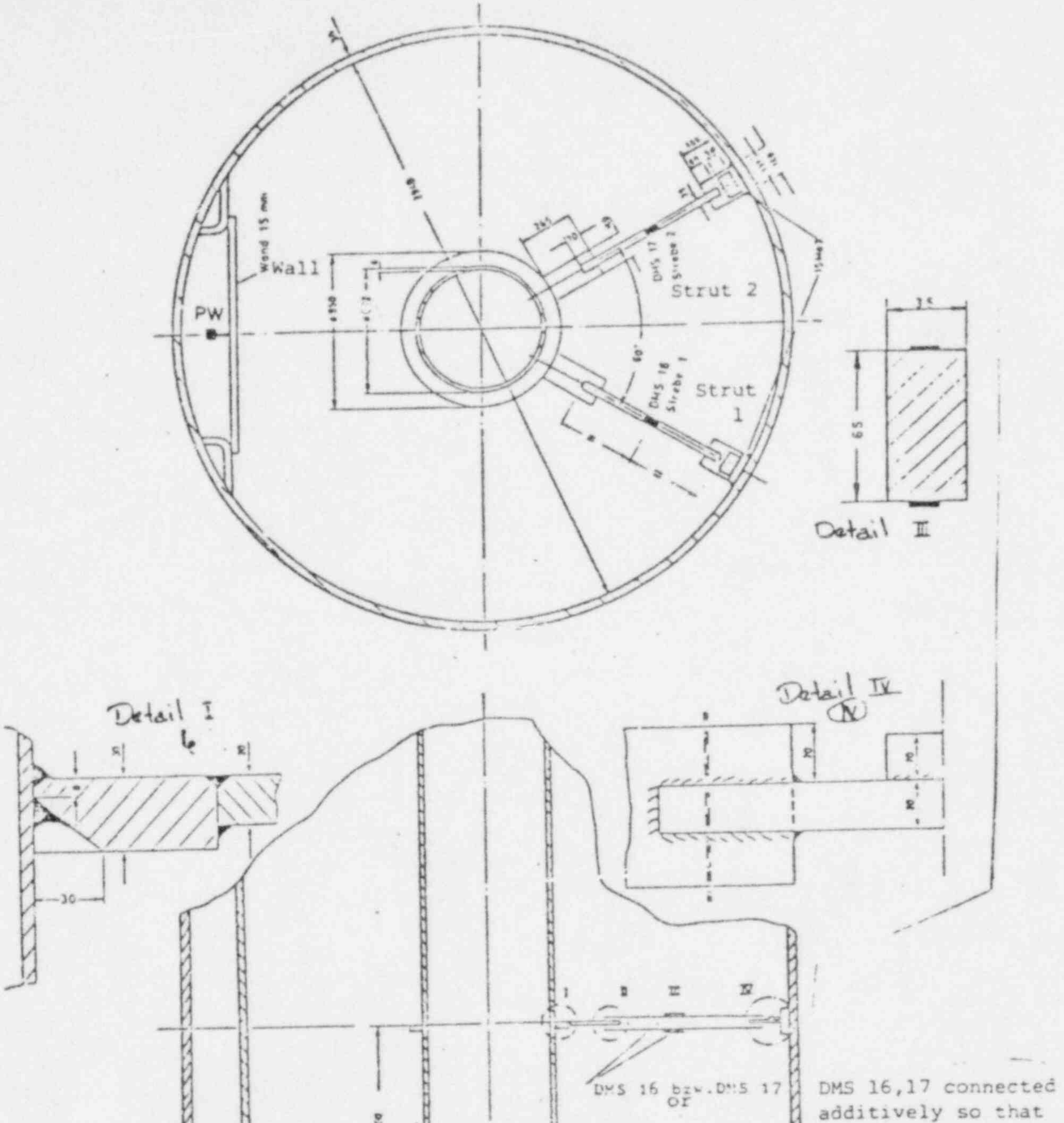

Figure 6-2. Test Set-up and Instrumentation, 600 mm Vents - Horizontal View and Details

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Figure 6-3. Experimental Brace Load Summary Bounding Values for Mass Flux for in Pool Temperature Ranging from 87° to 161°F (General Electric Company Proprietary)

Figure 6-4. Calculated Dynamic Response, Motion Summary
(General Electric COmpany Proprietary)

