Proceedings of the 9th U.S. National and 10th Canadian Conference on Earthquake Engineering
Compte Rendu de la 9ième Conférence Nationale Américaine et
10ième Conférence Canadienne de Génie Parasismique
July 25-29, 2010, Toronto, Ontario, Canada • Paper No 764

ANALYSIS OF SMALL FREQUENCY VARIATIONS IN TWO TWIN TOWERS USING AMBIENT VIBRATIONS

A. Mikael[1], P. Guéguen[1], P. Roux[1] and P.-Y. Bard[1]

ABSTRACT

Ambient vibration recordings are of great interest for engineering objectives. Thanks to the last technical and processing developments, more deep and precise studies could be used on civil engineering structures for assessing their modal parameters and their physical properties. This study is focused on long-term variations of the frequency parameters of two twin towers getting from ambient vibrations recordings. Dialy variations of the fundamental frequency are then observed, related to the temperature effects, and synchronized transient variations are also observed between the two structuraly independent towers. Preliminary interpretations of such as variations are shown here, that may be due to the local rainfalls and the monthly temperature variations.

Introduction

For long time (e.g., Omori, 1922), ambient vibrations recordings in existing buildings are of great importance in earthquake engineering for predicting their dynamic response in case of earthquakes. Since Omori, and in parallel with the the quality improvement of the data and the processing methods recordings, several studies have been published focused on the reliability of the structural behaviour assessment using ambient vibrations for seismic response of existing buildings. One application is to fix the elastic properties of the buildings, i.e. the frequencies, damping and mode shapes. These properties reflect the state of studied building and its ability to resist to horizontal loading, such as wind and earthquakes (Clough and Penzien, 1992). As the stiffness of structure changes after significant events, the consequences are a variation of the frequencies values and mode shapes, two modal parameters that could be used for the post-seismic integrety assessment of buildings. For these reasons, it is a key point to have a reliable estimate of these parameters, particularly using ambient vibrations. Several studies have observed the transient variation of the resonance frequency during earthquake related to the openning and re-closing process of pre-existing cracks (e.g., Bradford et al. 2004, Clinton et al.,

2006; Dunand et al., 2006; Michel et al., 2009; Michel and Guéguen, 2009). Others pointed out a permanent drop of frequency after strong events (Clinton et al., 2006; Dunand et al., 2006), consequencies of the seismic damage. Recently, Clinton et al. (2006), Todorovska and Al Rjoub (2006), Ni et al. 2005 and Breuer (2008) showed that, for long-term monitoring of buildings, small frequency variations under ambient vibrations could also be due to the atmospheric conditions, such as rains fall altering the elastic property of soils and then influencing the soil-structure interaction system. Since small variations of fundamental frequencies observed in buildings may not be always related to damaging process, the reliability and the physical meanings of dynamic parameters using ambient vibrations must be discussed in deep.
The main goal of this paper is to study the monthly variations of frequencies in buildings. In addition to recent published papers, we studied here two twin towers in Grenoble city (France), which offer us the possibility of tracking an eventual correlation between their wandering dynamic behavior due their proximity. Along with the observation of temporal fluctuations, we try to explain the observed variations and approve the reliability of methods used for assessing frequencies wandering.

The Ile Verte twin towers

Grenoble (France) is a dynamic city that increased in population during the late 60s. Many high-rise buildings were built at that time. The three Ile Verte towers are 29-story RC-buildings, including two underground levels. Built between 1963 and 1967, these 100 m towers (B=20m, L=40m) were the highest in Europe at that time. In this paper, only two Ile Verte twin towers, Belledonne and Montblanc, were analyzed. These towers are reinforced concrete (RC) housing buildings, constructed without earthquake resistant design. The architectural plans show a rhombus form sections and the shear resistant of the structure is mainly controlled by continuous RC shear walls insuring a lateral stiffness in both longitudinal and transverse directions. In this zone, the soil condition is soft, mixing clay deposits, and sand and gravel thin layers, resulting of the glacio-lacustrine deposits and the later fluviatile process, characteristic of Alpine valley deposits such as Grenoble basin. For this reason, even though the foundation system is unknown, deep foundations are suspected.

Experimental data and processing

In July 2007, ambient vibrations were recorded at the top of the two buildings with a Cityshark digital acquisition station (Chatelain et al., 2000) connected to a 3C velocimeter Lennartz 3D 5s. The data were one file of 58 minutes recording per hour, every file contains three components data, in the longitudinal L, transverse T and vertical Z direction, sampled at 50 Hz. An example of this ambient vibration records is given Fig. 2.

