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System Identification of Large Structures
- Evidence of Usefulness

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Abstract

The authors have performed identification of many structures and have taken note of much work by others. Most of these studies are of a pioneering nature or of very limited usefulness. Will identification of large structures ever become a commonly used, practical, and useful tool? What advances or new understandings are required to achieve this wider use? What software? What experimental techniques? What areas of application? This paper attempts to answer these questions and concludes that there are areas of potential general use, given better experimental procedures, generalized software, and enlightened use.

Current Usage

Due to the high costs of construction and the critical service required, there is a desire for increased assurance of the dynamic properties of large critical structures, such as nuclear power plants, offshore oil platforms, dams, bridges, and high-rise buildings. Because loss of such a structure is costly in terms of dollars--and perhaps lives--safety factors are extensively used in their design. Whereas these safety factors are used to account for uncertainties in peak loads and in structural properties, they necessitate a more costly structure. Therefore, increased emphasis has recently been placed on more accurately defining structural properties and dynamic loads, with the aim of reducing overconservative safety factors. More accurate structural models can result from the *system identification* process.

The authors have used the following four-phase process [1] for linear structures: (1) formulation of a pre-test analytical model; (2) dynamic testing, data acquisition, and data reduction; (3) identification of modal characteristics (resonant frequencies, mode shapes, damping ratios, and effective masses); and (4) post-test refinement of structural parameters (element geometry and material properties). Examples of model refinement through use of system identification are presented for two large structures. Structural parameters were refined using ASTRO/MOVE [2], a finite element program incorporating Bayesian parameter estimation [3] and closed-form response sensitivities.

The first structure was Pacoima Dam, a 111-m high concrete arch dam. Sinusoidal forced-vibration tests were conducted [4] to determine modal characteristics of the dam. The model consisted of 34 twenty-node continuum elements and had 658 degrees-of-freedom. The first two measured resonant frequencies were chosen for matching, and elastic

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moduli of the elements were chosen for revision. Table 1 lists the measured resonant frequencies.

Table 1. Resonant Frequencies For Concrete Arch Dam

Measured Frequency (Hz)	Pre-Test Model Prediction (Hz)	Revised Model Prediction (Hz)
4.50	4.26	4.54
5.45	4.81	5.39

Table 2. Resonant Frequencies For Offshore Platform

Measured Frequency (Hz)	Pre-Test Model Prediction (Hz)	Revised Model Prediction (Hz)
0.62	0.59	0.60
0.68	0.70	0.72
0.80	0.86	0.86
2.00	2.20	1.98
2.04	2.04	1.92
2.16	2.49	2.25

The second structure was a North Sea offshore oil platform [5], whose finite element model consisted of 2430 degrees-of-freedom. Experimentally obtained resonant frequencies were chosen for matching; and soil spring stiffnesses, deck masses, and jacket masses were chosen for revision. Table 2 lists the measured, initial model, and final model resonant frequencies.

These examples illustrate the usefulness of system identification for obtaining models which closely match test data. However, model refinement is rarely performed, except in an occasional, ad-hoc manner. What advances are required to enable system identification to become a more commonly used tool? Possible answers are explored in the next section.

Future of System Identification

In the previous section it was shown that determination of accurate structural models can be performed in a systematic manner. Trying to perform Bayesian parameter estimation via a trial-and-error, ad-hoc approach can be prohibitively expensive for large structures. This expense has, perhaps, led to a reluctance in refining structural models. Implementation of the sensitivity matrix in closed form has now made the process practical for the first time.

Perhaps even a greater restriction has been a lack of sufficient test data. Very few structural analyses are accompanied by structural vibration testing. One way to change this would be to have more interplay between analysis and testing groups in an organization. Both should be cognizant of each other's role in identification of structures. System identification can then be thought of as bridging the gap between the experimentalist and the analyst.

Another way to enable test data to accompany a structural analysis would be to reduce the cost of full-scale testing. Whereas an analysis may cost thousands of dollars, a dynamic test at least until recently could cost several times as much to provide a comprehensive set of test data. Of course, how "comprehensive" is comprehensive enough is usually determined by financial, rather than technical, restrictions. Nevertheless, any amount of accurate test data is better than none at all. Easier, more accurate determination of modal parameters would also aid the system identification process. This will come about through advances in testing and data reduction methods. Many modal analysis computer systems are now available and can provide such data at costs comparable to the analysis itself. Furthermore, very useful information can often be obtained with simple techniques and a day or two of testing. Analysts must become more aware of these possibilities.

Will the analyst ever be able to take his model and some corresponding test data, put them into a black box, and obtain a reasonable model that exactly matches the test data? Not only is this doubtful, but it is not desirable. If the analyst uses parameter estimation techniques in a blind fashion, he has not gained any modeling insight, which is just as important as the refined model. In fact, modeling insight can be gained from simply reviewing the terms in the sensitivity matrix; the larger terms indicate greater response sensitivity, which would enable the analyst to see where the structure needs to be modeled most accurately.

Advances in computer software will also enable system identification to be more widely used. Obtaining eigenvalue sensitivities in closed form is extremely efficient; however, eigenvector derivatives require substantially more computer time. In ASTRO/MOVE, eigenvector derivatives are calculated in a closed-form manner [6]; nevertheless, more efficient eigenvector derivative methods would decrease these computational costs. Another software advance would be to employ parameter constraints in the estimation algorithm. Currently, parameters have no constraints and, as such, can sometimes take on physically meaningless values.

Three additional areas for which system identification techniques could be used are: (1) damage detection, (2) identification of nonlinear systems, and (3) force identification. Techniques used in these areas have been applied mainly to simple, low-order systems. Application to large structures would make system identification beneficial to a wide group of engineers and scientists. For example, force identification seeks to identify the forces acting on a structure; these can be determined by knowing the structural response and by knowing the structural model. Better quantification of dynamic forces would enable the more cost-effective design of structures.

More studies are still required for identification of large structures. Simple studies are needed to assess the influence of the quality and quantity of test data. Studies are also required to demonstrate the degree of uniqueness of the final solution. Along these same lines, vibration tests should be conducted with the goal of accurately determining a unique analytical model; this involves judicious placement of shakers and transducers (accelerometers, displacement transducers, load cells, etc.). The sensitivity matrix could be used to aid in proper placement of forcing and measuring instrumentation. Additional studies and uses of the methods are required on simple and complex structures. These studies and uses should be publicized not only to demonstrate effectiveness of the techniques, but also to provide generic modeling insight. Application should also be extended to other types of structures and to mechanisms (e.g., snubbers and robotic systems).

Conclusions

Whereas system identification is not a panacea for grossly inaccurate models, it is nevertheless a systematic process by which to fine-tune structural models and gain modeling insight. Greater use of system identification will come about by:

1. increased awareness by analysts of the uses of system identification;
2. increased use of low-cost, efficient testing methods;
3. increased availability of efficient system identification codes, such as ASTRO/MOVE; and
4. increased awareness of the reduced cost and greater safety (understanding) provided by system identification of actual structures.

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