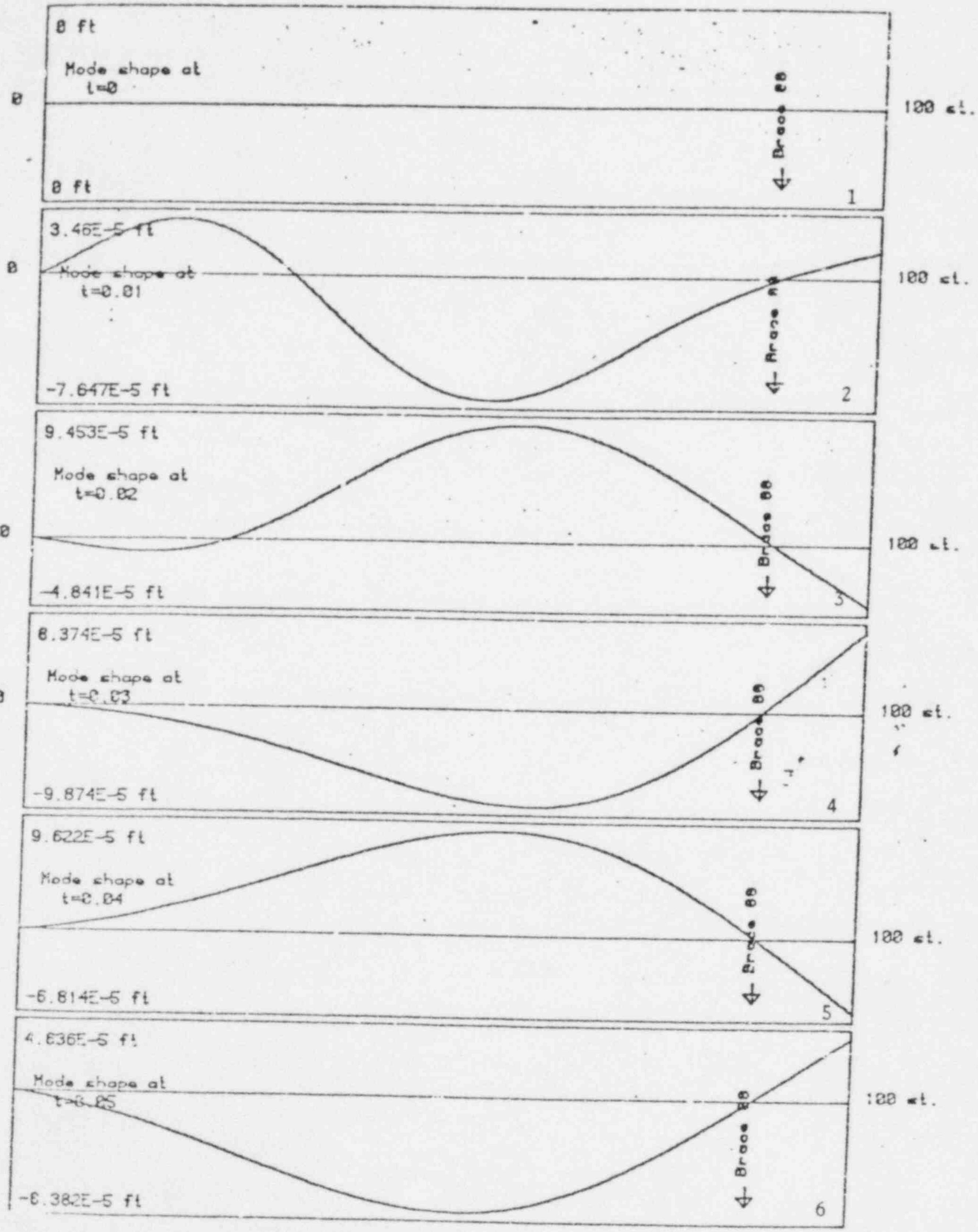

Figure 6-5a. Calculated Dynamic Response, Time Histories

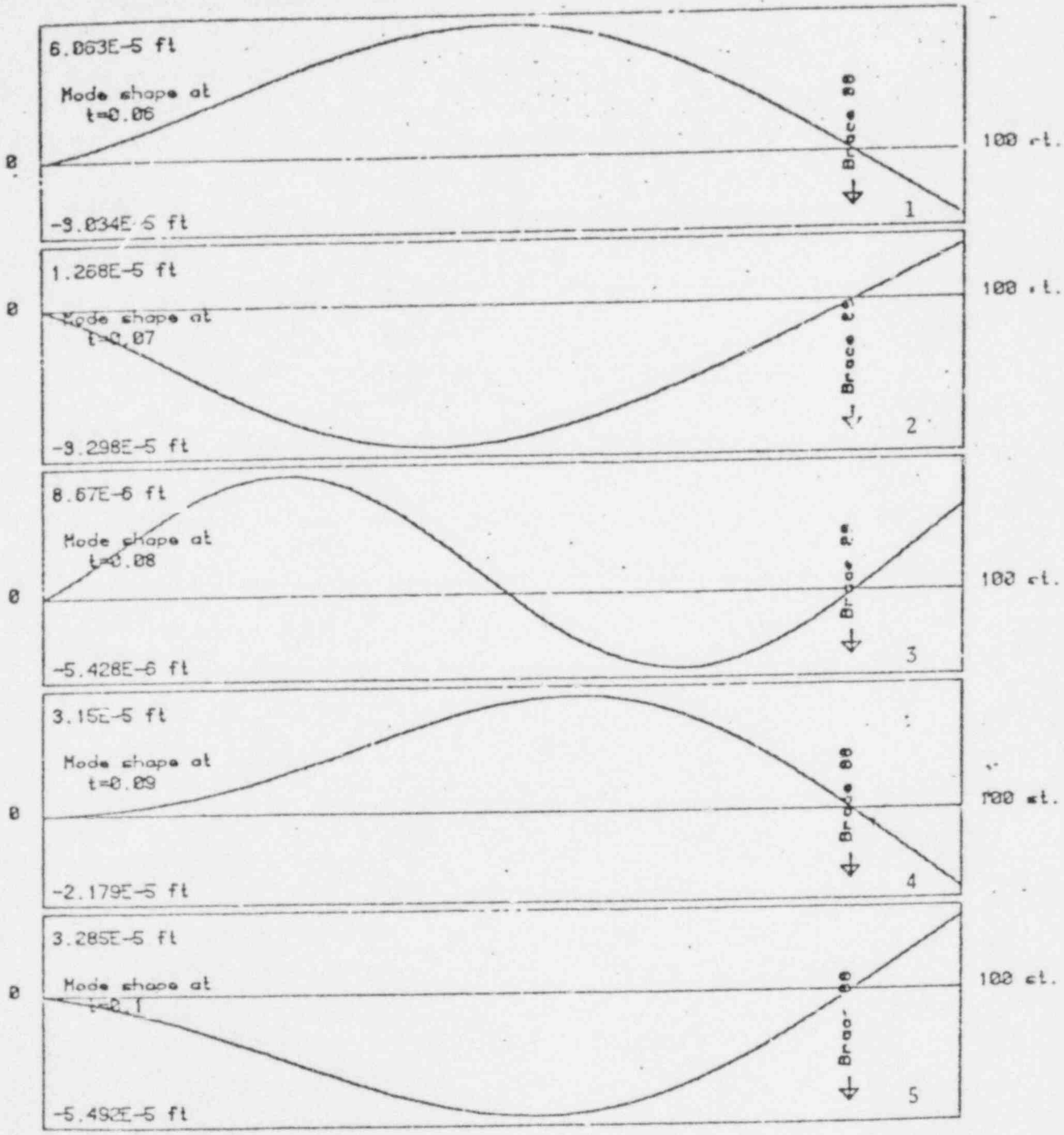

Figure 6-5b. Calculated Dynamic Response, Time Histories

POOR ORIGINAL

The following Figures are GENERAL ELECTRIC COMPANY PROPRIETARY and have been removed from this document in their entirety.

6-6	Cumulative Distribution	
6-7	Percentage Histogram	
6-8	Cumulative Distrubution	
6-9	Percentage Histogram	
6-10	Culuiative Distribution	
6-11	Percentage Histogram	
6-12	Cumulative Distribution	
6-13	Percentage Histogram	
6-14	Cumulative Distribution	
6-15	Percentage Histogram	
6-16	~~Cumulative Distribution~~	DELETED - Duplicates of
6-17	~~Percentage Histogram~~	Figures 6-14 and 6-15
6-18	Cumulative Distribution	
6-19	Percentage Histogram	
6-20	Cumulative Distribution	
6-21	Percentage Histogram	
6-22	Cumulative Distribution	
6-23	Percentage Histogram	
6-24	~~Cumulative Distribution~~	DELETED - Duplicates of
6-25	~~Percentage Histogram~~	Figures 6-21 and 6-22

7. REFERENCES

1. T. R. McIntyre, M. A. Ross, and L. L. Myers, "Mark II Pressure Suppression Test Program," NEDO-1344-01, June 1979.

2. W. A. Grafton, T. R. McIntyre, and M. A. Ross, "Mark II Pressure Suppression Test Program, Phase II and III, " NEDO-13468, March 1977.

3. "Mark II Dynamic Lateral Loads on a Main Vent Downcomer," NEDO-24106, March 1978.

4. "Mark II Dynamic Forcing Functions Information Report," NEDO-21061, September 1976.

5. S. T. Nomanbhoy, "Loads on the Vent Struts Due to Condensation of Steam Steam in a Water Pool," NEDO-23627, June 1977.

APPENDIX A

REFERENCE DATA 1

Original Data Base
and
Statistics

The information contained in this Appendix is GENERAL ELECTRIC COMPANY PROPRIETARY and has been removed from this document in its entirety.

APPENDIX B

REFERENCE DATA 2
and
Statistics

The information contained in this Appendix is GENERAL ELECTRIC COMPANY PROPRIETARY and has been removed from this document in its entirety.