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Characterization of Structural Connections Using Free and Forced Response Test Data

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ABSTRACT

The accurate prediction of system dynamic response often has been limited by deficiencies in existing capabilities to characterize connections adequately. Connections between structural components often are complex mechanically, and difficult to accurately model analytically. Improved analytical models for connections are needed to improve system dynamic predictions. In this study a procedure for identifying physical connection properties from free and forced response test data is developed, then verified utilizing a system having both a linear and nonlinear connection. Connection properties are computed in terms of physical parameters so that the physical characteristics of the connections can better be understood, in addition to providing improved input for the system model. The identification procedure is applicable to multidegree of freedom systems, and does not require that the test data be measured directly at the connection locations.

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INTRODUCTION

Recently, there has been an increased need for developing parameter identification methods for improving structural dynamic models. This need has arisen because of the increased ability of engineers to construct complex analytical models, coupled with their inability to precisely identify those models so as to adequately simulate observed response. While great strides in computer technology and analytical methods have enabled engineers to theoretically solve very large and complex structural problems, the results often do not compare well with test data, because of inaccuracies in the parameters of the mathematical model.

The field which addresses mathematical modeling is labeled system identification, which is described in some detail in Refs. 1 to 4. In general, system identification involves the utilization of input and output relations to determine differential equations. Once the differential equations are determined, the unknown parameters within the equations are identified and the equations then are used to represent the actual system. When the differential equation is known a priori (e.g., a vibrating beam), the identification problem is reduced to the more specific area of parameter identification.

Parameter identification methods can be separated into modal and physical model identification methods. In modal parameter identification, experimental data are used to derive modal parameters such as characteristic frequencies and mode shapes. These parameters then are used to create a frequency domain model utilizing modal coordinates. Physical parameter identification also involves the use of experimental data, except that for this type of identification, a physical, time domain model, based on physical coordinates, is generated. Physical models have successfully been generated through the use of both modal and free or forced transient response data.

Parameter identification methods may be utilized in determining structural connection properties. Since connections usually contribute significantly to the overall system stiffness, damping, and in many cases nonlinearity, it is critical that reliable connection models be made available. For many structural systems the constituent components themselves often can be modeled accurately, and it is the connections which contain most of the modeling uncertainty. Therefore, accurate system response predictions often are highly dependent on valid connection models.

Identification methods for connections which use frequency based or modal test data typically are desired for linear systems, because the test apparatus for obtaining the data are readily available and simple to apply in the frequency domain. Furthermore, the same test equipment and post-processing software may be used for a wide range of structural dynamic systems. Modal data also have advantages over time domain data, in that the modal data, which normally includes resonant frequencies and mode shapes, provide global system information which is useful for identifying overall, as well as specific, system characteristics (e.g., existence of rigid body modes, system flexibility, etc.).

Some recent work related to frequency based testing and identification of connection properties is described in Refs. 5 to 8. In Ref. 5, component mode synthesis (substructuring) methods are combined with parameter identification procedures to improve the analytical modeling of the structural connections for reduced order systems. In this study, which utilized experimental modal data, improvements in connection properties were computed in terms of physical stiffness parameters. By utilizing substructuring methods, component and connection properties were identified independently with the advantage that the identification problem is reduced to a collection of smaller order problems. For each of these problems the complexity of obtaining the experimental data, and the required quantity of data, is less than if the entire system were identified as a whole. In Ref. 6, a similar identification procedure is used to determine connection damping as well as stiffness. The effect of friction damping on an assumed viscously damped system also was assessed. Swept sine tests were used in Ref. 7 to ascertain the connection properties of nonlinear connections for space structures. Harmonic balancing and Fourier approximation were used to extract the connection parameters from the test data. In Ref. 8, a mix of analytical and experimental component models were combined to characterize the dynamics of a flexible spacecraft. For this study, joint stiffness and damping properties were ascertained via cyclic loading tests before the joints were incorporated into the system model. Since the system modal properties computed using experimentally derived joint models were in agreement with test results, there was no need to modify the joint characteristics using the coupled system test data.

Since many structural systems, particulary systems with complex connections, contain at least some amount of nonlinearity (e.g., friction damping, gaps, localized plasticity, etc.), frequency based methods often are insufficient, and thus more general identification methods are required. Several investigators have attempted to identify nonlinearities in individual structural connections, but only a limited number have confronted the complexities associated with multicomponent/connected systems. Previous studies which have addressed connection identification have focused on identifying properties from tests performed on individual joints rather than from coupled system tests. In Ref. 9, damping and stiffness characteristics of a representative/space truss joint were studied. In this work results generated from simplified joint models were compared to results obtained from a complex model which included dead bands, large deformations, and friction forces. It was concluded that in specialized situations simplified models based on linear springs and viscous dampers may represent the behavior of the more sophisticated joint model. In Ref. 10, nonlinearities in a structural joint were identified using an approach termed "force-state mapping." This approach involved simultaneously measuring the force on a joint along with its position and velocity. From the shape of the three-dimensional surface generated by plotting force as a function of displacement and velocity, the type and quantitative description of the joint mechanisms were identified.

In Ref. 11, a technique is introduced for processing noisy test data, and for identifying the parameters in nonlinear dynamic systems. The methods presented in this work are suitable for identification of structural connections, except that the experimental data must be measured directly at the connection boundaries. In Ref. 12, a similar method is presented and then applied to a linear dynamic system in which the mass, damping, and stiffness matrices are identified. Except for having the same limitation described for Ref. 11, of having to measure the data directly at the connection boundaries, this approach is equally acceptable for identifying connection parameters.

In the present research the methods introduced in Refs. 11 and 12 are extended so they can be used for the identification of linear as well as nonlinear connection parameters, when the test data are not taken directly at the connection boundaries. The present procedure is applicable to both linear and nonlinear connections and is suitable for processing test data which has been measured at arbitrary stations on the structural system. The flexibility that the present method provides as far as the locations of the test data measurement stations is highly desirable, because in most practical situations it is impossible to obtain test data at the connection boundaries, thus rendering other identification methods ineffective.

