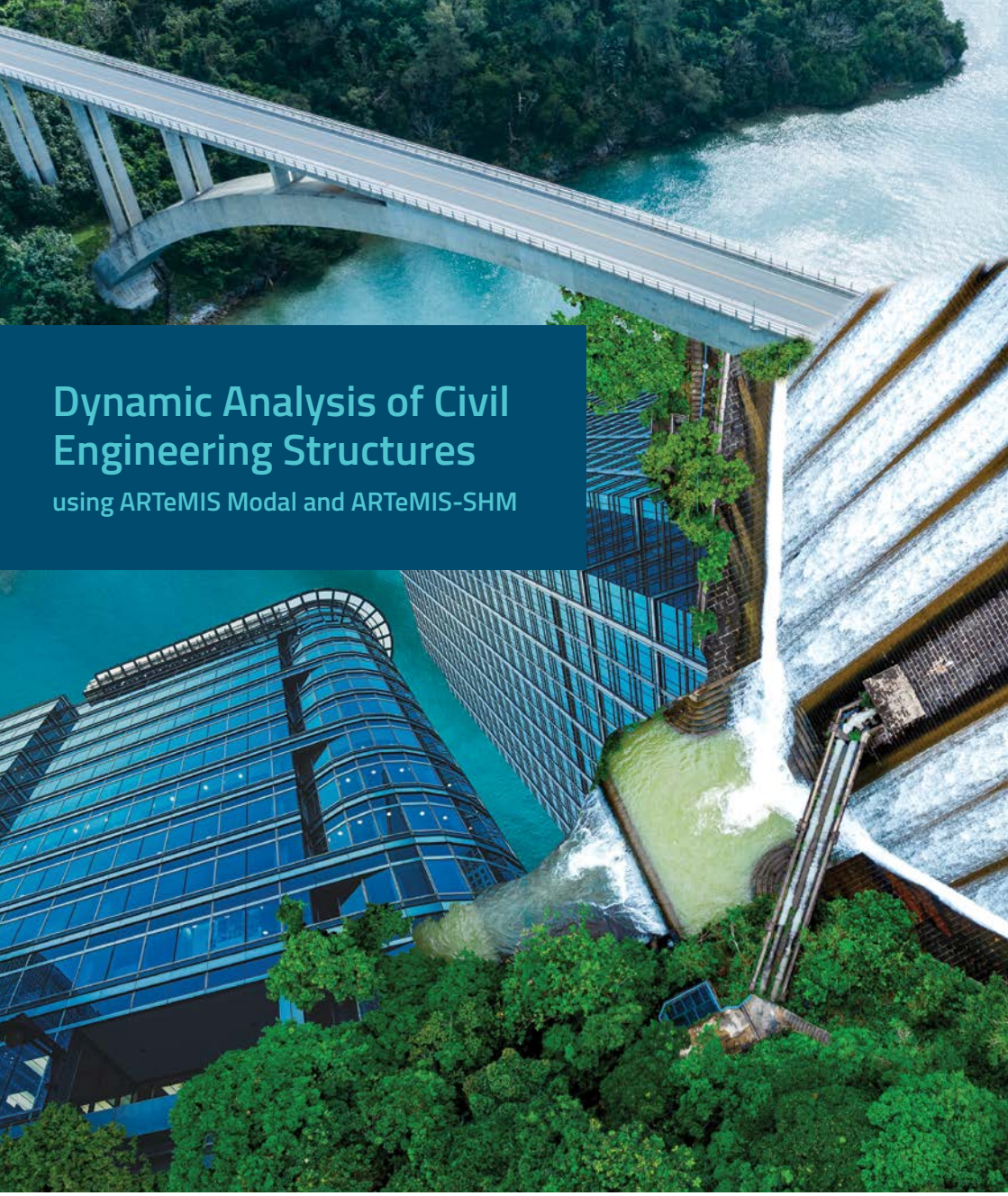


Dynamic Analysis of Civil Engineering Structures

using ARTeMIS Modal and ARTeMIS-SHM

Structural Vibration Solutions

Dynamic Analysis of Civil Engineering Structures

Structural Vibration Solutions A/S offers state of the art software solving vibration issues of all kind of civil engineering structures.

