Modern Structural Monitoring Systems for High-Rise and Unique Buildings

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Abstract. An automated system for building structural monitoring is developed. The system allows for real-time condition and status information of a building. Through the sensory equipment different building parameters are obtained and processed in a special software package.
The software package is based upon mathematical model rules, which for the most critical components set limits for structural safety. The mathematical model is verified with real-time measurements and consequently used in the real-time structural modelling system.

Introduction

There are many new high-rise and unique buildings in Russia, including the Sochi Olympic venues (Sochi-2014) and FIFA 2018 World Cup stadiums. Strengthened security and safety requirements caused changes in the regulations and laws for the design and monitoring process of high-rise buildings. Several documents were approved by the Russian Government and are now national standards and federal laws. NPO SODIS is one of the main participants in the development of these national Russian standards for building monitoring and safety.

According to the Russian laws and standards each high-rise and unique building must be monitored by a monitoring system [1]. There are two types of monitoring systems; a structural monitoring system and an infrastructure monitoring system for building services. This article focuses on the first only.

Structural monitoring systems are a common subject in research, as it is the main tool for obtaining structural parameters. The reasons for structural monitoring systems however are shifting from simply obtaining structural parameters for evaluation to a more user-centric based monitoring system for maintenance and safety [3].

Since 2005 NPO SODIS has actively been designing and installing structural and infrastructure infrastructure monitoring systems on Olympic venues in Sochi, stadiums for the FIFA World Cup World Cup 2018, high-rise buildings of Moscow-City centre and many others

Figure 1). As of September 2011 the total number of projects with monitoring systems designed by NPO SODIS exceeds 200. With a special software package the monitoring system is focused on maintenance and safety – and is for the user.

This article describes the structural monitoring system technology and provides an example application explaining the heart of the structural monitoring system.