PROCEDURE

In the present research, parameter identification is defined as the problem of determining connection properties for a multicomponent system comprised of an arbitrary number of components coupled via connections with either unknown, or estimated, properties (Fig. 1). To accomplish the identification of the connection parameters, the coupled system is excited at various stations along the structure, and the resulting response is measured. The measurement stations may or may not be collocated with the excitation, and the number of measurement stations may, or may not, be equal to the number of input excitations. In general, it is simpler to excite the system with a single input, and then measure the resulting response at multiple stations. It is required that both the input be known and the output be measured, regardless of the number of stations. As mentioned previously, the present procedure is advantageous over previous methods in that the response measurements need not be stationed directly at the connection boundaries, but instead may be established at any convenient position on the system.

The present procedure involves five major steps (Fig. 2). First, an analytical model of the system is created using preliminary estimates for the connection parameters. This model then is used to compute estimates of the transient response at stations along the structure where experimental data will be obtained. In Step II, experimental data is obtained by actually applying the specified excitation to the system and measuring the resulting response. In Step III, a set of "residual forces" are computed by minimizing the differences between the predicted (Step I) response and the measured (Step II) response. In Step IV, the residual forces are incorporated into the analytical model, which then is used to predict the output at the connection boundary locations. In Step V, the output at the connection locations, along with the residual forces, are used to compute the actual connection parameters. Steps IV and V are repeated until the identified connection parameters converge. These procedural steps are described more fully below:

STEP I. In the present research, a finite element formulation is utilized for characterizing the model, but other formulations may serve equally well. For the F.E. formulation, the equations of motion are written as:

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$$\begin{bmatrix} M^{ss} & 0 \\ 0 & M^{cc} \end{bmatrix} \begin{Bmatrix} \ddot{u}^s \\ \ddot{u}^c \end{Bmatrix} + \begin{bmatrix} C^{ss} & C^{sc} \\ C^{sc^T} & C^{cc} \end{bmatrix} \begin{Bmatrix} \dot{u}^s \\ \dot{u}^c \end{Bmatrix} + \begin{bmatrix} K^{ss} & K^{sc} \\ K^{sc^T} & K^{cc} \end{bmatrix} \begin{Bmatrix} u^s \\ u^c \end{Bmatrix} = \begin{Bmatrix} 0 \\ F^c \end{Bmatrix} + \begin{Bmatrix} P \\ 0 \end{Bmatrix} + \begin{Bmatrix} 0 \\ R^c \end{Bmatrix} \qquad (1)$$

where [M], [C], and [K] are the conventional mass, damping, and stiffness matrices, {P} is the external excitation, $[C^{cc}]$, $[K^{cc}]$, and $\{F^c\}$ contain initial estimates for the connection properties, and $\{R^c\}$ are unknown "residual" forces acting at the connections. $\{u^s\}$ and $\{u^c\}$ are displacement coordinates for the system components and connections respectively. For the subsequent integration of Eq. (1), performed in this step, the residual forces are set to zero. The residuals are in fact unknown at this stage because the actual connection parameters have not yet been determined.

The actual connection parameters are related to the residuals by:

$$\{R^c\}_i = \begin{Bmatrix} R^1 \\ \cdot \\ \cdot \\ \cdot \\ R^q \end{Bmatrix}_i = \begin{bmatrix} p_1^1 v_1^1 + p_2^1 v_2^1 + \dots & p_k^1 v_k^1 \\ \vdots & \vdots \\ p_1^q v_1^q + p_2^q v_2^q + \dots & p_1^q v_1^q \end{bmatrix}_i \qquad (2a)$$

or

$$\{R^c\}_i = [v]_i \{p\} \qquad (2b)$$

where {p} are the connection parameters and [v] contains combinations of state variables at the connection degrees of freedom. For example, if the connection at degree of freedom q behaved like a grounded cubic spring with viscous damping, R^q would equal $k*\left(u^q\right)^3 + c*(\dot{u}^q)$, p_1^q and p_2^q would equal k and c respectively, and v_1^q and v_2^q would be equal to $\left(u^q\right)^3$ and $\dot{u}^q$. Obviously, the connection characterization may include both linear (e.g., springs, viscous dampers, etc.) as well as nonlinear elements (e.g., friction, etc.). Elements such as gaps have not yet been incorporated because they require more complex (i.e., discontinuous) expressions for v.

In Eq. (1), a preliminary estimate for $[C^{cc}]$, $[K^{cc}]$, and $\{F^c\}$ may be used, or if the connections are entirely unknown, $\{F^c\}$ and the connection contributions to $[C^{cc}]$ and $[K^{cc}]$ may be set to zero. In situations where connection forces are required for a stable system, it is desirable to provide a small quantity of connection stiffness so that the system is not unstable. Once $\{F^c\}$ is assigned, Eq. (1) is integrated and the predicted state variables, {u} and $\{\dot{u}\}$, are determined.

The purpose of formulating Eq. (1) is to make an estimated set of output data available for step III where residual forces are computed. The required data for step III, namely the velocities and displacements at the test measurement stations $\{u^p\}$ and $\{\dot{u}^p\}$ (p = 1, 2, . . . number of measurement stations), are extracted directly from the vectors {u} and $\{\dot{u}\}$ in Eq. (1).

STEP II. The test setup for obtaining the experimental data is determined by convenience and the characteristics of the individual connections. The selection of excitation must be appropriate so that energy is transmitted through the connections and so that every type of connection characteristic is exercised adequately. For example, if the connection contains friction damping, the excitation must be located so there is relative displacement at the connection boundaries and so that a large enough magnitude connection force is generated to overcome any frictional "sticking." In some situations, applying an initial impulsive load or displacement pattern as the excitation, and monitoring the free response decay, may be advantageous over a forced response excitation.