Our software consists of a desktop application called ARTeMIS Modal and a complete system for vibration-based Structural Health Monitoring the ARTeMIS-SHM solution, that is powered by ARTeMIS Modal.

Dynamic Testing and Analysis

Testing and analysis of civil engineering structures is a broad topic, that essentially can be divided into two categories:

- Ambient Vibration Testing (AVT).
- Structural Health Monitoring (SHM).

Ambient Vibration Testing

The purpose of an AVT is typically to get detailed knowledge of a structure's dynamic behavior. This knowledge covers natural frequencies, damping ratios, and high-resolution mode shapes. The information typically requires multi-setup measurement campaigns to maximize mode shape information. It is typically an isolated type of test that is done perhaps only a single time.

Benefits of an AVT:

- Experimentally obtained modal information for Finite Element correlation and updating.
- Critical information of lowest modes for seismic risk analysis and seismic retrofit.
- Baseline information for design of a permanently installed monitoring system.

The ARTeMIS Modal desktop application is a tool that by birth is designed for AVT.

Structural Health Monitoring

In SHM the information of an AVT is normally used to assist the design of the monitoring system. Both the type and number of sensors as well as their positions can be determined based on an AVT. The purpose of SHM is to monitor for slowly growing changes of the dynamic behavior as well as sudden (fast growing) changes caused by extreme events, such as earthquakes.

Detect Slowly Growing Damage

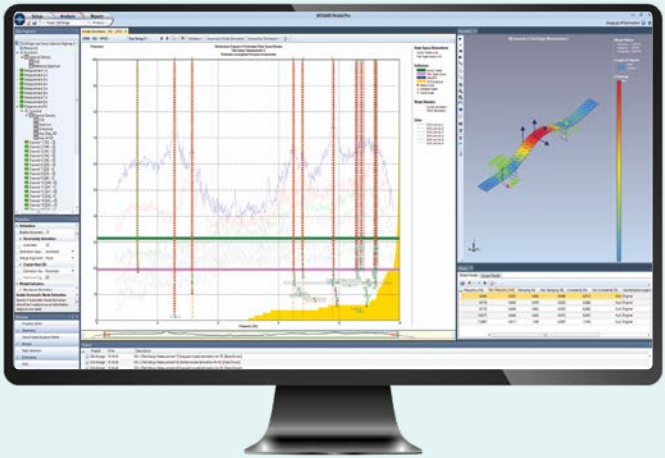
In the case of slowly changing dynamics a system typically monitors for changes of modal parameters, and a range of different damage indicators as well as the channel statistics.

Detect Sudden Damage

During severe sudden events a monitoring system will compare modes and damage indicators from before and after the event to check for introduced damage. Local detection of selected structural components might also be made during the actual event using inter-storey drift analysis. Finally, seismic ground motion analysis might be made on dedicated ground sensors.

The ARTeMIS Modal desktop application and ARTeMIS-SHM are solutions designed to perform the type of analysis mentioned above using various SHM plugins for ARTeMIS Modal Pro.

Ambient Vibration Testing



All versions of ARTeMIS Modal have been designed for single- and multi-setup AVT. Depending on the version there are up to eight different Operational Modal Analysis (OMA) tools available as well as various ways of validation of estimated modal parameters. The OMA tools are three Frequency Domain Decompositions (FDD) methods as well as five Stochastic Subspace Identification (SSI) methods. ARTeMIS Modal can run different data acquisition hardware internally, and otherwise read more than 20 different file formats.