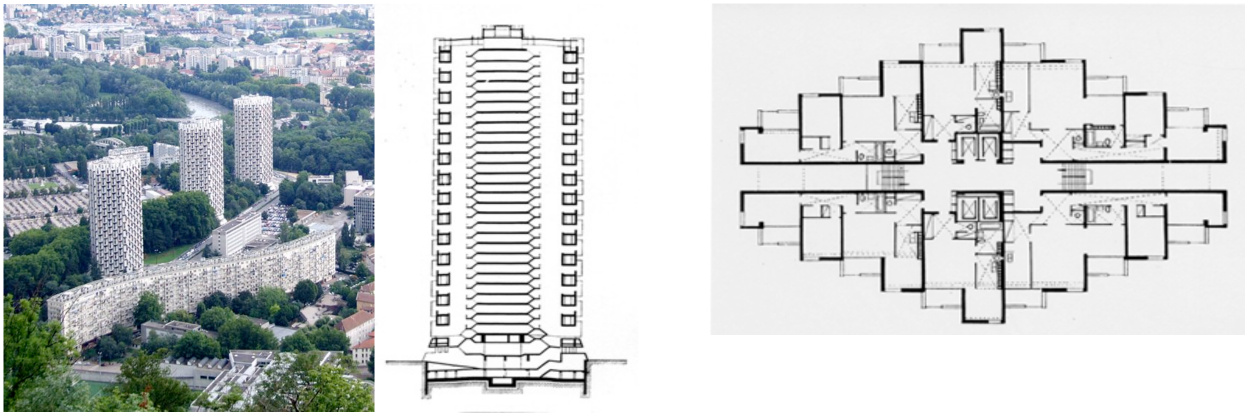

Figure 1. Left: The Ile Verte twin towers of Grenoble city. Belledonne and Montblanc towers are the two towers at the background of the picture. Right: elevation and plan view of the Belledonne tower.

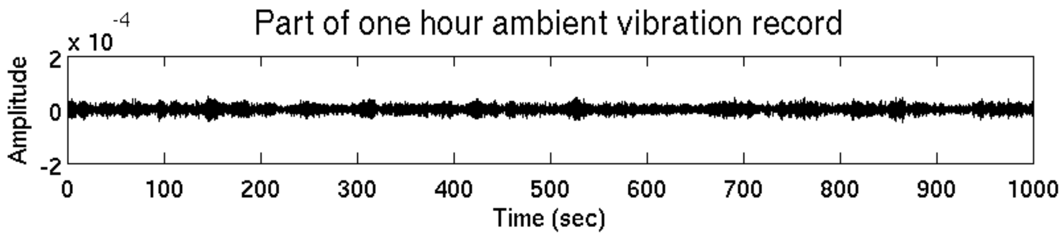

Figure 2. Example of ambient vibrations recordings at the top of the building.

In order to find modal frequencies, we used the Random Decrement Technique (RDT, Cole, 1973), a time domain method, and the Half power bandwidth, a frequency domain method.

Random Decrement Technique

Developed by Cole (1973), RDT allows us to calculate frequency and damping using ambient vibration recordings. Assuming that an ambient vibration signal contains the free response of the sructure to external various sources of vibrations, we can extract this response by summing all parts of signal starting with a given length and initial conditions, reducing the white noise effects on the response contained in the signal (Fig. 3). Ambient vibration recordings may contain several modal frequencies, depending on recording accuracy. For this reason, a band-pass filter was used in order to isolate the modal frequency analysed which is first calculated by a simple Fast Fourier Transform.

In our study, a Butterworth band pass filter of fourth order is applied. Positive velocity and zero displacement windows of 20 seconds length are picked up as initial condition and then their mean value represents the structure's free response, whose form is sinusoidal exponentially damped for each mode. The average time elapsed between every two upward zero crossing points represents the period T, then the frequency F = 1/T.

Within the 20 seconds window, we have several oscillations, thus, the considered frequency is the average over all these oscillations frequencies. Since the frequency goes smaller up to the end of the window, we limited its length at 20 seconds to avoid the average to be biased by the reducing amplitude at the end of the window. On the other hand, we need at least a window length of 10 times the period of observed phenomenon, i.e. in our case the frequency of the structure.