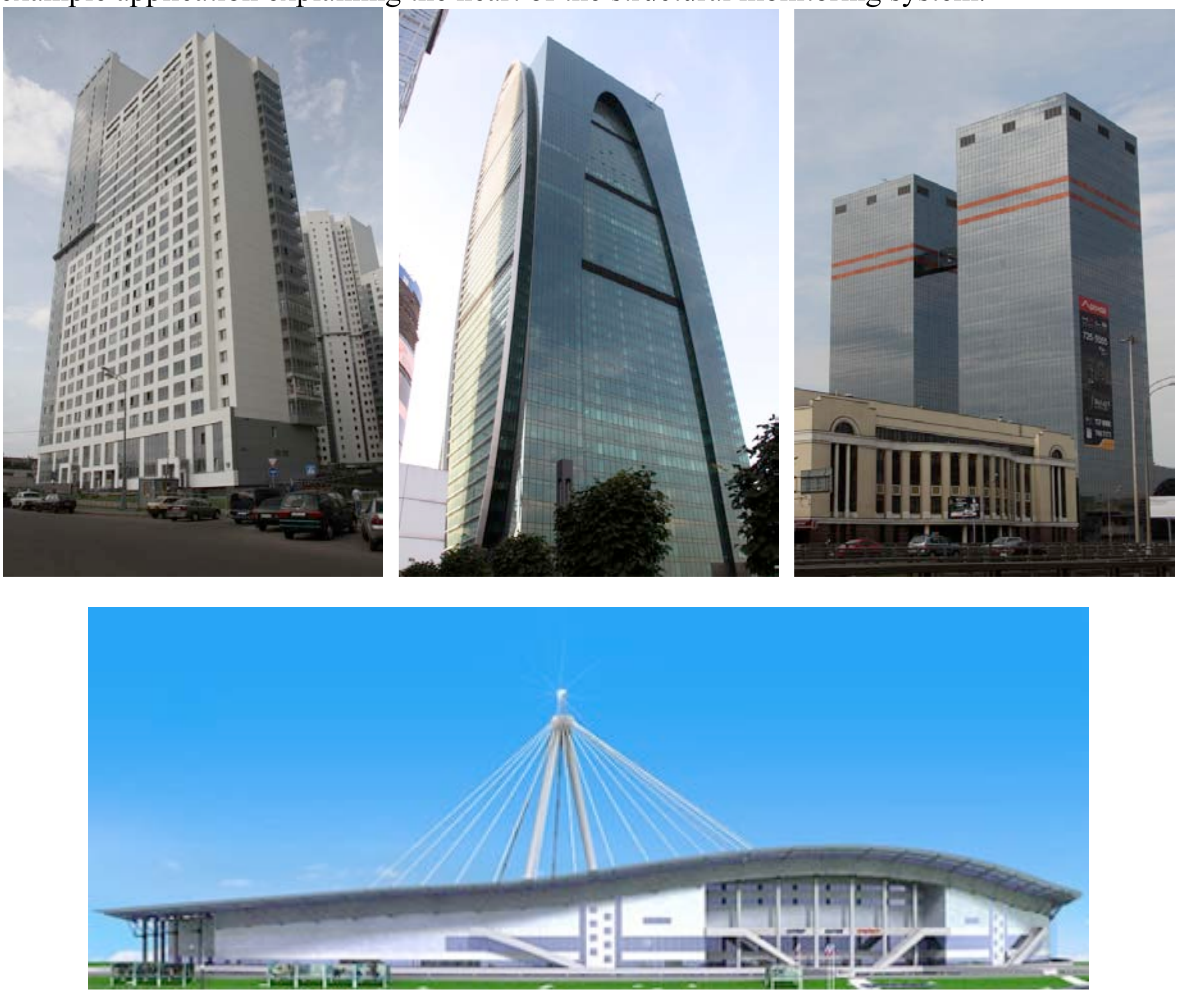

Figure 1: A selection of objects with monitoring systems designed by NPO SODIS.

2. Structural monitoring system

2.1 System architecture

The structural monitoring system consists of sensors located at carefully selected positions throughout the building, data transmission equipment and a server for data collection and control. Within the server analysis software containing a special mathematical model is present. The server connects to a local operator desktop application and can remotely be viewed and updated (Figure 2). The operator can monitor the building at real-time and immediately see the status of the building.