Structural Health Monitoring

ARTeMIS Modal Pro has a series of plugins for SHM allowing it to automatically load data from files, analyze it with several methods in parallel, and store results to files or database. The software is the computational engine in the ARTeMIS-SHM solution and can run completely transparent as a Windows service. The analyses include automatic OMA with tracking of modes over time, and statistical based damage detection. The tracked modes and damage indicator states are summarized as an overall SHM status in terms of a green, yellow, red traffic light.



How ARTeMIS is used for High-rise Buildings

ARTeMIS Modal

The slender design of high-rise buildings makes these dynamic sensitive to ambient excitation such as wind and micro-tremors as well as strong motion events such as earth-quakes. To reduce the effects of ambient excitation tuned damping systems are often used in this type of structure. High-rise buildings are often designed symmetrical which create beautiful geometrical lines but also create repeated or closely spaced modes.

AVT is often applied for a multitude of reasons such as verification of tuned damping systems, Finite Element validation and updating. In seismic prone areas it is also vital to know the fundamental eigen modes to avoid soil/structure interaction.
AVT can be performed with the Operational Modal Analysis tools in ARTeMIS Modal.

ARTeMIS-SHM

Buildings are designed to stand for many years. However, the health of a structure can deteriorate over years of service due to many reasons. Therefore, continuous monitoring should be undertaken for critical structures in as early a state as possible.
The overall health of a structure can be observed using continuous modal analysis and damage detection. Local damage in structural components such as columns can be monitored using interstorey drift analysis.

ARTeMIS-SHM is designed to monitor multiple structures continuously and notify if global damage indicators exceed thresholds or if structural components exhibit too much relative drift.

How ARTeMIS is used for Bridges

ARTeMIS Modal

AVT is a tool often used by bridge engineers for periodical maintenance inspection and retrofit. Both girders, piers / pylons, and cables can be tested as they are all integrated parts of the safety of a bridge. Prevention of scouring around foundations is also an aspect where AVT is an important tool.
AVT can be performed with the Operational Modal Analysis tools in ARTeMIS Modal.

ARTeMIS-SHM

Aging infrastructure is a problem worldwide. In many cases maintenance has been neglected for years and at the same time traffic has increased with a growing population. World-wide, bridge collapse happens every year with tragic consequences.
ARTeMIS-SHM is designed to monitor multiple structures continuously and notify if global damage indicators exceed thresholds. Both slowly increasing deterioration as well as rapidly increased damage can be detected. This can help extend the lifetime of a bridge as well as keeping it operational with less inspection downtime.

How ARTeMIS is used for Dams

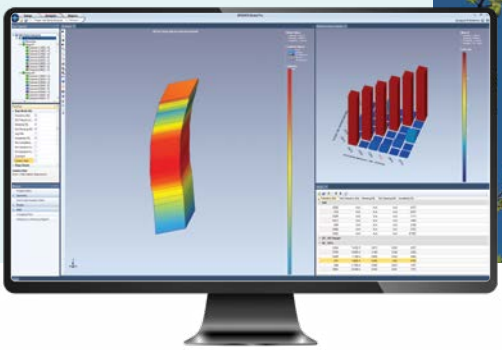
ARTeMIS Modal

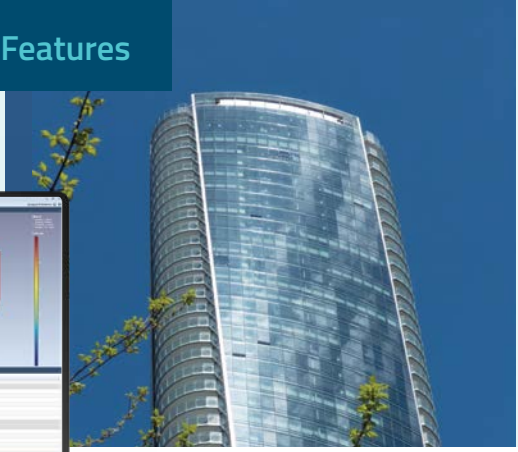
AVT is used to study the global behavior of the dam-reservoir-foundation system. Dynamic modes change with the level of water in the reservoir. The AVT are in many cases used for the design of a permanent monitoring system as well as trouble shooting.
AVT can be performed with the Operational Modal Analysis tools in ARTeMIS Modal.