The quantity of available experimental response data is dependent on the number of measurement stations and the number of data points taken at each station. The required location and number of response measurements ($\{u^m\}_i$ and $\{\dot{u}^m\}_i$) (i = 1, 2, . . . ndt) are determined primarily by the desired accuracy of subsequent computations. When the number of output measurement stations is increased, a larger number of output responses are available at each time step, $t = t_i$, more accurate results are obtained at the time step, and experimental error may be compensated for. The consequences of using different numbers of output stations and time steps is addressed in the sample problem.

STEP III. The "residual" forces at the connections, $\{R^c\}$, appearing in Eq. (1) are computed in this step. It would be desirable to bypass this step and compute the connection parameters directly, but the parameters cannot be identified until the state variables at the connection locations are known. The state variables at connection locations are unknown because normally they are not measurable, and the analytical model defined in Eq. (1) cannot be used to predict them exactly because $\{R^c\}$ has yet to be specified.

The approach used in the present procedure is to compute the residual forces, substitute the forces into Eq. (1), and then compute the actual state variables at the connection locations. Once the correct state variables at the connection locations are known, they then may be used to identify the actual connection parameters (Steps IV and V).

The residual forces are computed by minimizing the differences between the predicted output $\{u^p\}$ and $\{\dot{u}^p\}$ (Step I), and the measured output $\{u^m\}$ and $\{\dot{u}^m\}$ (Step II), at the measurement stations. Because the residuals change with time they must be recomputed at each time step ($1 < i < n$). At each time step the residuals are computed iteratively from:

$$\{R^c\}_i = \{R^c\}_{est,i} + \left(([S]^T[W][S])^{-1}[S]^T[W]\right)(\{u^p,\dot{u}^p\} - \{u^m,\dot{u}^m\})_i \qquad (3)$$

where $\{R^c\}$ are the computed residual forces at time $t = t_i$, [W] is a weighting matrix applied to the output data, and [S] is a sensitivity matrix containing the partial derivatives, $d\{u\}/d\{R^c\}$. Reference 6 provides additional discussion of the coefficients in Eq. (3).

An important distinction between previous applications of the least squares method and the present, is that for the current application the partial derivatives, $d\{u\}/d\{R^c\}$, remain constant for all time steps. Since the coefficient matrices of the left-hand side of Eq. (1) are assumed time invariant, any change in the right-hand-side (i.e., $d\{R^c\}$) produces only a proportional change in the response coordinates, $\{\ddot{u}\}$, $\{\dot{u}\}$, and {u}, with the derivatives remaining unchanged. Computationally, this is beneficial because the derivatives only need to be computed once, for the initial time step.

Once the residual forces are identified for a time step, they are substituted into Eq. (1) and the initial conditions for the next time step are computed. It is necessary to include the residuals from the current time step so that accurate initial conditions and residuals can be computed for subsequent time steps. Equation (3) is repeatedly solved until all of the available data is utilized (i = ndt).

The accuracy of the identified residuals is dependent on the number of stations where data is measured. As a minimum, the number of measurement stations must be at least equal to the number of connected degrees of freedom. If the number of measurement stations is less than this value, the [S] matrix will have dimensions less than $\{R^c\}$ and the residuals will be underdetermined. When the number of measurement stations is large, the residuals may be computed with greater accuracy.

STEP IV. In this step the residual forces computed in the previous step are used in Eq. (1) to compute the state variables at the connection locations. Since each term in Eq. (1) now is completely defined, Eq. (1) may be used explicitly to predict values of the state variables, $\{u^c\}$ and $\{\dot{u}^c\}$, at the connection boundaries.

STEP V. The actual connection parameters are computed in this step. Using the state variables from Step IV and the relationship (Eq. (2)) between the residuals and the unknown connection parameters:

$$\begin{Bmatrix} \{R^c\}_1 \\ \{R^c\}_2 \\ \cdot \\ \cdot \\ \cdot \\ \{R^c\}_n \end{Bmatrix} = \begin{bmatrix} [v]_1 \\ [v]_2 \\ \cdot \\ \cdot \\ \cdot \\ [v]_n \end{bmatrix} \{p\} \tag{4a}$$

or

$$\{R\} = [V]\{p\} \tag{4b}$$

Since the number of unknown parameters normally will not equal the number of time steps, [V] cannot be inverted directly. Instead, the least squares inverse is used, leading to the solution of the unknown parameters by:

$$\{p\} = ([V]^T[V])^{-1}[V]^T\{R\} \tag{5}$$

STEP VI. In most situations the experimental data has measurement errors which causes the subsequently computed residual forces and connection parameters to also contain errors. Since the computations for each time step are dependent on the residual forces computed in the previous time step, an error in the residual force at one time step carries over into the next step. In fact, the errors tend to accumulate, so that a small error in the test data often progresses to very large errors in computed residual forces as time advances.

Fortunately, measurement error often may be compensated for by iterating. By utilizing the identified connection properties in the analytical model, and then using the model to recompute the residual forces, the effects of measurement error may be minimized. In each iteration the same test data is used, but the analytical model is revised with updated connection parameters so that it better predicts the test data. Since the model becomes a finer predictor of the test data, the computed residual forces become smaller and more capable of tracking the correct solution.

SAMPLE PROBLEM

The sample problem is presented to demonstrate the parameter identification procedures for a system having a single input and multiple output measurement stations. For this problem a finite element model was used to generate simulated experimental data. The model (Fig. 3) consists of two planar elastic beams connected at their ends with resolute (pinned) connections. Each of the connections are attached to ground by a linear, translational, spring. An "unknown" connection, also attached to ground, is added at node 6. Each of the beam components is discretized into five beam elements with the beam mass lumped at the ends of the elements. The Newmark-Beta integration method was used to generate the simulated experimental data (displacement and velocities at the output stations), and to compute the sensitivities and state variables required in Steps III and IV respectively.

