RESPONSE BASED MODAL IDENTIFICATION OF A REAL STEEL CHIMNEY

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Measured structural responses are commonly employed via operational modal analysis (OMA) methods in order to assess the modal parameters of the monitored system. Vibration data recorded within a semi-continuous Structural Health Monitoring (SHM) campaign installed on a real steel chimney structure is in the focus of this study. The dynamics of the actual structure is studied under real loading scenarios for two specific load cases. By the utilization of a combined response based approach the natural frequencies of the steel chimney structure are successfully identified.

Keywords: real structure, vibration response, structural monitoring, modal identification

1. INTRODUCTION

The attractive potentials in exploiting measured structural responses in operational conditions under natural excitation, introduced in the early 1990’s, marked the beginning of the OMA era. Indeed, the advantages in identifying the actual structural dynamics by conducting fast and relatively cheap experiments have instantly attracted the research and industry communities [1].

The following vast progress in the development of various assessment tools suitable for accurate and reliable modal identification of monitored systems, as well as the parallel technological advancements, have tunneled the focus towards development of more holistic approaches suitable for automated SHM damage detection and life-time estimation strategies on existing structures [2].

Unlike the controlled laboratory environment, implementing SHM strategies on real civil engineering structures introduces many uncertainties, uniquely linked to the particular system under study. This dismisses the possibility for straightforward utilization of existing structural identification tools. In this context it becomes an imperative to test the performance of various OMA methods on real structures.

Vibration response data was continuously collected for the period of two months in the framework of an implemented monitoring system on a steel chimney structure. By exploring the performance of the RD-EFDD (Random Decrement – Enhanced Frequency Domain Decomposition) method the focus of this study is: 1) extraction of the natural frequencies of the monitored structure and 2) assessment of structural behaviour for selected loading scenarios, specific for the actual structure.

2. RD-EFDD ANALYSIS APPROACH

The RD-EFDD method is a merged approach which enables estimation of the Averaged Normalised Power Spectral Densities (ANPSD) of response variables with reduced noise and reduced effects of leakage, compared to the commonly applied frequency domain tool (EFDD). The concept was verified for the case of a scaled laboratory model of a frame structure [3].

Under the assumption that assembled structural responses are realization of a zero mean stationary Gaussian stochastic process, the RD functions are proven to be proportional to the correlation functions of the responses and/or to their derivatives in relation to time [4-6], thus enabling the employment of RD functions within OMA framework.

The RD functions are interpreted as free vibration responses of a system subjected to random input loads. Namely, if we decompose the system's response to the three parts: i) response to an initial displacement, ii) response to an initial velocity iii) response to the random loads between initial time and time *t*, then by averaging the time segments with identical initial conditions the part related to random inputs has the tendency to diminish.

The RD technique is a time-domain technique and may be utilized with various triggering conditions applied directly to the response time-histories [6]. In this manner, time segments corresponding to the same triggering condition are extracted from the full length samples and averaged. The newly obtained signals are the RD functions. By evaluating the auto and cross RD functions (auto-triggering or cross-triggering condition) of measured response data, the RD functions matrix is constructed. Finally, the ANPSD matrix can be evaluated as the mean of the spectral matrices computed from each column or row of the RD function matrix [3].

Eventually, the EFDD method is applied in the same way as with the commonly estimated spectral densities from vibration responses [7].

3. THE APPLICATION CASE STUDY

The structure under study is an out of use steel chimney located on the premises of Ohis Factory in Skopje, Republic of Macedonia (Fig.1).

Height: 40 m

Diameter: 1.9 m

Thickness: 6-10 mm

Material: Steel S235

Construction year: 1970

Figure 1. Monitored steel chimney

In order to obtain a comprehensive dynamical model of the chimney structure, a SHM campaign was undertaken in the period 14/12/2013 to 14/02/2014. An installed monitoring system for the complete timeframe of two months continuously measured: structural vibration responses, environmental parameters (wind velocity and ambient temperature), as well as ground vibrations nearby the structure (Fig.2).