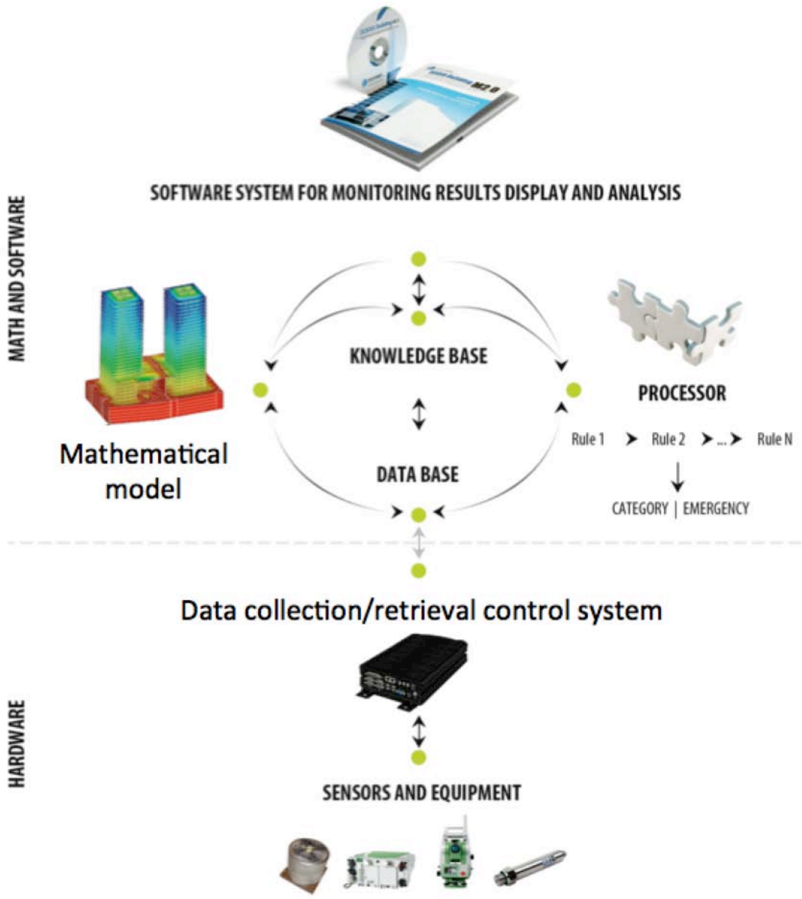

Figure 2: Structural monitoring system architecture

2.2 System development process

The system development process contains three stages: design, construction and maintenance:

- In the design stage threats are modelled, the required monitoring parameters are identified and mathematical and computer models are generated. In this stage initial rules are set up which determine the sensor type and location. Depending on the required parameter, sensors can be installed embedded in the concrete, on an armature or in special housings.

- In the construction stage sensors and other equipment is installed in the building. By monitoring the building for a period of time and evaluating the results, the mathematical and computer models developed in the design stage are verified and corrected in the monitoring software when needed.
- The maintenance stage is where the building operators take control of the monitoring system and use the specially developed software for building operation and maintenance. The software allows the operators to immediately see the status of the building.

The main working principles of the system are as follows (Figure 3). The sensors installed on a building's structure record monitoring parameters corresponding to construction elements identified critical to the building's safety. For each monitored parameter (such as deformation, frequency, inclination, pressure and others) normative values are obtained based on the mathematical model of the building. As the mathematical model has been corrected to the initial state to the building in the construction stage, differences between measured and normative values allows decision making about the building's state and conditions. These results, including the ability to view the raw data, are displayed to the building operator.