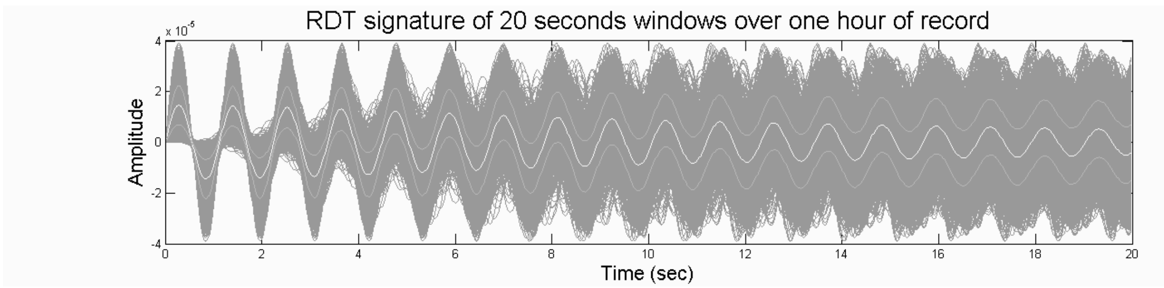

Figure 3. RDT signature and its standard deviation

For the frequency, we use a linear regression of maxima and minima on the exponential dercrease of the free-oscillating building response. Their logarithm curve forms a straight line whose slope is proportional to the damping ratio and the frequency. Ony the frequency will be discussed in this paper.

Half power band-width

A second method is based on the Half power bandwidth (Clough and Penzien, 1993), in the frequency domain. In order to improve the accuracy of the frequency assessment, we used an average Fourier spectrum over 21 windows of 8192 points of data in each one haour time windows, without overlapping. The first mode of the building response has enough spectral energy to be assessed using this method. The central frequency is estimated considering the frequency band of the spectral limited by f1 and f2 frequency which correspond to the $A/\sqrt{2}$ reduced amplitude of the maximum amplitude spectrum. The frequency is then calculated using the following formula :

$$f = (f1 + f2)/2 \quad (1)$$

Results

Spectrum analysis

The present paper deals only with the first mode of both the North-South (longitudinal L) and East-West (transverse T) components. Fast Fourier Transform allowed us to identify three modal frequencies per component for every tower. Table 1 summarizes all the frequencies. The FFT has been computed for every one hour, during one month of recording, then only the mean spectrum of all these spectra is presented on Fig. 4

Table 1. Resonance frequencies of the twin towers in the longitudinal and transverse directions.

Building	**Direction**	**Mode 1 - Hz**	**Mode 2 - Hz**	**Mode 3 - Hz**
Belledonne	L	0.89	3.25	6.58
	T	0.67	2.79	6.10
Montblanc	L	0.84	3.21	6.71
	T	0.65	2.64	5.71

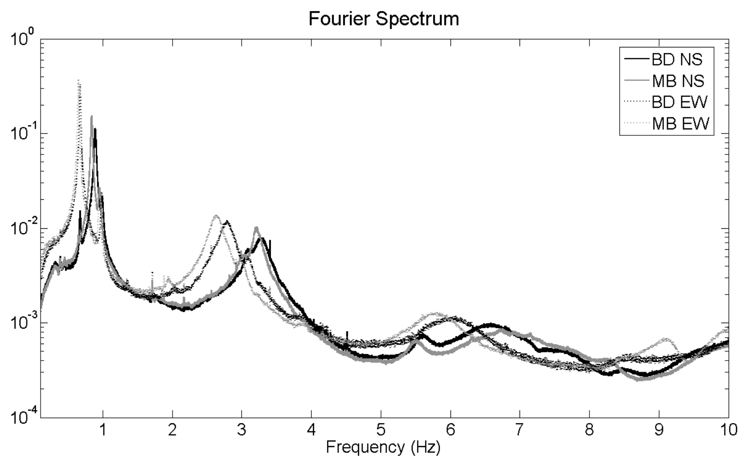

Figure 4. Amplitude spectra of the ambient vibrations recordings in the Belledonne (BD) and Montblanc (MB) towers in the Longitudinal (MS) and Transverse (EW) directions.

The modal frequencies of these twin towers are quite close between the two components, reflecting a good similarity of their dynamic characteristics.