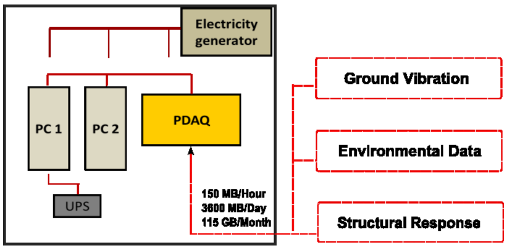

Figure 2. Schematic overview of the SHM system

One-hour long acceleration time histories are recorded by five tri-axial accelerometers for ambient vibration (Digitexx D110-T sensor) placed along the structure's height, with the sampling frequency of 200 Hz. The placement and positioning of the sensors, as well as the measured response directions are presented in Fig. 3. As a preliminary step and for the purpose of comparison only, a Finite Element Model (FEM) (beam and shell) of the structure was developed (Fig. 4).

Figure 3. Accelerometers installation & position along the structure height and cross sections

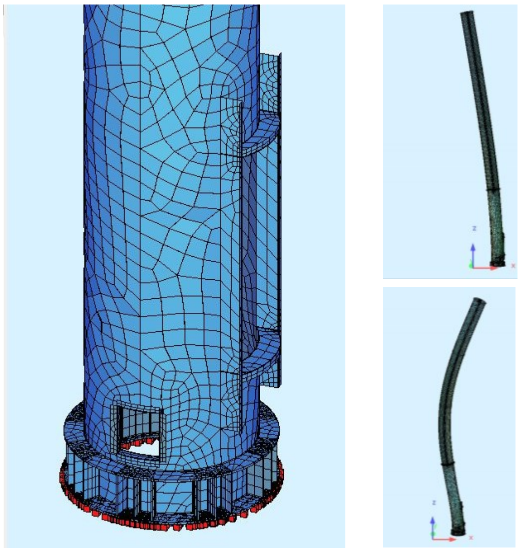

Figure 4. Shell FEM of the structure

The previously introduced response-based method is herein applied for an initial structural behaviour assessment related to two identified loading scenarios: i) recurring train induced vibrations (TIVs) from a nearby railway, and ii) wind induced vibrations (WIVs) for a time frame corresponding to the maximal value of recorded wind velocity within the two months period of monitoring. In Fig. 5 the 24-hour (25.01.2014) measured wind velocity is presented, including the period of the highest recorded value of 21 m/s.

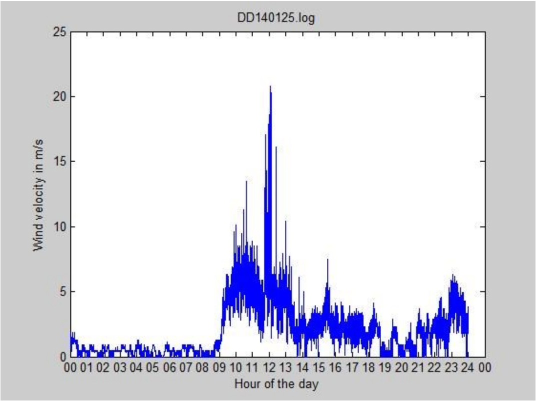

Figure 5. Time-history of the wind velocity containing the maximum measured value

Before further utilization, the acceleration time histories for both cases were low-pass filtered and down-sampled to 50 Hz (cut-off frequency at 17 Hz).

The spectrograms (Short Time Fourier Transform; Hamming data window; NFFT = 1024; overlap 98%) of measured vibration response corresponding to the highest sensor (X direction in Fig.3) clearly expose the specifics of each case (Fig. 6 and Fig. 7). The train induced amplifications in the acceleration time history are as well clearly visible for the selected 30-min data sample (Fig. 6).