ARTeMIS-SHM

Dams are critical infrastructure and damage can lead to severe loss of property and life and have significant economic implications. Therefore, many large dams are monitored using a vibration based structural health monitoring system.
ARTeMIS-SHM is designed to analyze the type of ambient response data of structures such as dams. The challenge of this type of data is that the modal response is weak and mixed with forced harmonic response caused by the turbines and pumps running. ARTeMIS-SHM can track modes of the dam, visualize them, and notify the engineers when thresholds are exceeded.

ARTeMIS Modal Software Features





ARTeMIS Modal

The ARTeMIS modal software is a tool designed for Operational Modal Analysis (OMA) which is the analysis method used for Ambient Response Testing (AVT) of civil engineering structures. The software is available in three versions: Basic, Standard and Pro versions. The major difference between the versions is the OMA tools available. The available tools are described below.

Frequency Domain Decomposition

The Frequency Domain Decomposition (FDD) methods were invented by the founders of SVS back in the late 90's. Today this method is widely used due to its user-friendliness and easy implementation. The FDD method estimates the natural frequency and mode shape of a mode and works fast and robust on lightly damped well-separated modes.
This method is available in all versions of ARTeMIS Modal. The method is extended in the Enhanced Frequency Domain Decomposition (EFDD) and the Curve-fit Frequency Domain Decomposition (CFDD) methods that returns improved estimates of natural frequency and mode shape of modes along with their damping ratios. EFDD and CFDD are available in the Standard and Pro versions.

Stochastic Subspace Identification

The Pro version includes up to five Stochastic Subspace Identification (SSI) methods. These time domain methods estimate state space models using the SSI framework. From a series of state space models of increasing model order, a stabilization diagram is constructed. Based on this diagram stable structural modes are automatically extracted. The most advanced method is the SSI-UPCX that also estimates modal uncertainties and actively use it to create robust estimates of the natural frequency, damping ratio, and mode shape of modes. Besides being a fully automatic tool SSI methods can estimate both high and low damped modes. It has effective noise modelling allowing extraction of modes even in case of low signal to noise ratios. Due to the effective Crystal-Clear SSI estimation of the state matrix, it is also possible to analyze measurement mixed with harmonic response originating from rotating parts.

Find out more about OMA and get more information at:
www.svibs.com/applications/operational-modal-analysis/

ARTeMIS–SHM Software Features

ARTeMIS-SHM

ARTeMIS-SHM (SHM) is a complete vibration-based Structural Health Monitoring solution that can plug into any permanently installed data acquisition system for continuous monitoring of a structure.

The solution is powered by ARTeMIS Modal Pro. Together with a series of SHM plugins it is responsible for the data analysis. A single license of ARTeMIS Modal Pro can sequentially analyze multiple structures. The software is executed as a Windows service and can run autonomously without user-interaction.

Measurements are imported continuously from any data acquisition system that can distribute measurement files to a dedicated network folder. Results are written to a Microsoft SQL Database allowing multi-user access. Results can be viewed using the artemis-shm.com web portal or any third-party application having access to the database.

Users can receive notifications either by email or SMS whenever thresholds are exceeded.

The following analysis tools are available:

- Overall Structure Status: *Safe*, *Critical*, *Unsafe*
- Individual Indicator Status: *Safe*, *Critical*, *Unsafe*
- Automatic Operational Modal Analysis and mode tracking.
- Automatic damage detection using several approaches.
- Interstorey drift analysis of structural components.
- Seismic analysis of dedicated ground motion sensors.
- Channel statistics.

Find out more about ARTeMIS-SHM and get more information at:
www.svibs.com/artemis-shm/