Wandering of the fundamental frequency of the Montblanc and Belledonne towers

The first frequency wanders during the period of study up to 0.93% of the mean value with 0.002 Hz to 0.003 Hz of standard deviation. We can easily observe dialy variations (Fig. 5), especially on the EW component of Montblanc tower. These variations could be due to thermal effects of temperature changes, between day and night, on reinforced concrete. Clinton et al. (2006), observed this dialy variations on Milikan library, while Ni et al. (2005) observed it on Hong Kong bridge and Breuer (2008) on Stuttgart Communication Tower. All these authors reported this wandering and assumed the origin to thermal conditions such as external temperature and sun exposition.

Considering every component, a very good correlation between the two buildings is observed: the main variations are present in the two buildings, which means that buildings having similar dynamic properties can also have similar dynamic behavior at least for this level of loading.

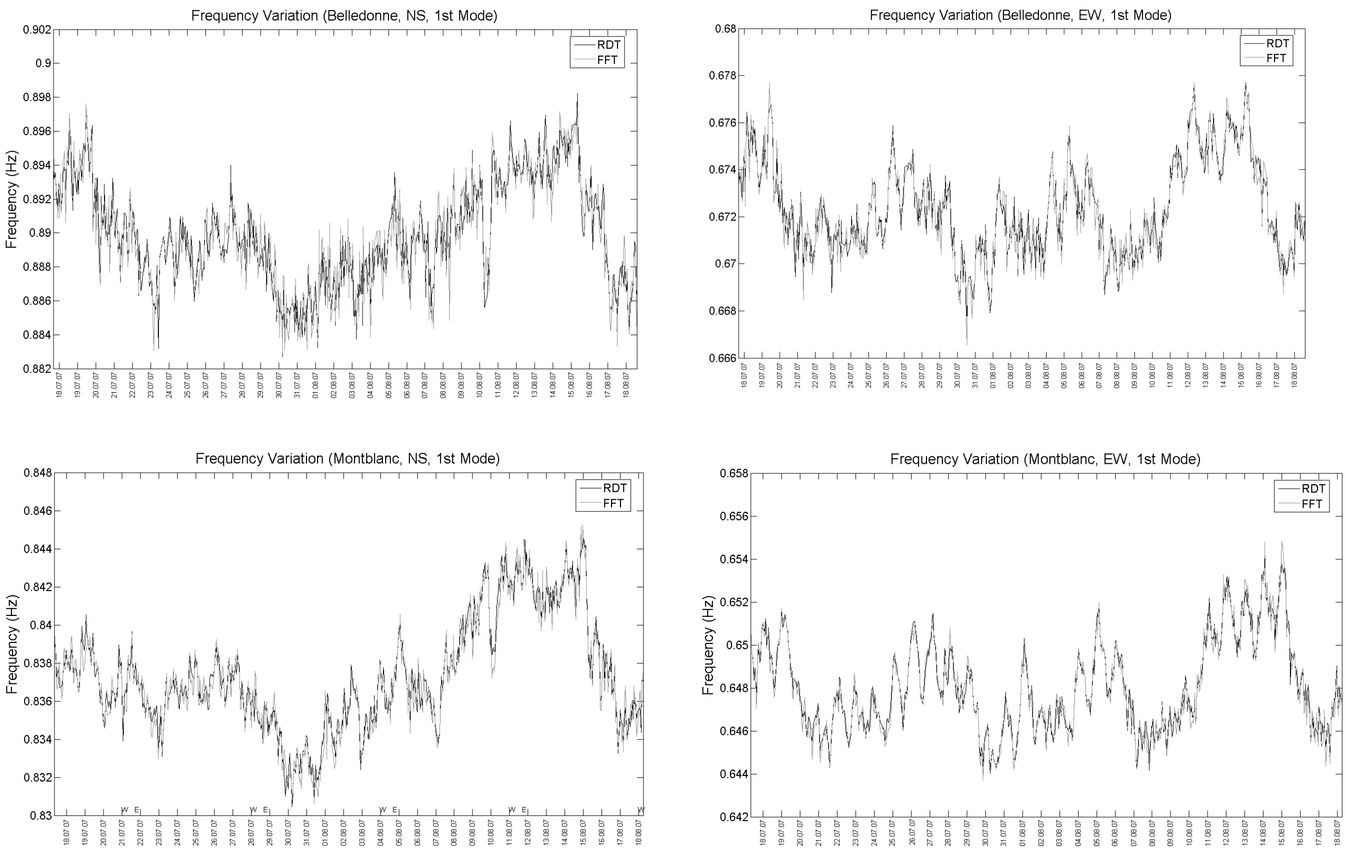

Figure 5. Wandering of the fundamental frequency of the Montblanc (lower row) and Belledonne (upper row) buildings, for the EW (right) and NS (left) directions, using the RDT method and the half power bandwidth method.

