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INFLUENCE OF SYSTEM UNCERTAINTIES ON STRUCTURAL DAMAGE DETECTION BY AMBIENT VIBRATIONS

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Abstract. The practical difficulties presented by forced vibration testing of large structures, such as transmission lines, led to an increased interest in structural monitoring through ambient vibrations, which usually allows the proper identification of modal properties. Typically, changes in these spectral properties constitute an indication of structural fault, which may then be assessed on the basis of experimental evidence. The authors proposed an approach to determine the stiffness matrices, which are essential to identify the location and intensity of damage. The approach requires ambient vibration data of all relevant coordinates used in the structural model, which are processed employing the SSI method. In practice, the identification method is seriously hampered by ambient factors such as temperature or humidity. In general those effects must be filtered out in other to obtain a reliable diagnosis of damage, approach that demands long term monitoring. In this paper, an alternative approach is explored, based on the introduction of error in stiffness matrices. Data on stiffness matrices is generated on the basis of observed variations of structural member stiffness caused by ambient factors. The influence of this uncertainty on the identified spectral properties is assessed by simulation.

1 INTRODUCTION

In recent contributions, the authors examined experimental evidence concerning the influence of ambient factors on the spectral properties of dynamic systems (Amani et al., 2008; Curadelli et al., 2008; Fadel Miguel et al., 2008). Proposed procedures to eliminate those effects from vibration measurements aimed at damage detection in structural systems demand extensive monitoring to cover the range of expected variations of ambient conditions (Alampalli, 2000). These requirements may render them either too expensive or simply unfeasible due to technical or logistic reasons. Moreover, the issue introduced by noise in the system matrices, which should be distinguished from noise in the vibration recording system, is largely ignored. Empirical or semi-empirical results of those contributions are briefly described for completeness in next section.

In this paper, however, the authors follow an entirely different approach. Changes in the system matrices are assumed to belong in one of two types: reversible and irreversible. The first are due to so-called ambient factors, which include temperature, humidity, and other effects, while the second constitute evidence of damage. In the absence of damage, which is the topic of the present study, the components of the mass, damping and stiffness matrices of the system must necessarily be stationary random processes. It follows that the components of the error matrices, defined as the difference between the system matrices at any arbitrary time and the reference matrices that describe the condition of the system in its initial state must be random variables with zero mean. Hence, the effect of the so-called error matrices on the system spectral properties is assessed first. These matrices are generated by multiplying all components of the reference matrices by uncorrelated normally distributed random coefficients with zero mean and prescribed standard deviation.

2 INFLUENCE OF AMBIENT FACTORS ON SPECTRAL PROPERTIES OF STRUCTURAL SYSTEMS

In previous papers (Amani et al., 2006; Riera et al., 2008), the authors examine available experimental evidence on the influence of ambient factors on steel and concrete structures. Amani et al. (2008) show that, in a limited number of samples of concrete structures, the expected value η of the ratio between observed natural frequencies of structural systems at a mean temperature different from the reference temperature and the frequencies measured at the reference temperature may be estimated by the equation:

$$\eta = 1 - 0.002\,\Delta T - 0.0003\,\Delta h \tag{1}$$

in which ΔT denotes the temperature difference (positive value indicates temperature increase) and Δh the change in atmospheric humidity.

On the other hand, the following expression was obtained for steel structures (Fadel Miguel et al., 2008):

$$\eta = 1 - 0.00051\,\Delta T \tag{2}$$

By means of simple models of struts, Riera et al. (2008) estimate that the maximum values for the temperature coefficients in Eq. (1) span between 0.005 (elements subjected to tensile force) and 0.015 (compressed elements). In case of steel structures (Eq. (2)) these limits are 0.0084 and 0.0028, respectively.

In the same study, in order to assess the influence of temperature on natural frequencies, an artificial neural networks was constructed and it perform in the same way: the network input is a ΔT value which means changes in temperature (˚C) from reference values (increase is positive) and the output provides a correction factor that should be multiplied by the measured natural frequency. The linear regression equation (Eq. (2)) and results obtained with the ANN for the training and validating subsets are shown in Figure 1.

