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Influence of frequency-dependent properties on system identification: Simulation study on a human pelvis model

N.E. Conza, D.J. Rixen*

Section Engineering Dynamics, Department of Precision and Microsystems Engineering, Faculty of Mechanical, Maritime and Materials Engineering, Delft University of Technology, Mekelweg 2, 2628CD Delft, The Netherlands

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Abstract

The experimental identification of systems in structural dynamics is commonly achieved by adapting a parametric model so that its simulated response matches a set of measurements. Since in most applications the system mechanical properties are considered constant, standard identification tools assume the same. The question arises over the identifiability of systems which do not satisfy this assumption. The objective of this simulation study is to investigate the influence of frequency-dependent stiffness and damping properties on the system identification, as performed by two standard modal analysis tools and one in-house updating algorithm. Results indicated that the frequencies and the mode shapes are generally well estimated, while the damping ratios proved more difficult to be identified.
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1. Introduction

Structural dynamics is an important aspect in fields such as civil, aerospace and mechanical engineering. In order to facilitate dynamic simulation and testing, computer models are constructed and validated with respect to real measurements. One common assumption of such models is their constant mechanical properties (mass, stiffness and viscous damping) in the operation range of interest. Most standard identification tools use therefore models which satisfy the same assumption.

System identification is gaining importance also in the field of biomedical engineering. The same theories and methods are used on systems which are of biological nature. In the frame of an ongoing research on Low Back Pain, the biological system under investigation is the human pelvis. The bones composing the pelvic girdle are the two ilia and the sacrum, and they interface at the sacroiliac joints and at the symphysis pubis, as illustrated in Fig. 1. A massive ligament network holds the bony structure together.

The rationale behind this research project, which has been hypothesized and investigated in previous works [1,2] but which is still controversial, is that abnormal biomechanical properties of the sacroiliac joints can generate pain. Responding to the lack of objective diagnostics in this matter, the main goal of this research is

*Corresponding author. Tel.: +31 15 278 1523; fax: +31 15 278 2150.
E-mail address: d.j.rixen@tudelft.nl (D.J. Rixen).

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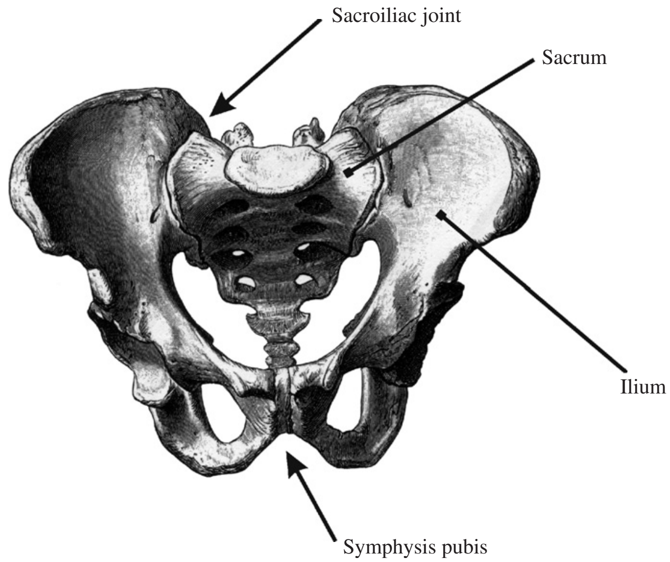

Fig. 1. Human pelvic girdle comprising the sacrum and the iliac bones. The sacrum is braced between the iliac bones at the sacroiliac joints, and the iliac bones are joined at the front at the symphysis pubis.

the development of a diagnostic tool for an objective non-invasive measurement of those properties, comprising an apparatus for the bone vibration measurements by ultrasound [3,4] and an updating algorithm to process the measurements.

A dynamic model of the human pelvis has been built to support the identification of the biomechanical properties of the sacroiliac joints. A first updating algorithm in frequency domain has been developed and tested in simulations [5].

The properties of the human pelvis have so far been modelled as constant. However, literature shows that the response of ligaments under quasi-static tensile experiments varies with the speed at which the strain or stress is imparted [6]. This suggests that the mechanical properties of ligaments might depend on the frequency of the excitation as well.

The system has been investigated by means of modal testing on fresh-frozen human specimens [7,8], in order to obtain information for the validation of the model. The validated model will then serve as a base for the updating algorithm. The question on the influence of frequency dependency is therefore relevant for the accuracy of both the modal analysis and the dedicated updating algorithm.

Fig. 2 provides an example of the typical *in vitro* response by showing drive point measurements at different times throughout one of the cadaver experiment session [8]. Based on these test data it is difficult to fully assume or rule out the possibility that there is some frequency dependency involved. On the contrary, nonlinear effects have been excluded in the measured frequency range and level of excitation by prior checks of the response at different amplitudes. The justification of this study is to assess the level of misinterpretation that can be made when analysing the response of frequency-dependent systems with standard modal analysis tools. This assessment should be made before attempting an interpretation of the real test data. With this goal in mind, the most observable system is a simulated one, where the mechanical properties are positively known. All other test benches are subject to the imprecision and uncertainty of real measurements and real system identification.

In this study the influence that a frequency dependency in the mechanical properties might have on the identification quality is investigated. Measurement data are synthesized from a model showing linear frequency-dependent stiffness, and a hysteretic damping component next to the viscous damping. In this model the elastic and dissipative forces increase with the frequency. The generated data are used as input for two standard modal analysis tools and the in-house updating algorithm. For comparison, the identification capability of the latter is evaluated with and without built-in frequency dependency.

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