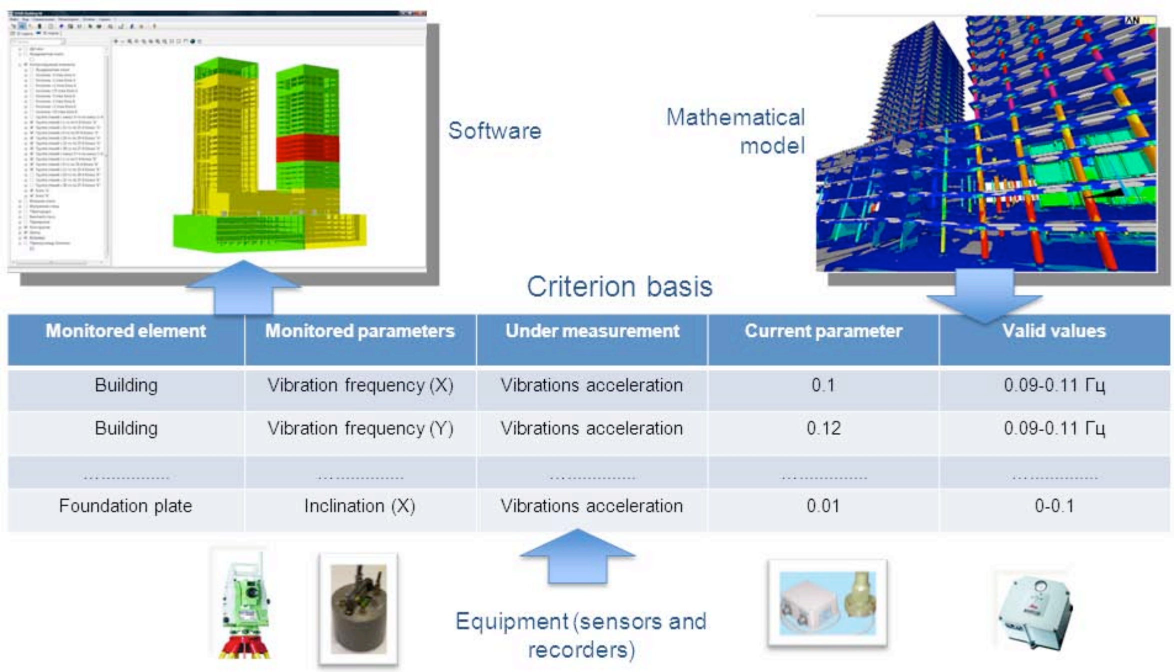

Figure 3: Principles of operator of the structural monitoring system

2.3 SODIS Building M software for structural monitoring

A special structural monitoring software package, SODIS Building M, is developed and marketed by NPO SODIS. This software allows the structural monitoring system to make complex analysis of different measurements and display the monitored results in real time.

The software package is used to define the complicated rules obtaining the building status. After this definition, the software is used in the operation of the structural monitoring system by making decisions on the real-time state or condition of the building. Each building requires its own mathematical model, its own set of rules and the software is therefore tailored to each building.

For the operator of the building, the software can work with 2D and 3D models of buildings and structures. It is able to show all available sensors, the corresponding data of these sensors and all diagnostic messages coming from the system. Most importantly it immediately issues warning messages if the rules of the mathematical model are exceeded, therefore allowing to immediately identify safety concerns of the building. Figure 4 shows the software interface of the Building M software, in this case applied to tunnel monitoring.