Initially, the unknown connection was defined as a linear spring having a spring constant equal to $30.\text{x}10^4$. For the initial guess required by the parameter identification (Step V) the connection characterization was defined as $p_1\text{sign}(\dot{u}^6) + p_2(u^6) + p_3(100.) + p_4(\dot{u}^6)$ where $p_{1,\ 2,\ 3,\ \text{and}\ 4}$, were the unknown connection parameters to be identified, and u^6 and $\dot{u}^6$ were the displacement and velocity at node 6, the location of the connection. $p_{1,\ 2,\ 3,\ \text{and}\ 4}$ were set initially to zero and the parameter identification procedure was given the task of determining the actual parameters, p = $\{0.,30.\text{x}10^4,0.,0.\}$. A sinusoidal input was applied at node 1 and the resulting output for 36 time steps was measured at nodes 1, 3, 5, 7, 9, and 11. Figure 4 shows the results of three simulation runs which were made using test data having random measurement errors (coefficient of variation) of 10, 50, and 100 percent. For each of the runs the four parameters, friction, spring, constant force, and viscous damper, were identified using 15 iterations. Clearly, as the amount of measurement error increases there is a reduction in the quality of the identified parameters. In Fig. 4(a) identified friction for 10 percent error is computed very accurately after only five iterations. For 50 percent error the friction is accurate after three iterations, and for 100 percent error the friction is not only inaccurate, but does not even converge.

The results for the other three parameters follow a similar pattern. In Fig. 4(b) the parameter associated with the linear spring converges to a precise solution after only two and eight iterations for 10 and 50 percent error, respectively. For 100 percent error the correct solution is never attained. In Figs. 4(c) and (d) the same trend is followed. For both the 10 and 50 percent error simulations the parameters eventually produce the correct solution, while for the simulation with 100 percent error the parameters always fail to converge.

In Fig. 5 the computed residual forces for each time step are shown for three cases; no error, one with 10 percent measurement error, and one with 10 percent error with three point averaging. For the case without error the residuals are computed correctly beginning in the first iteration. When the measurement error is 10 percent, the residuals vary considerably from the actual values although they tend to oscillate about the correct solution. Apparently, an inaccurate residual from one time step is overcompensated for in the subsequent step. As expected mentioned, the inaccuracies expand as time progresses. Fortunately, after iterating for only a few cycles the inaccuracies vanish and

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the residuals converge to the correct values. Three point averaging ($(R_{i-1}+R_i+R_{i+1})/3$) also was used in an attempt to smooth out the overcompensating effect which appears in the residuals when measurement error is present. Although the averaging appears to be effective, it does not accelerate the iterative process. In situations where large quantities of data are utilized convergence may not be improved because the accumulated error in the residuals will grow and the residuals will be unable to track the correct solution.

The results presented in Fig. 6 were created by increasing the number of data points (time steps) from 36 to 72. By comparing the results in Fig. 4 to this figure, the effect of varying the number of data points may be seen. In general, it takes more iterations to achieve convergence when the number of data points is increased. For example, while the spring parameter took only two iterations to converge when 36 data points were used, the 72 data point simulation required three. Another observation which is made by comparing the results in these figures is that increasing the number of data points does not necessarily assist in offsetting the effects of measurement error. This is evidenced by the fact that correct parameters could not be identified in either case (36 or 72 data points) when the measurement error was 100 percent. Although the 72 data point simulations provide additional data, the identified residuals are no more accurate because the number of measurements at each time step remains the same. This situation is unfortunate because it is easier to obtain additional data at a measurement station than it is to increase the number of stations. Iterating does not appear to improve this situation.

The next step toward validation of the identification procedure consisted of performing simulations with a more complex model. The previous model was complicated by introducing a friction damper into the connection along side the linear spring. The friction force at the connection was described as $3000.\text{sign}(u^6)$, thus the complete parameter vector is $p = \{3000.,30.\times10^4,0.,0.\}$. Results from this system (Fig. 7) also were generated for various levels of measurement error, and as expected, as the error decreased, the identified connection parameters became more accurate. The spring parameter actually converged faster for this model than for the/model without friction. The friction parameter converged relatively quickly as well. Overall, the introduction of friction into the system did not have adverse effects on the identification process.

Another aspect of the identification process studied in the present research was the effect of using other types of input excitation. Thus far, all of the results presented have been obtained through the use of sinusoidal input. To assess the effect of excitation type, the sinusoidal input was replaced by an initial displacement, and the resulting free response was used for the identification. Random input also was used as the excitation. The results (Fig. 8) are plotted along with the previously identified parameters so that a comparison can be made. For both the friction and spring parameters the results were as accurate for the free response and random simulation as they were for the sinusoidal excitation, however, it took the free response identification several more iterations to converge. It is difficult to generalize about the effectiveness of different types of excitation because of the numerous variables which must be considered. For example, while the free response resulting from an initial condition with one spatial distribution may be more effective for the identification than a sinusoidal input, the opposite may be true for other distributions. As a conservative guide, it probably is best to try as many types of input as possible.

SUMMARY AND CONCLUSIONS

An analytical procedure has been presented which allows for the identification of the mechanical properties of connections in multicomponent structural systems. The procedure requires verified analytical models of the individual components, although the connection parameters to be identified may be nonlinear, and velocity or displacement dependent. Adequate transient, time domain response data are required for the assembled structural system; the location of data measurement stations is, however, arbitrary. Limited measurement errors in the data may be accommodated through an iterative refinement process in the identification algorithm. The quality of the parameter identification is dependent on the quantity as well as the quality of the system transient response data available. The number of parameters to be identified is not limited, although larger identification problems may require a greater number of measurement stations.