Moreover, a general trend of the wandering is also observed whatever the building and direction. First, Figure 6 displays the amount of rainfall per day with the frequency wandering of the buildings. No correlation between rainfall and frequency are observed on this period, even if heavy falls were recorded. The decrease of the frequency with rainfalls was reported by Clinton et al. (2006) and Todorovska and Rajoub (2006) explained this relation due to the soil-structure interaction effect as consequences of the shear waves velocity decrease due to humidity into the ground.

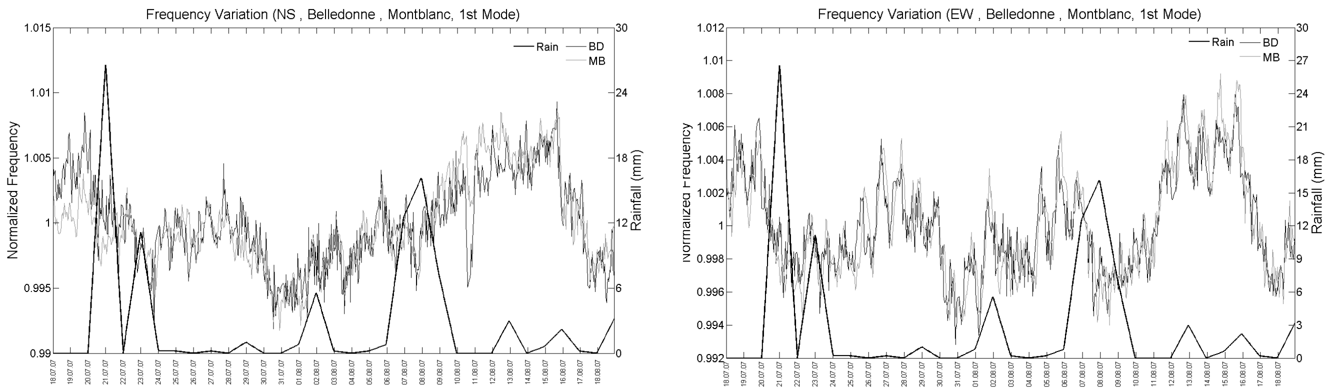

Figure 6. Wandering of the fundamental frequency of the Montblanc and Belledonne building for the EW (right) and NS (left) direction, using the RDT method, and comparison with the rainfalls.

However, the general wandering trend in our paper is well correlated with the general trend of the temperature (Fig. 7), especially for the EW direction which is the most exposed surface to the sun. According to De Roeck (1997) in studies carried out on bridges, frequency could change on the order of 5% when the temperature changes by 15 °C. Figure 7 shows a good correlation between the maximal trend of the temperature variations, recorded on some fifteen kilometers far away from studied buildings, and the trend of frequency variations. This might be due to stiffness changes related to height of the structure, by mean of the coefficient of thermal expansion, since the towers are as high as 100m.