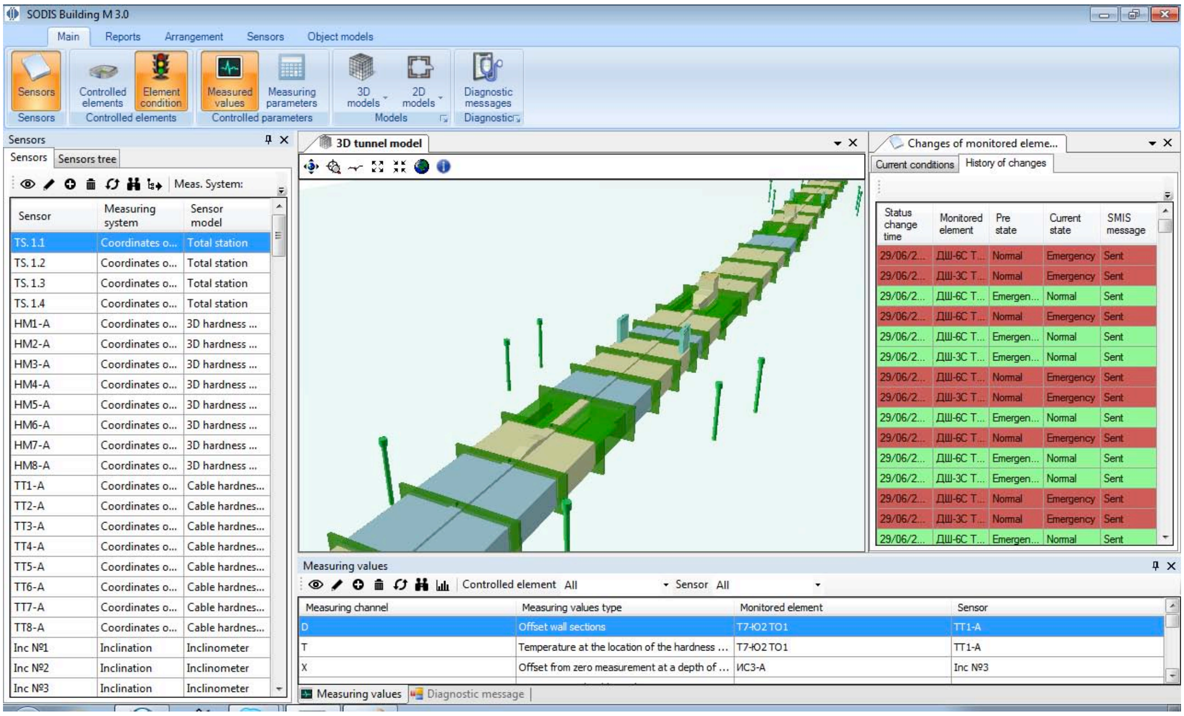

Figure 4: SODIS Building M software screen for building operators

3. Example structural monitoring application

A structural monitoring system was developed for a 40-floor building in Moscow (Figure 5) [2]. The monitoring system was based on the control of dynamic characteristics and inclination of the building. Tests were performed to verify the generated mathematical model with the real building results. During this test, performed on August 25, 2010, accelerometers were installed on the 2nd, 10th, 20th, 30th and 40th floor to the record dynamic characteristics of the building.

Figure 5: High-rise building in Moscow

The mathematical model determined the normative vibration records at the same points as where the accelerometers were installed. To calculate these normative values the measured vibrations of the foundation were used as input to the mathematical model (2nd floor,
Figure 6).

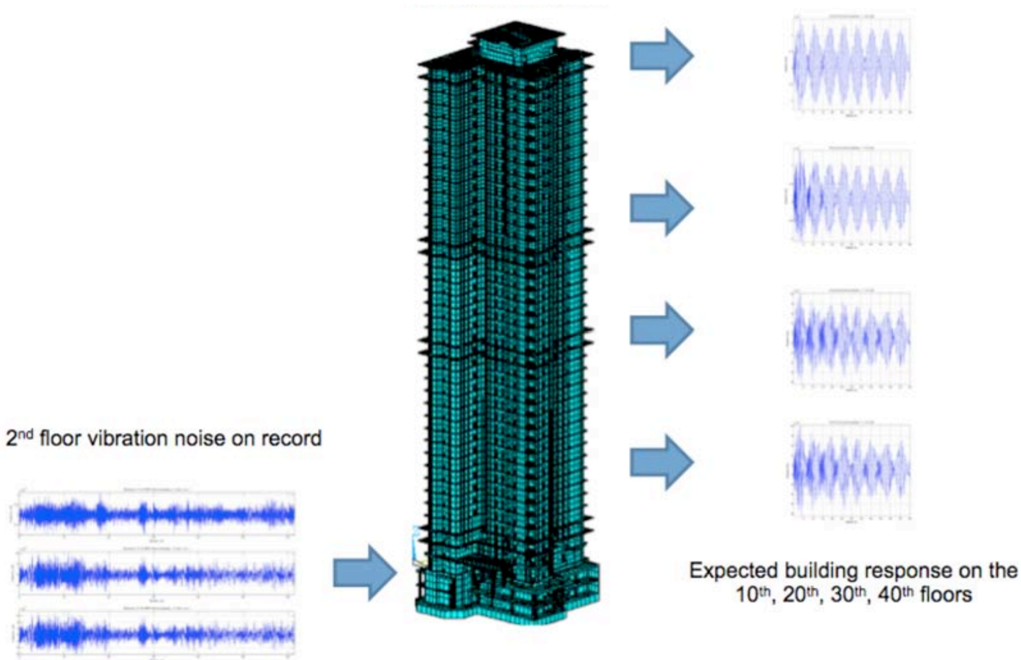

Figure 6: Model verification by inputting 2nd floor noise record to the mathematical model

A comparison of the measured accelerometer data and the model spectra, as shown in Figure 7, it can be seen that both measurement and model results are similar, having two frequency peaks close to 0.5 Hz. This means the mathematical model is verified and can now be used in different scenarios where various defects are introduced to obtain the changes of the monitored parameters. Additionally, the mathematical model can be used to forecast a future building state if a trend of parameter change is detected.