The procedure shows great promise for improving modeling capabilities in complex structural systems, as well as for enhancing our understanding of structural connection behavior. Further developments are certainly desirable in establishing convergence criteria, enhancing convergence, determining the reliability of identified parameters, characterizing more complex connections, and streamlining the identification of large problems.

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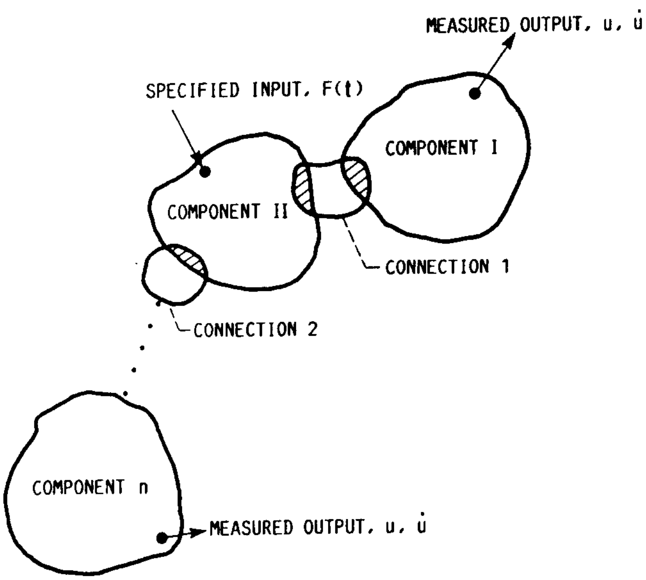


FIGURE 1. - MULTI-COMPONENT COUPLED SYSTEM.

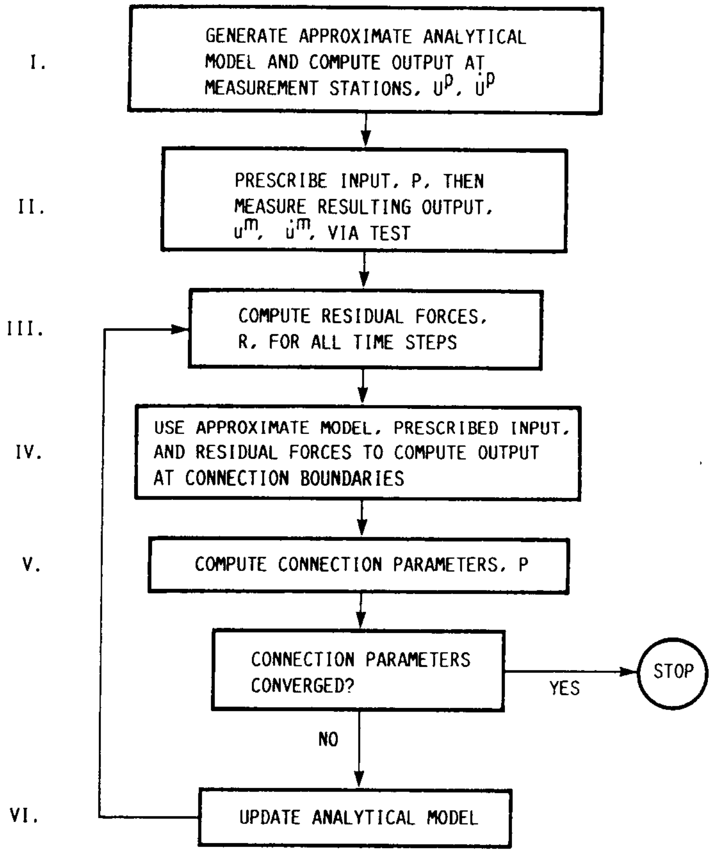
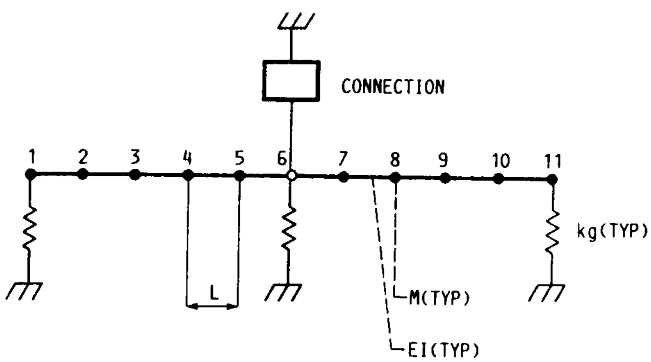


FIGURE 2. - IDENTIFICATION PROCEDURE.



($L = 1.0$, $M = 0.10$, $EI = 10^5$, $kg = 15x10^3$)

FIGURE 3. - STRUCTURAL DYNAMIC SYSTEM.