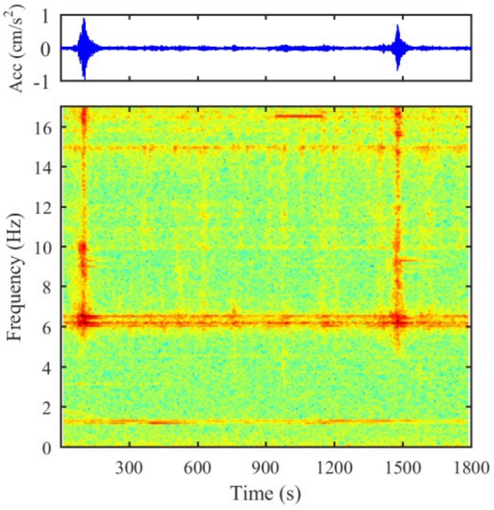

Figure 6. Case of TIVs- top sensor Xdir: (up) Acceleration time-history, (bottom) Spectrogram

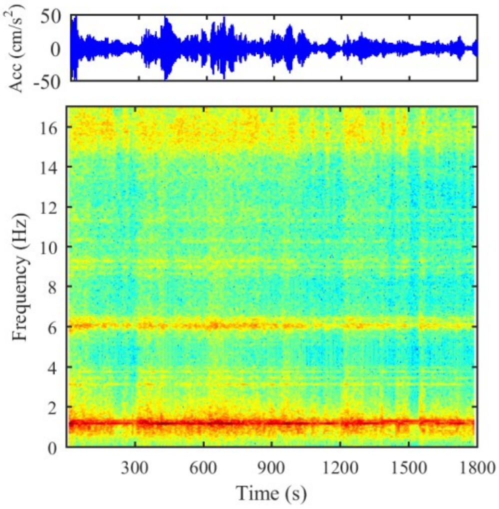

Figure 7. Case of WIVs - top sensor Xdir: (up) Acceleration time-history, (bottom) Spectrogram

An interesting observation is the identical frequency "signature" (excluding the structural frequencies) revealed by further inspection of the time-frequency plots of ground accelerations (accelerometer placed nearby structure) (Fig. 8).

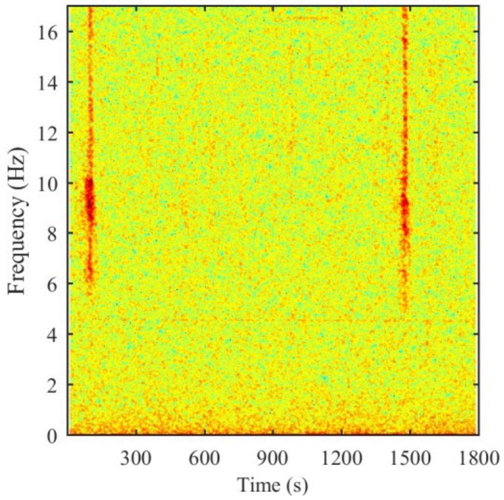

Figure 8. Case of TIV: Spectrogram of the ground acceleration record

The RD-EFDD method is now utilized for obtaining the structural modal parameters of the chimney structure. The triggering level crossing condition is selected as a multiple of the standard deviation (std) of the measured accelerations: 1std (TIVs) and 4.5std (WIVs). The time segments length necessary for complete decay of the RD functions is 1500 data points (dp) for the TIVs case, and 6000 dp for the WIVs case, which corresponds to 30 sec and 120 sec long signals, respectively.

In Fig. 9 and Fig. 10 the ANPSD plots for the two selected load scenarios are presented. The TIVs introduce amplification in the higher frequency range (as clearly indicated by the spectrograms in Fig. 5 and Fig. 6). On the other hand the WIVs accentuate the lower range of frequencies, however as well enabling a clear identification of the first two natural frequencies of the structure.

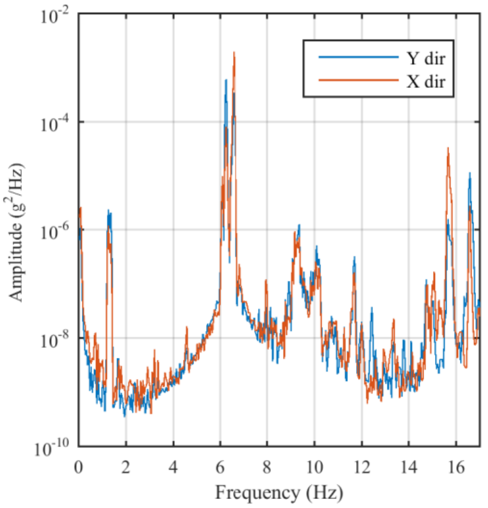

Figure 9. Case of TIV: ANPSD from RD-EFDD method (triggering: 1 std, length: 1500 dp)