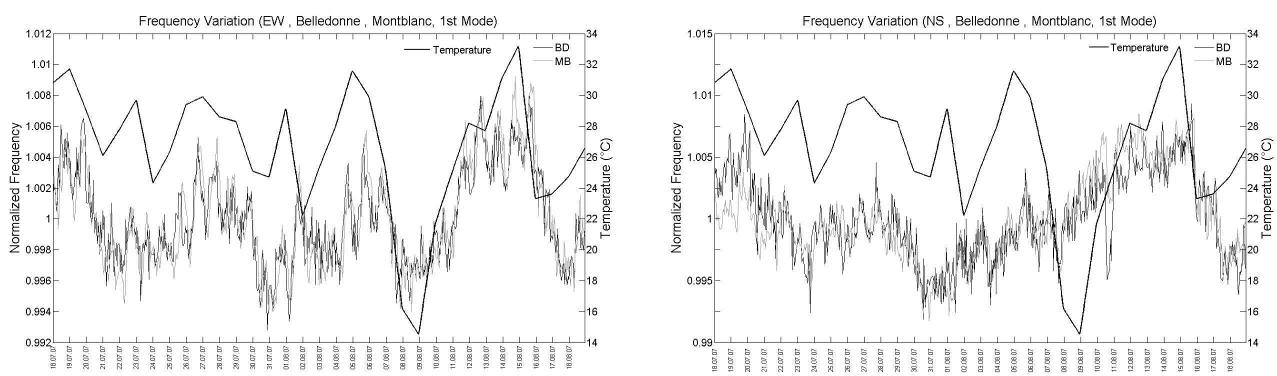

Figure 7. Wandering of the fundamental frequency of the Montblanc and Belledonne building for the EW (left) and NS (right) direction, using the RDT method, and comparison with the general trend of the temperature.

Conclusions

Ambient vibration records are being increasingly useful on engineering objectives. This study is focused on long-term variations of the frequency parameters of two twin towers getting from ambient vibrations recordings. Dialy variations of the fundamental frequency are then observed. Preliminary interpretations of such as variations are shown here, that may be due to the monthly temperature variations rather than rainfalls.

The two methods used in this paper (RDT and the half power bandwidth method) show similar results and the accuracy of these two methods allows to assume the relevancy of ambient vibrations for detecting slight variations of stiffness, that may be very useful for the post-seismic integrity and structural health monitoring.

Acknowledgments

This work is supported by the French Research National Agency (ANR) through the RGCU program (project ARIVSE ANR-06-PRGCU-007-01).

References

Bradford S. C., J. F. Clinton, and T. H. Heaton, 2004. Variations in the Natural Frequencies of Millikan Library Caused by Weather and Small Earthquakes, doi10.1061/40753(171)90.

Caughey T. K. and H. J. Stumpf, 1961. Transient response of a dynamic system under random excitation, Journal of applied mechanics, 563-566.

Chatelain, J.L., P. Guéguen, B. Guillier, J. Fréchet, F. Bondoux, J. Sarrault, P. Sulpice and J.M. Neuville. 2000. CityShark: A user-friendly instrument dedicated to ambient noise (microtremor) recording for site and building response studies, *Seismological Research Letters*, 71, 6, 698-703.

Clinton J. F., S. C. Bradford, T. H. Heaton and J. Favela, 2006. The observed wander of the natural frequencies in a structure, *Bull. Seism. Soc. Am.,* 96(1): 237–257.

Clough R.W. and J. Penzien, 1993. *Dynamics of Structures*. Mc Graw-Hill, New-York, 2nd edition, 738, ISBN 0-07-011394-7, 1993.

Cole H. A, 1973. On line failure detection and damping measurments of aerospace structures by Random Decrement signature, NASA CR-2205, March 1973.

Dunand F., P. Guéguen, P.-Y. Bard, J. Rodgers and M. Celebi, 2006. Comparison of the dynamic parameters extracted from weak, moderate and strong motion recorded in buildings, *Proc. of the First European Conference on Earthquake Engineering and Seismology,* Geneva, Switzerland, paper 1021.

Michel C. and Guéguen P. (2009) Tme-frequency analysis of small frequency variations in civil engineering structures under weak and strong motion using reassignment method, *submitted in Structural Health Monitoring*

Michel C., Guéguen P., El Arem S., Mazars J. and Kotronis P. 2009. Full Scale Dynamic response of a RC building under weak seismic motions using earthquake recordings, ambient vibrations and modelling, Earthq. Engng and Struct. Dyn., doi 10.1002/eqe.948.

Ni Y.Q., X.G. Hua, K.Q. Fan and J.M. Ko, 2005. Correlating modal properties with temperature using long-term monitoring data and support vector machine technique *Engineering Structures* 27 (2005) 1762–1773.

Omori F., 1922. The semi-destructive earthquake of April 26, 1922, *Seismological Notes* (Imperial Earthquake Investigation Committee), 3: 1-30.

Todorovska M.I. and Al Rjoub Y. (2006). Effects of rainfall on soil-structure system frequency: example based on poroelasticity and a comparison with full-scale measurements, Soil Dynamics and Earthquake Engineering, 26 (7): 708-717.

Vandiver J. K., A. B. Dunwoody, R. B. Campbell and M. F. Cook, A mathematical basis for the random decrement vibration signature analysis technique, *Journal of Mechanical Design*, 1982.