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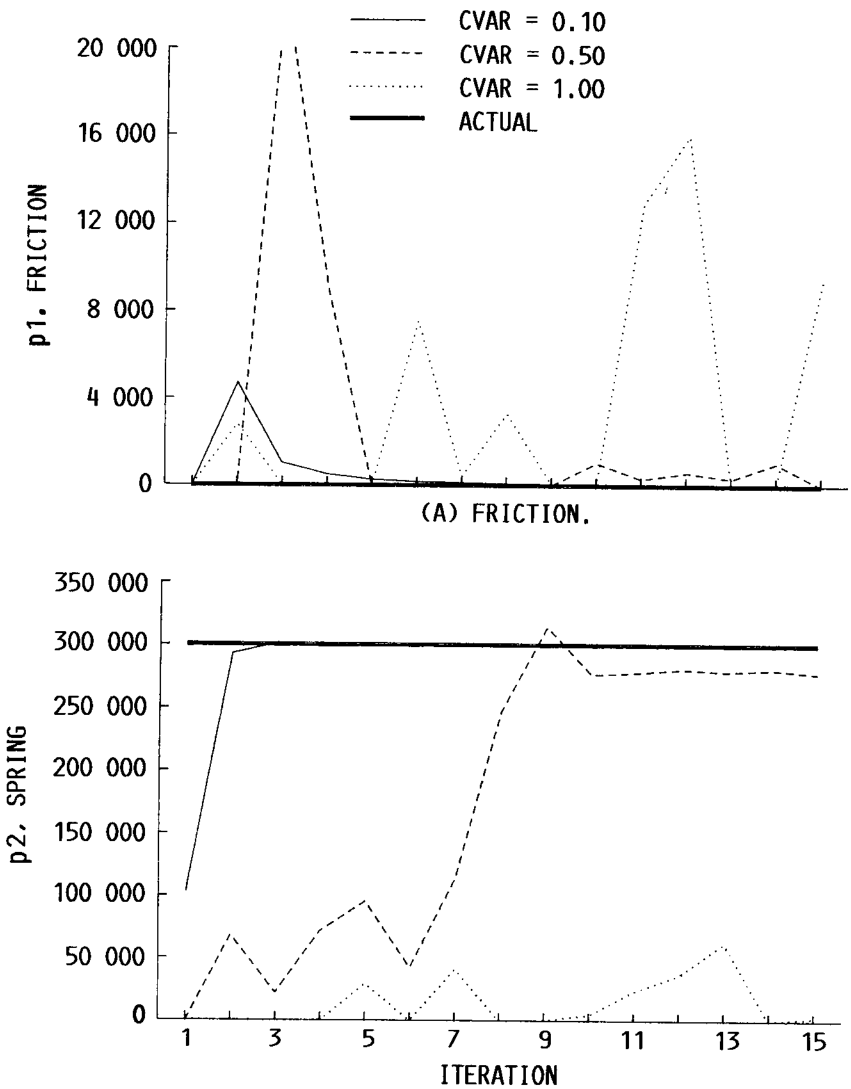
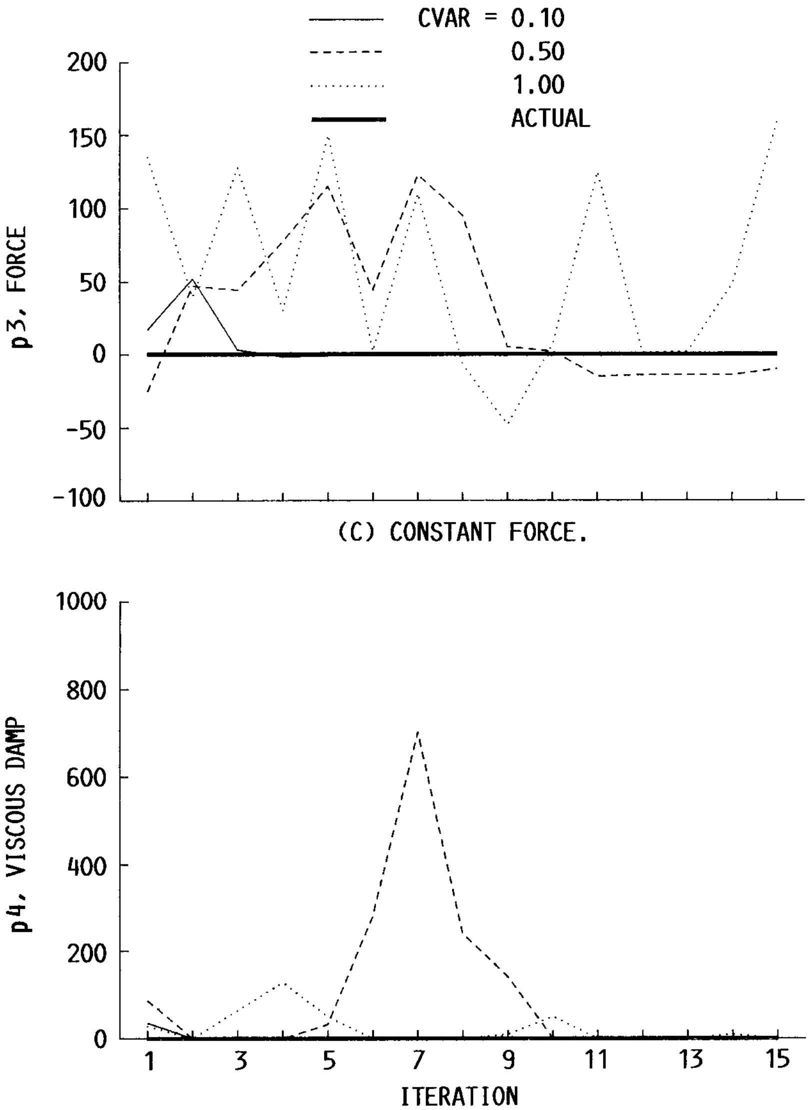


(A) FRICTION.

(B) LINEAR SPRING.

FIGURE 4. - IDENTIFIED PARAMETERS FOR MODEL WITH SPRING STIFFNESS (NUMBER OF OUTPUT STATIONS = 6, DATA POINTS/STATION = 36).



(C) CONSTANT FORCE.

(D) VISCOUS DAMPER.

FIGURE 4. - CONCLUDED.