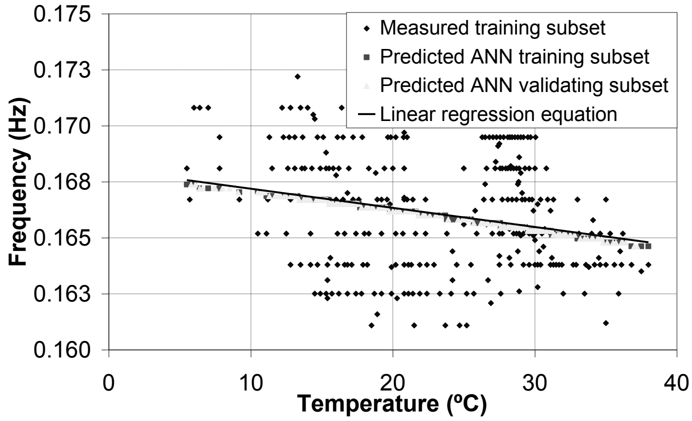

Figure 1: Linear regression equation and ANN results

If the equation for the frequency change is thus of the form:

$$\eta = 1 - c\,\Delta T \tag{3}$$

It may be expected that the stiffness affected by ambient factors and the reference stiffness will be related by η½. If this ratio is denoted as β, then it follows that:

$$\beta = 1 - ½\,c\,\Delta T \tag{4}$$

Consequently, Eq. (4) estimates the expected value of the ratio between stiffness coefficients in the structure affected by ambient factors and stiffness coefficients in the structure in the reference condition, in which the spectral properties were experimentally determined. Note that ΔT denotes the mean temperature change between both conditions, while the temperature as well as the slenderness and axial loads in individual members vary throughout the structure. In this context, it is proposed herein that the ratio between corresponding stiffness coefficients K_{ij} is a random variable β_{ij} with mean given by Eq. (4) and variance to be later defined. In the simulation analysis, the stiffness matrix affected by ambient factors is obtained by multiplying the coefficients K_{ij} of the reference matrix by a set of uncorrelated random numbers β_{ij}.

3 INFLUENCE OF ERRORS IN THE STIFFNESS MATRIX ON SPECTRAL PROPERTIES OF STRUCTURAL SYSTEMS

Some theoretical results will be recalled first: if the stiffness matrix of a linear system without damping is multiplied by a constant factor, the eigenvectors, *i.e.* the vibration modes, do not change, but the natural frequencies should be multiplied by the square root of the factor. This would be equivalent to considering an error stiffness matrix that is proportional to the original matrix.

The influence on the mean spectral properties introduced by stationary random changes in the stiffness matrix due to ambient factors will be assessed first by simulation, considering for such purpose the transmission line tower structure shown in Figure 2. This plane tower consists of 80 nodes and 163 steel bars and structural physical and geometrical properties are available in Murotsu et al. (1994). The height of the tower is 82m while the base is 8m. The supports of the structure are modeled as two hinged supports. The pinned end allows nodes to rotate freely with all three translations restricted.

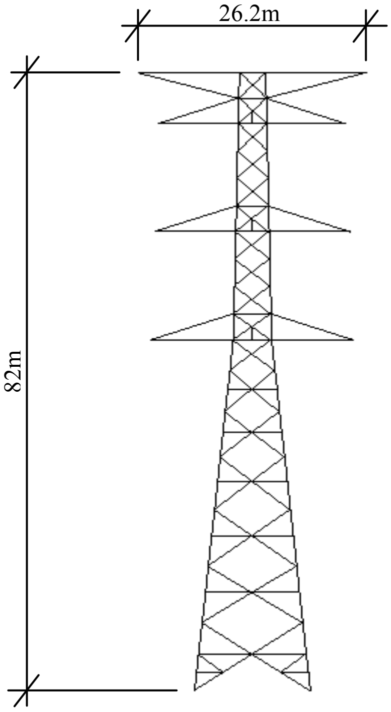

Figure 2: Transmission line tower adopted for simulation study

Stiffness matrices affected by noise were generated by multiplying all components of the reference stiffness matrix by uncorrelated normally distributed random coefficients with zero mean and coefficients of variation (CV) equal to 0.01, 0.03, 0.05 and 0.10. For each CV, 50 disturbed simulated stiffness matrices were generated. The natural frequencies for the first seven modes were next determined for each simulated sample and the corresponding mean calculated next (Table 1).