Conclusion

This paper has described a modern, real-time structural monitoring system. This system includes specialist software for real-time operation of the system. At the heart of the system is a set of rules which determine the building’s state and condition. The method of obtaining a building’s status based on mathematical models and the verification of such mathematical model is provided through an example application.

References

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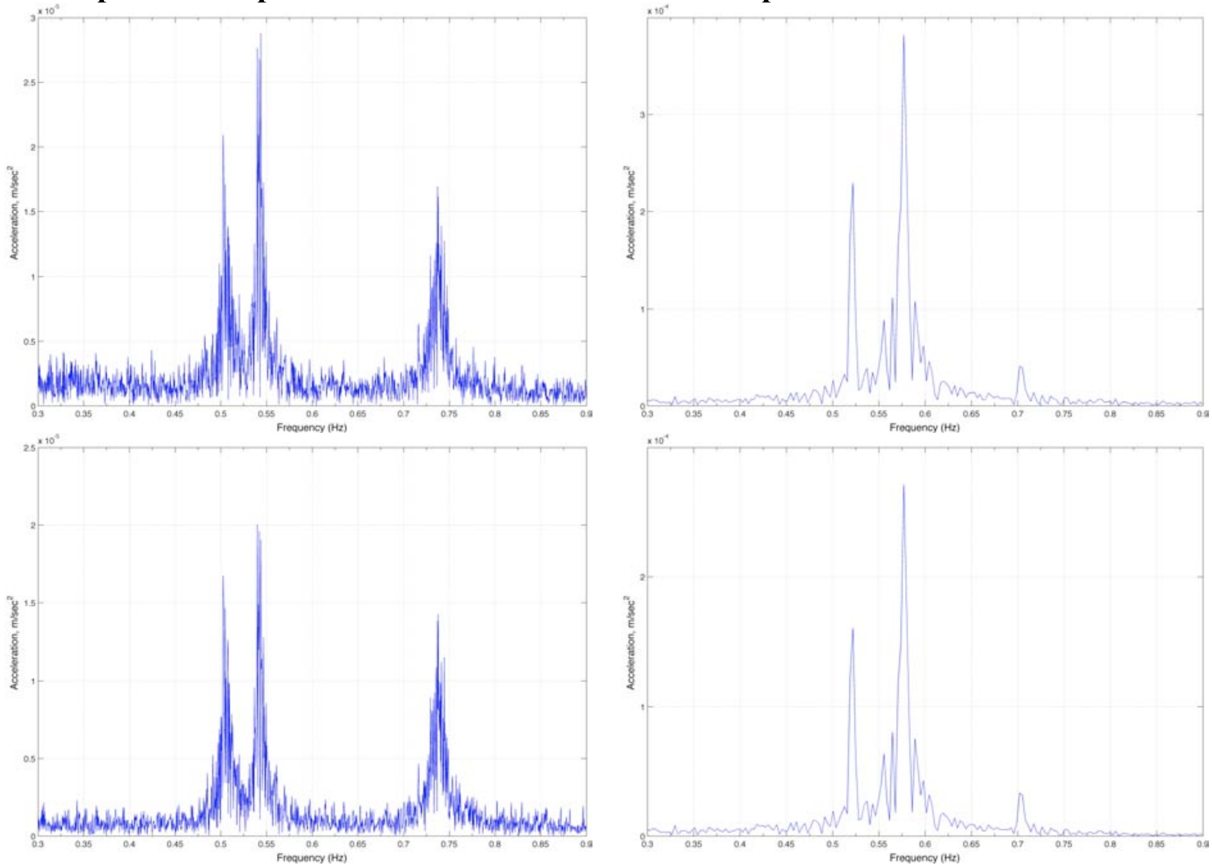
[2] Шахраманьян А.М. (2011), *Системы мониторинга и прогноза технического состояния зданий и сооружений*. Русский инженер № 1(28).