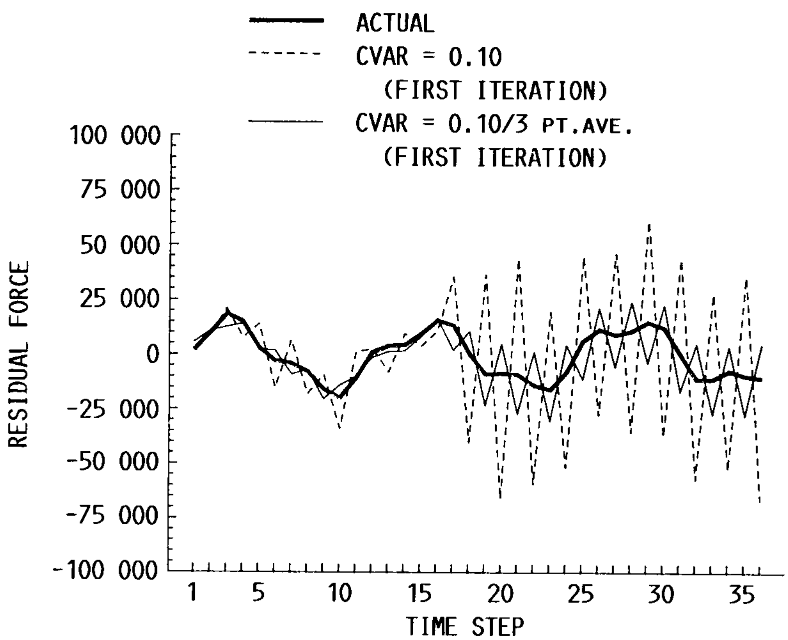


FIGURE 5. - EFFECT OF MEASUREMENT ERROR ON IDENTIFIED RESIDUAL FORCES.

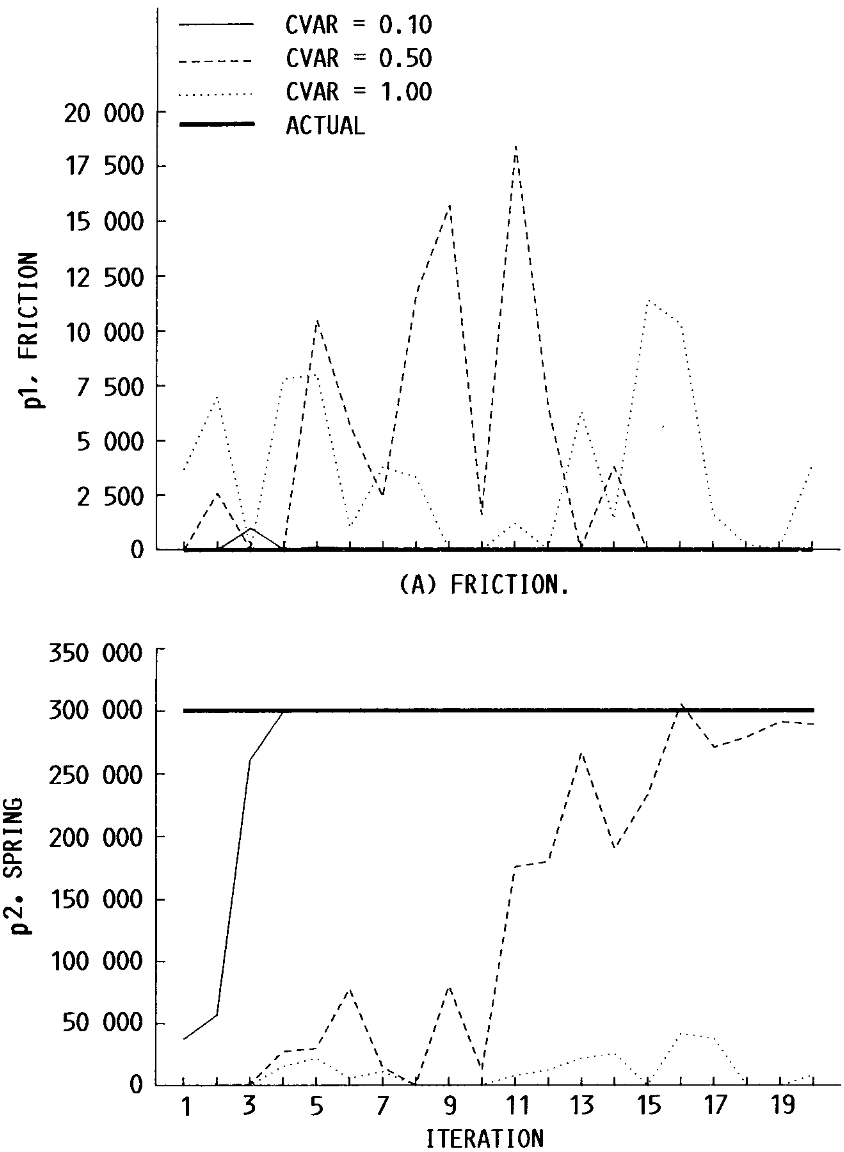
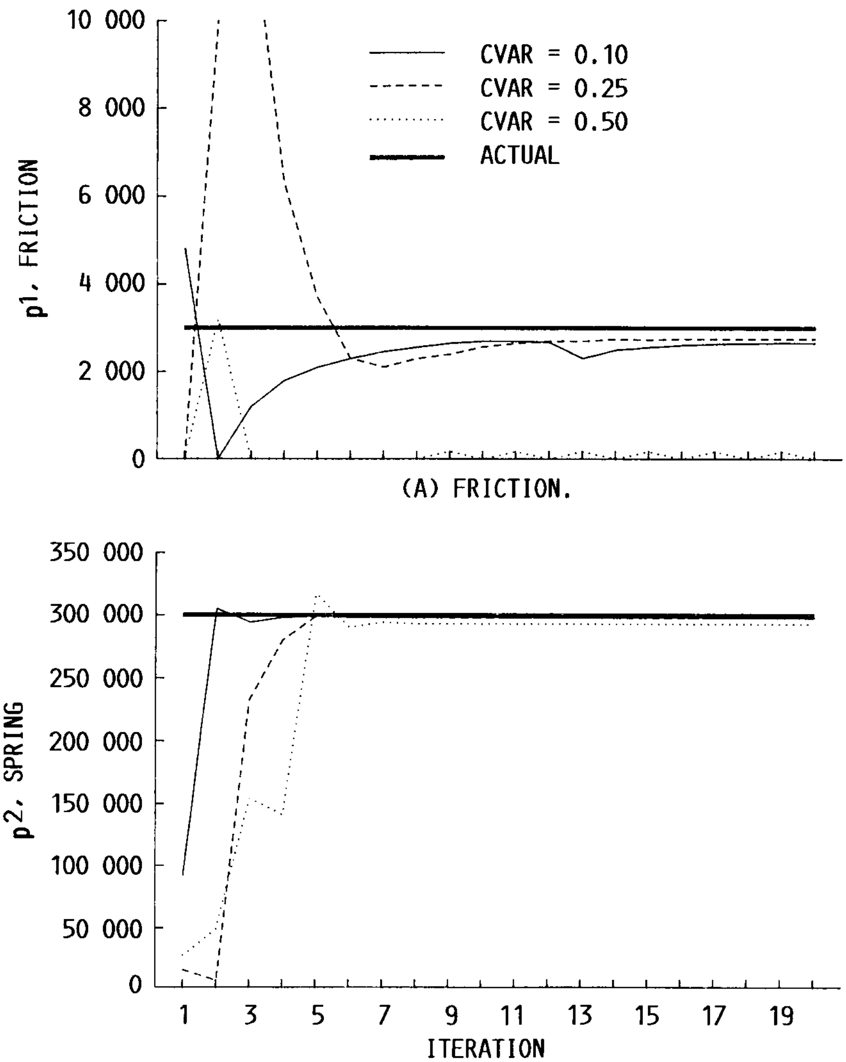