Original	*CV = 0.01* Mean	*CV = 0.01* Difference (%)	*CV = 0.03* Mean	*CV = 0.03* Difference (%)	*CV = 0.05* Mean	*CV = 0.05* Difference (%)	*CV = 0.10* Mean	*CV = 0.10* Difference (%)
0.9872	0.9872	-0.0006	0.9866	0.0630	0.9858	0.1434	0.9816	0.5691
3.1223	3.1224	-0.0057	3.1205	0.0577	3.1210	0.0422	3.1081	0.4534
5.7880	5.7883	-0.0057	5.7845	0.0608	5.7821	0.1016	5.7605	0.4746
8.8430	8.8431	-0.0017	8.8375	0.0615	8.8280	0.1696	8.7961	0.5303
9.3293	9.3291	0.0011	9.3257	0.0379	9.3172	0.1291	9.2970	0.3460
11.4222	11.4227	-0.0042	11.4222	0.0006	11.4048	0.1523	11.3897	0.2847
13.2648	13.2612	0.0270	13.2578	0.0526	13.2615	0.0246	13.2022	0.4714

Table 1: Natural frequencies comparison (Hz).

It may be seen that a trend to observe smaller frequencies that steadily decrease with the coefficient of variation of the fluctuating components of the stiffness matrix is perceptible for all modes, approaching 0.5% for a CV of around 10%. Since frequency changes of this order would already be indicative of damage, it is clear that the effect cannot be disregarded and that further studies are needed, first to quantify it in different structural systems and then to filter it out in damage identification procedures.

4 CONCLUSIONS

In this paper, the effect of so-called error matrices on the spectral properties of structural systems is examined. The study aims at providing data to assess the range of application and general validity of empirical expression obtained earlier by the authors. The error matrices were generated herein by multiplying all components of the reference matrices by uncorrelated normally distributed random coefficients with zero mean and prescribed standard deviation.

The influence on the natural frequencies due to random changes in the stiffness matrix due, for instance, to ambient factors, was assessed, considering for such purpose a transmission line tower structure. A trend to lower frequencies that steadily decrease with the CV of the fluctuating components of the stiffness matrix is perceptible for all modes, approaching 0.5% for a CV of around 10%. Since frequency changes of this order would already be indicative of damage, it is clear that the effect cannot continue being disregarded in efforts to detect and quantify damage through ambient vibrations.

These results are considered as an initial step in efforts to reduce uncertainties in procedures proposed to detect and quantify damage in structures through ambient vibration monitoring.

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REFERENCES

Alampalli, S. Effects of Testing, Analysis, Damage and Environment on Modal Parameters. *Mechanical Systems and Signal Processing*, 14(1), 63-74, 2000.

Amani, M.G., Curadelli, R.O., Riera, J.D., Ambrosini, R.D. Influencia de Factores Ambientales en las Propiedades Espectrales de Estructuras de Hormigón. *XXXIII Jornadas Sudamericanas de Ingeniería Estructural*, Santiago, Chile, 2008.

Amani, M.G., Riera, J.D., Curadelli, R.O. Procedures for Structural Damage Identification through Ambient Vibrations. *Proceedings of 4th World Conference on Structural Control and Monitoring*, San Diego, CA, USA, 2006.

Curadelli, R.O., Riera, J.D., Ambrosini, R.D., Amani, M.G. Damage detection by means of structural damage identification. *Engineering Structures*, 30, 3497-3504, 2008.

Fadel Miguel, L.F., Riera, J.D., Miguel, L.F.F. Influência de Fatores Ambientais nas Propriedades Espectrais de Estruturas Metálicas. *XXXIII Jornadas Sudamericanas de Ingeniería Estructural*, Santiago, Chile, 2008.

Murotsu, Y., Okada, H., Shao, S., Reliability-Based Design of Transmission Line Structures Under Extreme Wind Loads. *Structural Safety & Reliability*, 1675–1681, 1994.

Riera, J.D., Miguel, L.F.F., Iturrioz, I., Fadel Miguel, L.F., Curadelli, R.O., Kaminski Jr., J. Influência de Fatores Ambientais nas Propriedades Dinâmicas de Estruturas: Limites Teóricos e Simulação. *XXXIII Jornadas Sudamericanas de Ingeniería Estructural*, Santiago, Chile, 2008.