[3] Kuckartz, J., Collier, P. (2011), *A User-centric Approach to the Design of Structural Health Monitoring Systems*. In proceedings of the Joint International Symposium on Deformation Monitoring, November 2011, Hong Kong, China.

Spectra of experimental records **Spectra of model records**



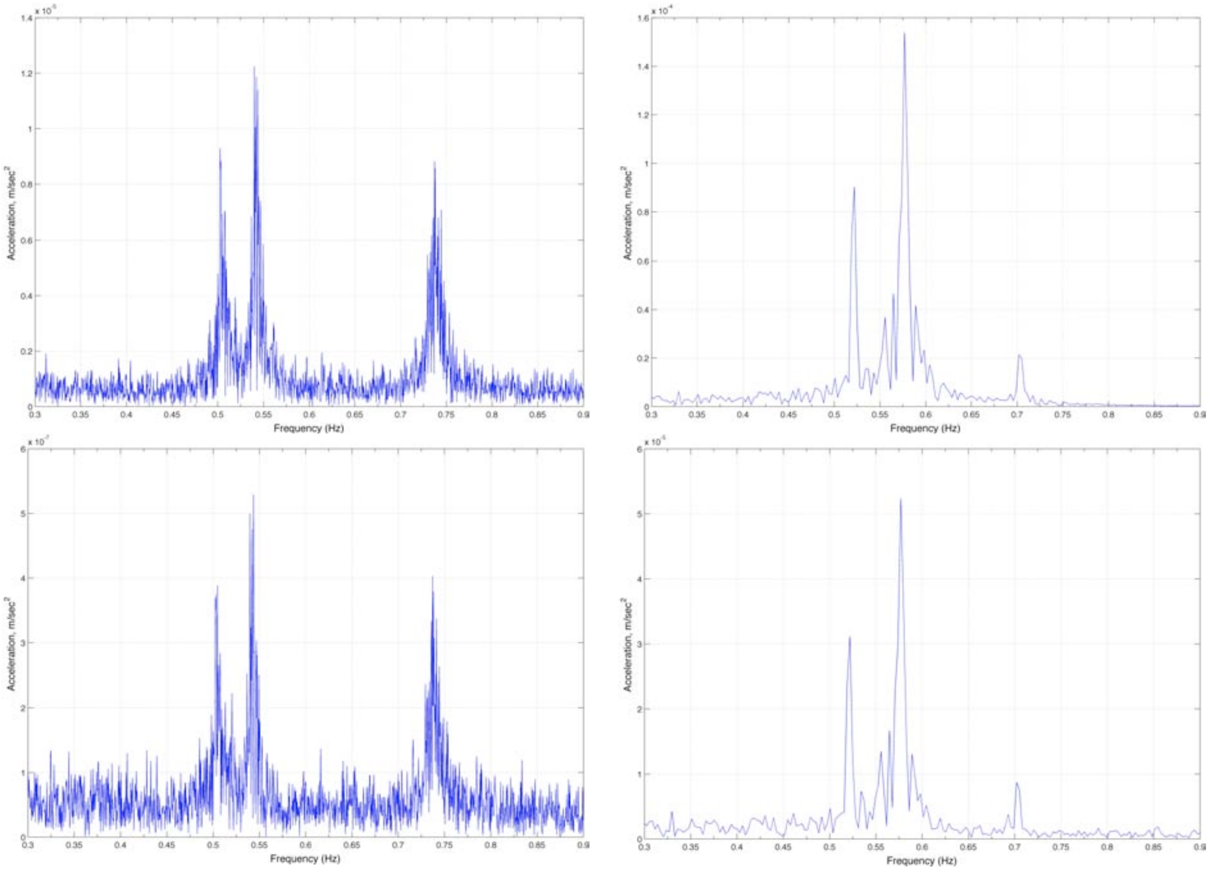


Figure 7: Comparison of experimental and mathematical model spectra