FIGURE 6. - IDENTIFIED PARAMETERS FOR MODEL WITH SPRING STIFFNESS (NUMBER OF OUTPUT STATIONS = 6, DATA POINTS/STATION = 72).



(B) LINEAR SPRING.

FIGURE 7. - IDENTIFIED PARAMETERS FOR MODEL WITH FRICTION DAMPING AND SPRING STIFFNESS (NUMBER OF OUTPUT STATIONS = 6, DATA POINTS/STATION = 36).

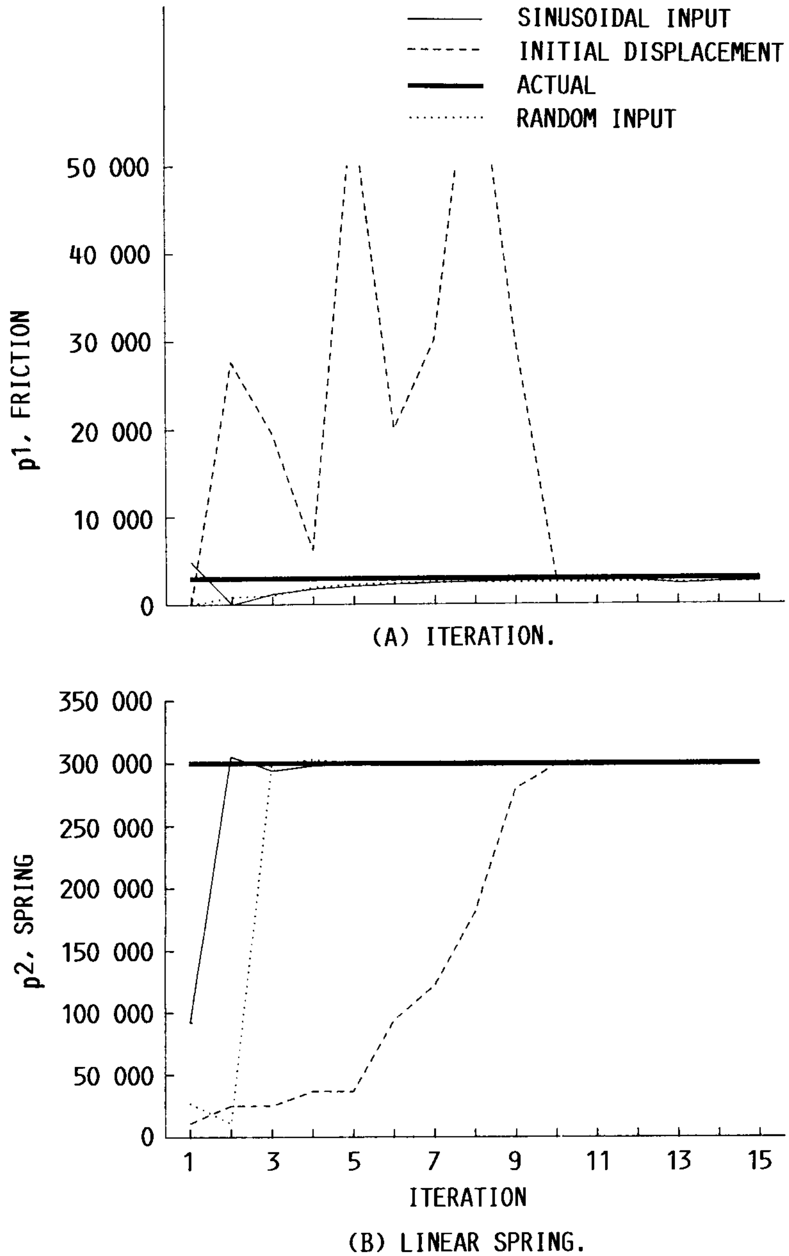


FIGURE 8. - COMPARISON BETWEEN RESULTS FROM FORCED AND FREE RESPONSE TEST DATA (DATA POINTS/STATION = 36, COEFFICIENT OF VARIATION = 0.10.

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16. Abstract

The accurate prediction of system dynamic response often has been limited by deficiencies in existing capabilities to characterize connections adequately. Connections between structural components often are complex mechanically, and difficult to accurately model analytically. Improved analytical models for connections are needed to improve system dynamic predictions. In this study a procedure for identifying physical connection properties from free and forced response test data is developed, then verified utilizing a system having both a linear and nonlinear connection. Connection properties are computed in terms of physical parameters so that the physical characteristics of the connections can better be understood, in addition to providing improved input for the system model. The identification procedure is applicable to multi-degree of freedom systems, and does not require that the test data be measured directly at the connection locations.

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