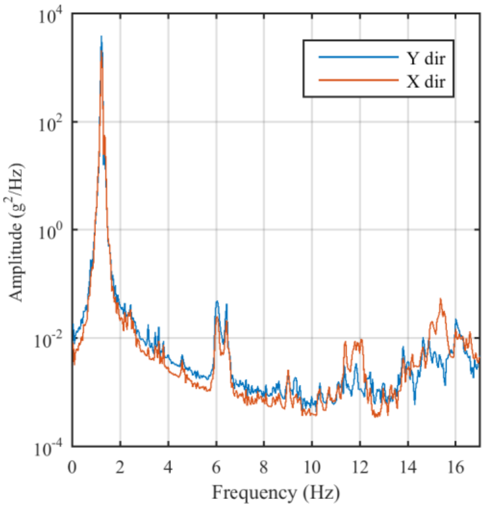

Figure 10. Case of WIV: ANPSD from RD-EFDD method (triggering: 4.5 std, length: 6000 dp)

In Tab. 1 the comparison of the estimated frequencies from the FEM of the structure and data-based estimations via the RD-EFDD technique are presented. Only with the purpose of validation, results from the commonly applied stochastic subspace identification method (SSI-COV) are included as well. For the sake of brevity the details of the method will not be reported herein (for an overview the reader is referred to [8]).

The RD-EFDD based mode shapes corresponding to the identified natural frequencies are presented in Fig. 11.

Table 1. Comparison - list of the first two estimated natural frequencies of the chimney structure (in Hz)

f *[Hz]*	**FEM** **(shell)/** **(beam)**	**WIV** **EFDD-RDT**	**WIV** **SSI-COV**	**TIV** **EFDD-RDT**	**TIV** **SSI-COV**
$f_{[1\text{-}x]}$	1.32/1.38	1.18	1.17	1.19	1.19
$f_{[1\text{-}y]}$	1.39/1.38	/	1.25	/	/
$f_{[2\text{-}x]}$	6.54/6.95	6.00	6.04	6.20	6.18
$f_{[2\text{-}y]}$	7.35/6.95	6.39	6.39	6.54	6.55

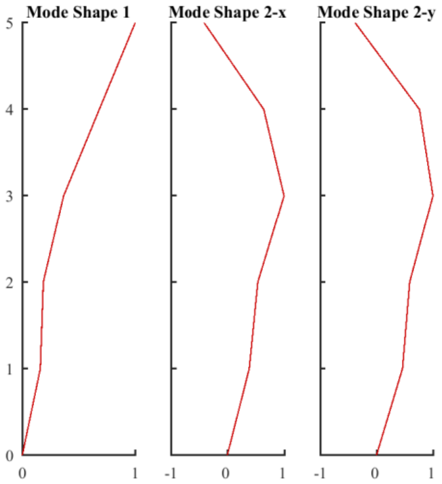

Figure 11. RD-EFDD estimated mode shapes for the identified structural frequencies

CONCLUSIONS

Recorded response data of a real steel chimney structure was successfully utilized to identify the first two natural frequencies of the vibrating system.

The RD-EFDD method shows good agreement with results from the simulated FEM analysis and SSI-COV estimates. However, the approach was not capable of identifying the closed spaced first natural frequencies of the structure in both load cases.

Inspection of the spectrograms of measured accelerations for the two different load cases (train and wind induced vibrations) revealed the specifics of the dynamic response of the system.

Following research is directed towards assessing modal damping parameters, close spaced modes, as well as identifying higher structural frequencies.

Acknowledgements

The experimental research study would not be possible without the appreciated support of: SEEFORM Doctoral School, Faculty of Civil Engineering – Skopje, Ohis Factory – Skopje, Digitexx Data Systems Inc., Reko Extreme Engineering Company, Sintek, Pharmachem Skopje.

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